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Moroccan Weather Radar Network Feasibility Study

Final Report

Prepared for
Moroccan National Meteorology Department
(Direction de la Meteorologic Nationale)

November 2012

This report was funded by the U.S. Trade and Development Agency (USTDA), an export promotion agency of the United States Government. The opinions, findings, conclusions, or recommendations expressed in this document are those of author(s) and do not necessarily represent the official position of policies of USTDA. USTDA makes no representation about, nor does it accept responsibility for, the accuracy or completeness of the information contained in this report.

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This Feasibility Study was completed in partnership with the Direction de la Meteorologic Nationale (DMN). The following summarizes the B&N Team Members (Prime Contractor and Subconsultants) and the members of the DMN Team.

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EXECUTIVE SUMMARY

INTRODUCTION

The US Trade and Development Agency provided a grant to the Moroccan National Meteorology Department (DMN) to fund a feasibility study of the Kingdom's weather radar network. Adverse weather and flooding has cost the Kingdom of Morocco millions of dollars annually that has impacted the quality of life of its citizens and the ability to advance economic development. An effective national weather nowcasting system is a key element to respond to these crises and guarantee national security and stability. The objectives of the Feasibility Study are to provide:

- An assessment of the current radar network.
- An assessment of covered and non-covered areas within the study area, as well as identification of critical areas prone to the risks of dangerous climatic phenomena, such as flooding.
- Determination of needed upgrades and additions to existing radars.
- Development of technical specifications for the additional radars.
- Preparation of a feasibility analysis that evaluates the various leading institutions of investment to fund the radar network versus the environmental and socio-economic benefits of having wider coverage.
- Preparation of an investment program outlining network upgrades in phases, if appropriate.

Preparation of documents which summarize the aforementioned findings The goal of this Feasibility Study is to provide a technical solution(s) for upgrading and expanding the existing weather radar network, and the development of a procurement plan and procurement documents which allow recommended system improvements to be implemented. Figure EX-1 presents the approximate study area limits for this Weather Radar Network Feasibility Study.

DMN retained the Burgess & Niple, Inc. (B&N) Team to prepare the Feasibility Study.

Figure EX-1 Existing Radar Network.

INITIAL VISIT

For four days during the week of September 8, 2008, the B&N Team met in Morocco with representatives of DMN. The meeting purpose was to:

- Analyze costs of equipment, operation and benefits
- Understand DMN capabilities and current systems
- Agree on available data and identify additional data needed
- Agree on DMN's role in acquiring necessary data
- Develop a schedule for collecting data
- Visit various weather radar stations throughout Morocco

During the initial visit, presentations were provided by DMN personnel. They include:

- Mr. Saouri – Chief of Radar and Satellite Services and Project Lead
- Mr. Messoudi – Chief of the center for Meteorological Exploration
- Mr. Merrouchi – Chief of Maintenance and Equipment

Several visits were conducted at nearby radar stations and meetings with key governmental staff and a consultant. They include:

- Casablanca Radar Station
- Water Resource Management and Flood Forecasting Department
- Offices of Anzar
- Fes Radar Station, the Northeast Regional Department of Meteorology and the staff of Sebou Hydrologic Basin

CLIMATOLOGICALLY AND SOCIOECONOMIC ANALYSIS

The Kingdom of Morocco periodically experiences exceptional rainfall events which lead to flooding and landslides. These disasters often result in the loss of hundreds of human lives as well as considerable damage to property. The occurrence of weather-related disasters in the region and in the country in particular, underscores the importance of having an early warning system as a component in the Kingdom's total disaster risk management system.

Tables EX-1 through EX-3 summarize the weather rated impacts from severe storm events. Some percentage of these losses shown in Tables EX-1 through EX-3 could have been avoided with enhanced weather data leading toward better and timelier disaster planning and responses.

Natural disasters, especially floods, cause considerable damage to the Moroccan economy. These damages affect all facets of socio-economic life in Morocco: human life, infrastructure, industry, tourism, housing, and others. Nowcasting is imperative, particularly as the current technology in this area has progressed considerably. As a result, a National Flood Plan has been created to prevent and predict devastating floods. Through this plan, 391 sites throughout Morocco have been identified as flood-prone. The detrimental effects of flooding in the "at risk" areas are exacerbated by:

- Development of homes in flood areas
- Deforestation which allows for more runoff and sediment transport
- Lack of maintenance for watercourses
- Inadequate structural design of crossing rivers
- Lack of sanitation
- Insufficient level of prediction and warning

The DMN currently has weather radar coverage for a large part of the country, therefore increasing their nowcasting and warning capabilities. However, the extension of weather radar coverage to "at risk" areas is crucial for the protection of people and infrastructure, and for social and economic development.

The regions of Oujda, Errachidia, Ouarzazate have no weather radar coverage and, therefore, are a priority for radar installation. However, smaller regions also remain uncovered. DMN should consider radar coverage through the country using technology appropriate for each situation.

Table EX-1 Damages from Severe Weather Events 1980 – 2010
(www.preventionweb.net)

	Affected per Year	Killed per Year	Damages per Year $US x 1000
Drought	91,667	0	30,000
Flood	12,257	60	9,000
Extreme Temperature	---		27
Storms	---	7.5	2
Totals	**377,324**	**68**	**39,000**
Deaths valued at $525,750			35,751
Total Damages			**74,751**

Table EX-2 Population Affected by Severe Weather Events 1980 – 2010
(www.preventionweb.net)

	Population Exposed in High Hazard Areas	Population Affected Per Year	% Affected	GDP Exposure $US x 10000
Drought	7,500,000	91,667	1.2%	
Flood	23,500	12,257	52%	70,000
Extreme Temperature				
Storms	16,000			30,000
Total				100,000

Table EX-3 Estimated Damage Summaries

Category	Damages MAD	Damages $USD 1000
Human Lives	161,667,100	19,020
Direct Damage	5,059,915	595
Employment	11,855,520	1,395
Industrial Activity	534,880,400	62,927
Agricultural Activity	309,147,935	36,370
Construction	181,550,540	21,359
Property	125,382,100	14,750
Roads	13,735,130	1,616
Total	**1,343,278,640**	**158,032**
Number of Years	**23**	**23**
Average Per Year	**58,403,419**	**6,871**

RADAR DIAGNOSTICS

The B&N Team conducted detailed field assessments of five radar stations to detect failures and insufficiencies in the existing weather radar network, propose solutions for upgrading and expanding the network's existing coverage, and analyzed current operations and measures for improved operations, training needs, building capacity needs, maintenance, quality assurance systems, and interconnection with network telecommunications. Assessments included:

- Radar Station **Casablanca** – Mohamed V Airport
- Radar Station **Fes** – Fes Saiss Airport
- Radar Station **Larache** – weather station of Larache
- Radar Station **Agadir** – Agadir Massira Airport
- Radar Station **Khourigba** – Military Base Hayane

The field assessments were divided into six categories. These categories are summarized for each radar station in Table EX-4.

A field assessment was also conducted at the maintenance and supervision workstations in Casablanca, which has the capability to track and document the operations of the radar network. Based on our understanding of these facilities they do not appear to be fully utilized. Inadequate training appears to be the cause. Preventive maintenance is not documented, spare parts are not monitored and updated, and log files are not stored.

Detailed training of responsible personnel is recommended. The training should include delineated procedures for documenting and centralizing maintenance actions and knowledge of the radar network. With proper documentation, the maintenance manager could report the current status of the entire network, recent preventative actions, and other viable system monitoring parameters. DMN could then be alleviated from the current countless hours of surveys, from locating maintenance personnel and sorting through multiple accounts of the same event.

Finally, a Radar Site Analysis Severity Table (Table EX-5) was developed.

Table EX-4 Summary Results of the Field Assessments

		Casablanca	Fes	Larache	Khouribga	Agadir
1.	**Radar Performance**					
	Transmitter Test	Failed	Passed	Passed	Failed	Passed
	Receiver Test	Passed	Passed	Passed	Not Performed	Passed
2.	**Visual Transmitter and Antenna Inspection**					
	Transmitter Visual Inspection	Marginal	Passed	Passed	Failed	Passed
	Antenna Performance	Passed	Passed	Passed	Not Performed	Passed
3.	**Operations and Maintenance**					
	Operational Test	Passed	Passed	Passed	Failed	Passed
	Maintenance Practice and Records	Marginal	Marginal	Marginal	Failed	Marginal
4.	**Interconnections and Telecommunications**	Passed	Passed	Passed	Marginal	Passed
5.	**Potential Items of Interest**	*GenSet *Waveguide *Transmitter *BITE Status	*GenSet *Paint etc. *BITE Status *Radome	*Corrosion *Waveguide * Beam Blockage *BITE Status *Radome	*Corrosion *Radome Water Leakage *Clutter Rejection *AC *Radome	*Obstruction *GenSet *Radome Fan * Corrosion *Leakage *Pedestal *Leveling *BITE Status *Radome *Site Location
6.	**Site Summary**	Passed	Passed	Passed	Failed	Marginal

Table EX 5 – Radar Site Analysis Severity Table

SITE NAME	DATE OF VISIT	ITEM OF INTEREST	SEVERITY** (Scale 1 to 3, 5 INOP)
Casablanca	21-Apr-09	Transmitter will not operate in 2uS pulse width	2.3
Casablanca	21-Apr-09	Generator Set Exhaust cover not in place	1.8
Casablanca	21-Apr-09	Waveguide is leaking pressure	2.0
Casablanca	21-Apr-09	BITE Status does not correctly display status	1.4
Casablanca	21-Apr-09	Radome Dirty, potentially leaking	1.0
OVERALL SYSTEM STATUS* see note 1			1.7
Fes	22-Apr-09	Generator Set is not operational	5.0
Fes	22-Apr-09	Peeling Paint and Dirty Pedestal	1.0
Fes	22-Apr-09	BITE Status does not correctly display status	1.4
Fes	22-Apr-09	Radome Dirty, potentially leaking	1.5
OVERALL SYSTEM STATUS* see note 1			2.2
Larache	23-Apr-09	Magnetron has frequency drift issues	1.5
Larache	23-Apr-09	Corrosion on bolts, waveguide and exposed metal	1.3
Larache	23-Apr-09	Waveguide starting to deteriorate	1.0
Larache	23-Apr-09	Beam Blockage from nearby structure (May be acceptable)	1.7
Larache	23-Apr-09	BITE Status does not correctly display status	1.4
Larache	23-Apr-09	Radome Dirty, potentially leaking	1.0
OVERALL SYSTEM STATUS* see note 1			1.3
Khouribga	24-Apr-09	System is not operational due to equipment failure (GCP)	5.0
Khouribga	24-Apr-09	Corrosion on bolts, waveguide and exposed metal	1.5
Khouribga	24-Apr-09	Radome Water Leakage onto equipment	2.5
Khouribga	24-Apr-09	Clutter Rejection doesn't appear to function or be set correctly	2.0
Khouribga	24-Apr-09	Air Conditioner has had previous failures, no backup system installed	1.5
Khouribga	24-Apr-09	BITE Status does not correctly display status	1.4
Khouribga	24-Apr-09	Radome dirty, potentially leaking	1.5
OVERALL SYSTEM STATUS* see note 1			2.2
Agadir	27-Apr-09	Generator Set is not operational	5.0
Agadir	27-Apr-09	Obstruction light power cable rubs against antenna	1.8
Agadir	27-Apr-09	Radome Water Leakage onto equipment	2.5
Agadir	27-Apr-09	Radome fan is not functioning	1.5
Agadir	27-Apr-09	Corrosion and Condensation present inside of the radome / on tower	1.3
Agadir	27-Apr-09	Radome dirty	1.5
Agadir	27-Apr-09	BITE Status does not correctly display status	1.4
Agadir	27-Apr-09	Site Location is problematic due to ground clutter beam blockage	2.0
OVERALL SYSTEM STATUS* see note 1			2.1

* Note 1 - Overall system status is rated from 1 to 3. 1 is the ideal, 100% operational status and 3 requires immediate attention. Anything above 2 should be evaluated as soon as possible.

** Note 2 - SEVERITY is measured from 1 to 3. 1 is the idea, 100% operational status and 3 requires immediate attention. 5 means the equipment or software listed in the ITEM OF INTEREST is NON OPERATIONAL and requires an immediate maintenance action.

NEEDS ASSESSMENT

Currently, the Kingdom of Morocco radar stations has six weather radar installations. These radar installations are located principally to the north near the Mediterranean Sea and west along the Atlantic Coast (See Figure EX-1). There are several coverage gaps within the study area that limits the ability of DMN of providing early warning forecasts. Additional radar installation are needed to mitigate these issues.

Five social-economic criteria were considered in prioritizing the siting of new radars and the relocation of existing radars that would optimize the current network and expand coverage to the areas of greatest need. The same social-economic criteria were used in evaluating the relocation of existing radars or the siting of new radars. The criteria used, in order of importance, are summarized below.

Criteria 1 - Areas without radar coverage where the addition of a radar would improve public safety in the event of a weather related disaster; e.g., estimation of precipitation over key drainage basins where flooding has been common and resulted in loss of life.

Criteria 2 - Areas without coverage where a new radar would improve short-term forecasts and warnings that could result in a decrease in economic loss to urban areas, industry, and agriculture; e.g., as in Criteria 1, but where damage is more related to infrastructure or crops rather than people.

Criteria 3 - Areas without coverage where radar could generally improve the forecasts issued by the Department of Meteorology (DMN); generally filling in the gaps found in the current coverage, or extending coverage to offshore areas.

Criteria 4 - The addition of radar to improve warnings related to aviation safety (strong winds, wind shear, heavy precipitation, etc.).

Criteria 5 - The addition of radar to aid specific projects such as weather modification programs.

Based on the above criteria, a priority list of new weather radars was establish and summarized in Table EX 6.

Table EX 6 New Radar Sites Considered for Regions of Morocco

Site	Latitude	Longitude	Hydrologic Basins	Socio-economic	Logistics	Priority
Agadir	30.32764	-9.39769				Current
Ben Guerir	32.13897	-7.95198				Current
Casablanca	33.36862	-7.57687				Current
Fes	33.93078	-4.97402				Current
Khourigba	32.85518	-6.9568				Current
Larache	35.1635	-6.1167				Current
Debdou	33.96992	-3.02058				Planned
Finideq	35.8627	-5.40819	West 50% of Cotiers Mediterannes	1,2,3,4	R,C,P,L	1
Nador	35.22153	-2.99788	Isly 100%, east 60% of Cotiers Mediterannes	1,2,3,4	R,C,P,L	2
Erford	31.4336	-4.21836	Ziz-Rheris 100%, south 50% of Guir	1,2,3	R,C,P,L	3
Tan Tan AP	28.449	-11.1732	North edge of Sequia El Hamra (5%), south 50% of Cortiers Guelmin-Tiznit, western part of Draa (20%)	3,4	R,C,P,L	4
Oaarzazete	30.87863	-6.89441	North 33% of Draa (mountainous region)	1,2,3,4	R,C,P,L	5
Midelt	32.67147	-4.74102	West 50% of Guir, south 40% of Moulouya	1,2,3,4	R,C,P,L	6
Khemis Takate	31.73219	-9.45339	Cotiers Essaouria, Cotiers Safi-Judida (67%), east 70% of Tensift, Temri (100%), north 20% of Souss	1,2,3	R,C,P,L	7
Mengoub	32.26998	-2.34979	Nearly all of Guir (95%)	2,3	R,L	8
Guelmin	29.00665	-10.0246	Cotiers Guelmin-Tiznit (100%), South 33% Draa	2,3	R,C,P,L	9

ECONOMIC, FINANCIAL AND SOCIO-ECONOMIC ANALYSIS

The estimated project cost for the recommended radar installations is $31,360,000. This includes $28.2 million for 9 radars; $360,000 for annual training; and $2.8 million for the 1st year maintenance. The estimated damages caused by natural hazards exceed $1.5 billion over the last 30 years (an average of $50 million per year), and there is a strong economic incentive to reduce this impact.

Several leading institutions were considered to fund the recommended program. These include:

- World Bank
- Islamic Development Bank
- USAID
- The African Development Bank
- Kuwait Fund

However, based on our review, the most likely funding institution is the United States Export Import Bank (Exim Bank).

Financial projections were prepared to fund the recommended improvements. These can be found at the end of Section 6 of this Feasibility Study.

PRELIMINARY ENVIRONMENTAL IMPACT STATEMENT

The proposed weather radars will have a positive effect on the tourism and agricultural sectors, unemployment, transportation and goods movement, and private industries. However, the installation of the radars will have some temporary and long-term impacts that need to be identified and mitigated during the planning, construction, and operational phases of the project. Table 7.1, located in Section 7 of this Feasibility Study, summaries some of the issues that may be encountered during the siting of the recommended radar locations.

Issues that may be encountered, along with suggested measure to mitigate, are discussed in detail in Section 7.

PROCUREMENT PLAN AND BID PACKAGING PREPARATION

Procurement documents have two main components. The first component is the commercial conditions and the second component is the technical specifications. Within both the commercial conditions and technical specifications are standard clauses and special clauses that are used to point out various conditions of the contract. This could include qualification clauses that don't necessarily relate to the equipment or services being offered, but possibly to the strength of the bidder in performing the services needed, including previous similar contracts in both subject and size.

Section 8 of the Feasibility Study presents both elements of specifications developed by DMN in recent weather radar tenders as well as additional specifications that will improve the product delivered by the winning bidder. There is an emphasis in the added clauses to assure operational sustainability of the network, not only in the lifespan of the radar network but also in the efficient operation and use of the products from the radar network. An example of this is found in the training element. The weather forecast office of DMN should be one of the prime users of the numerous weather radar network products, but instead the B&N Team found the weather forecasters are in need of more training as they were only using a very small fraction of the products. Thus, the training element has been strengthened to provide on-going training through PC based multi-media training. In this way initial training can be given to new weather forecasters and refresher training can be given to established weather forecasters. This was not possible in the training environment that was evaluated by the B&N Team. A copy of the Baron Services Radar Training Manual is provided for reference as an Appendix at the end of this Feasibility Study.

DEVELOPMENT IMPACTS

Establishing an effective national system for nowcasting and responding to environmental crises will stabilize national security and stability. Specific sectors of society have varying needs for meteorological, hydrological and allied services. These needs will continue to grow to meet the demands of environmental changes and development.

Weather and climate influence agricultural production, transport (air, sea and surface), energy generation, water resources, disaster management, building and construction, commerce and industry, recreation and tourism and environmental management. Factoring weather and climate services into social and economic policy formulation and development plans is the key to achieving sustainable development. When planning for economic and social systems, and infrastructures, consideration of the potential impacts caused by severe weather and extreme climate events is needed to avoid potential negative impacts. The social and economic systems and infrastructure must be robust to withstand weather and climate extremes and resilient for rapid recovery following disasters.

The proposed weather radar system would provide betterment to the following sectors of Morocco:

- Public weather service nowcasting
- Agriculture
- Transportation
- Energy generation and distribution
- Building and construction
- Real-time data collection
- Real-time information dissemination

Human capacity building benefits include:

- Construction workers to build the radar system
- Permanent job creation
- Training
- Technology transfer
- Efficiency and productivity
- Off shore drilling activities
- Improvements to competence, industry and insurance
- The health sector
- Improvement to recreation and tourism

Market area benefits include:

- Conforming to legal and regulatory requirements for foreign investments that will further encourage foreign trade.
- Radar modernization that will keep work in country

Other benefits will include:

- Improvements in Public Safety
- Indirect Job Creation
- Demonstration Effects
- Regional Support and Technology Transfer to Developing Countries
- Improvements to the Environment

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1. INTRODUCTION

1.1. SUMMARY

The Burgess & Niple, Inc. (B&N) Team[1] was retained by the Moroccan National Meteorology Department (DMN) to prepare a feasibility study for upgrading the weather radar network to increase coverage in the Kingdom of Morocco. Adverse weather and flooding costs the Kingdom millions of dollars annually and impacts the quality of life and economic stability of the country. Therefore, the establishment of an effective national system for nowcasting and responding to environmental crises will stabilize national security and stability.

1.2. OBJECTIVES

- An assessment of the current radar network.
- An assessment of covered and non-covered areas within the study area, as well as identification of critical areas that cover the Moroccan areas in the north of Tan-Tan City. See Figure 1.1 for the approximate study area. Determination of needed upgrades and additions to existing radars.
- Development of technical specifications for the additional radars.
- Preparation of a feasibility analysis that evaluates the various leads of investment to the radar network versus the environmental and socio-economic benefits of having wider coverage.
- Preparation of an investment program outlining network upgrades in phases, if appropriate.
- Preparation of reports of findings of the above.

Figure 1.1 – Approximate Study Area

1.3. SCOPE OF WORK

Task 1 – Initial Visit

- Travel to Morocco and meet with DMN officials to understand their capabilities and current systems.
- Agree on available data and identify additional data needed.
- Agree on DMN's role in acquiring necessary data.
- Develop a schedule for collecting data.
- Visit various weather radar stations throughout Morocco.

1 The B&N Team includes Innovative Hydrology, Inc.; Desert Research Institute (DRI); Barons Advanced Meteorological Systems (BAMS); Enviromation, Inc.; and Financial Business Consulting Group.

Task 2 – Radar Diagnostics

- Field Assessment of the Five Radar Stations.
- Field assessment of radar concentrators installed in the weather regional offices (RMSs) at Rabat, Fez, Casablanca, and Agadir.
- Detailed field assessment of central radar concentrator of the radar network, located in Casablanca.
- Field assessment of maintenance and supervision stations in Casablanca.
- Detailed report of findings.

Task 3 – Climate Issues

- Extensively review statistics and reports on occurrences of floods, flash floods, excessive rain storms, and other weather-related phenomena in order to understand recurrence frequencies.
- Review the severity and the extent of damage and death by these occurrences
- Categorize information by geographic location to determine what areas were and were not covered by the network.

Task 4 – Needs Assessment

- Determine equipment needed to upgrade existing radar stations.
- Determine the number of additional radar stations needed, the equipment required, and the geographic locations.
- Develop justification for the additional station locations and their suitability.
- Detail technical specifications, quantities and requirements for equipment, and identify prospective U.S. sources of supply.

Task 5 – Economic, Financial and Socio-Economic

- Analyze costs of equipment, operation and benefits.
- Assess positive impacts of network upgrade.
- Determine least-cost solutions.
- Determine solutions to minimize environmental and other negative impacts.
- Quantify current value of damages.
- Prepare financial projections.
- Identify risk factors and propose mitigating measures.
- Identify sources of financing.

Task 6 – Preliminary Environmental Impact Assessment

- Prepare a statement on components preserved through improved prediction capacity.
- Address impact on tourism, agriculture, unemployment, transportation, and private industries.
- Identify potential negative impacts in regards to recommended locations and propose mitigating measures.

Task 7 – Procurement Plan

- Prepare prioritized phasing plan based on urgency, coverage and predictability capacity.
- Prepare recommendations for technical specifications, quantities, and requirements for all equipment suggested for the network upgrade.

Task 8 – Development of Impact Assessment

- Assess impacts on country infrastructure, technology transfer and productivity improvement, human capacity building, market-oriented reform, and other developmental benefits.

Task 9 – Prepare and Deliver Final Report

1.4. FUNDING

The feasibility study is being funded through a grant from the U.S. Trade and Development Agency (USTDA).

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2. INITIAL VISIT (TASK 1)

2.1. SUMMARY

Pursuant to Task 1, the B&N Team met in Morocco for a four-day meeting during the week of September 8, 2008.

Meeting Purpose

- Analyze costs of equipment, operation and benefits.
- Understand DMN capabilities and current systems.
- Agree on available data and identify additional data needed.
- Agree on DMN's role in acquiring necessary data.
- Develop a schedule for collecting data.
- Visit various weather radar stations throughout Morocco.

Participants

- The B&N Team — Mr. Bernard Bouman (Project Lead, B&N)
  Mr. Sacha Sirovica (B&N)
  Mr. Mark Heggli (Project Manager, Innovative Hydrology)
  Mr. Arlen Huggins (DRI)
  Mr. Rick Braswell (BAMS)
- DMN — Mr. Mustapha Geanah (Director)
  Mr. Saouri (Chief, Radar and Satellite Services and Project Lead)
  Mr. Messoudi (Chief, Center for Meteorology Exploitation)

2.2. KEY EXPECTATIONS

The B&N Team and DMN collaborated to review relevant reports and data, the current status of the radar network, and to identify data necessary for completion of the study. Two key project expectations were identified in order to determine the recommended technological improvements:

- Diagnosis of the existing network *currently* covering the region west of the Atlas Mountains, and
- Evaluation of areas *not currently* covered by the existing network (primarily in eastern and southern Morocco) to determine large areas of non-coverage and smaller gaps resulting from terrain blockage. This data will determine radar spacing with priority given to regions of highest societal and economic risk.

2.3. DMN DEPARTMENT PRESENTATIONS

Mr. Saouri, Chief of Radar and Satellite Services and Project Lead

- The current network was described as consisting of five C-band radars with a planned installation at a sixth site. Several of the tasks defined in the Contract, as well as the great need for solutions to network improvements, were restated.
- The B&N Team asked for documentation related to recently-performed upgrades on the five radars, as well as data on the performance of these new systems. However, a winter season of operation is first needed in order to evaluate this performance.
- A report of a previously conducted study of storms, floods, and other meteorological phenomena spanning a 13-year period would be provided.

Mr. Messoudi, Chief of the Center for Meteorological Exploitation

This department is responsible for issuing national, regional, and local weather forecasting; general, maritime, aviation forecasting, and telecommunications.

- The network includes 43 surface sites and four upper-air sites which serve as a basis for modeling and observation activities. Existing radar does not effectively cover the entire country, and terrain blockage creates gaps in coverage west of the mountains. These "black spots" must be eliminated to attain 100-percent coverage.
- Review of recent regional meteorological patterns:
  - Northern region: Occasional polar fronts; intense rain events (100 millmeters of rainfall in 24 hours).
  - Southwest region: Tropical and subtropical storms originate too far offshore in the vicinity of the Canary Islands where no effective radar coverage exists.
  - Southern region: Saharan tropical events are the primary source of rain.
  - Thunderstorms previously occurred only in summer months, but now occur throughout the year. In February 2007, severe rainfall (120 mm in 2 hours) occurred.
  - Significant amounts of water are stored in the Atlas Mountains as snow; 90 percent of the runoff is used for agricultural purposes.

Mr. Merrouchi, Chief of Maintenance and Equipment (DTE)

This department is responsible for radars, radar facility power and air conditioning, and radar software. The first radar was installed as a result of the Al Ghait Weather Modification Project, a snowfall enhancement project in the Atlas Mountains. The first five radars were built by Enterprise Electronics Corporation (EEC) with whom they retain a maintenance contract which includes:

- A central maintenance system monitoring each of the radars remotely from Casablanca. The current system has been unstable, and lack of spare parts has hindered maintenance.
- Routine performance of an internal calibration likely consisting of the insertion of a signal of known strength to test receiver sensitivity to ensure its stability over time.

- Performance of external calibration is incomplete because the required equipment is not functional. However, complete performance is critical to ensure that all radars are performing at the same level and to determine if sensitivity of the entire system is changing over time (particularly after changes have been made to radar hardware).
- A Z-R conversion was supplied with the software by the manufacturer, but has not been evaluated with the five network radars, most likely indicating that no actual comparisons have been made with radar estimated rainfall rates and actual gauge measurements.
- The current study should address issues of maintenance and training, such as subcontracts versus problem solving internally in DTE. A recommendation regarding the radar system itself and the sufficiency of the capabilities of the current 5-cm radar to address specific needs are also needed. If the study eventually concludes that several other radars are needed to address all coverage issues and specific needs, then DTE might need to reorganize to create a center that handles all radar issues (calibrations, maintenance, radar algorithms, data formatting and archiving, etc.) internally to ensure uniformity of data quality throughout the network.

2.4. SITE VISITS

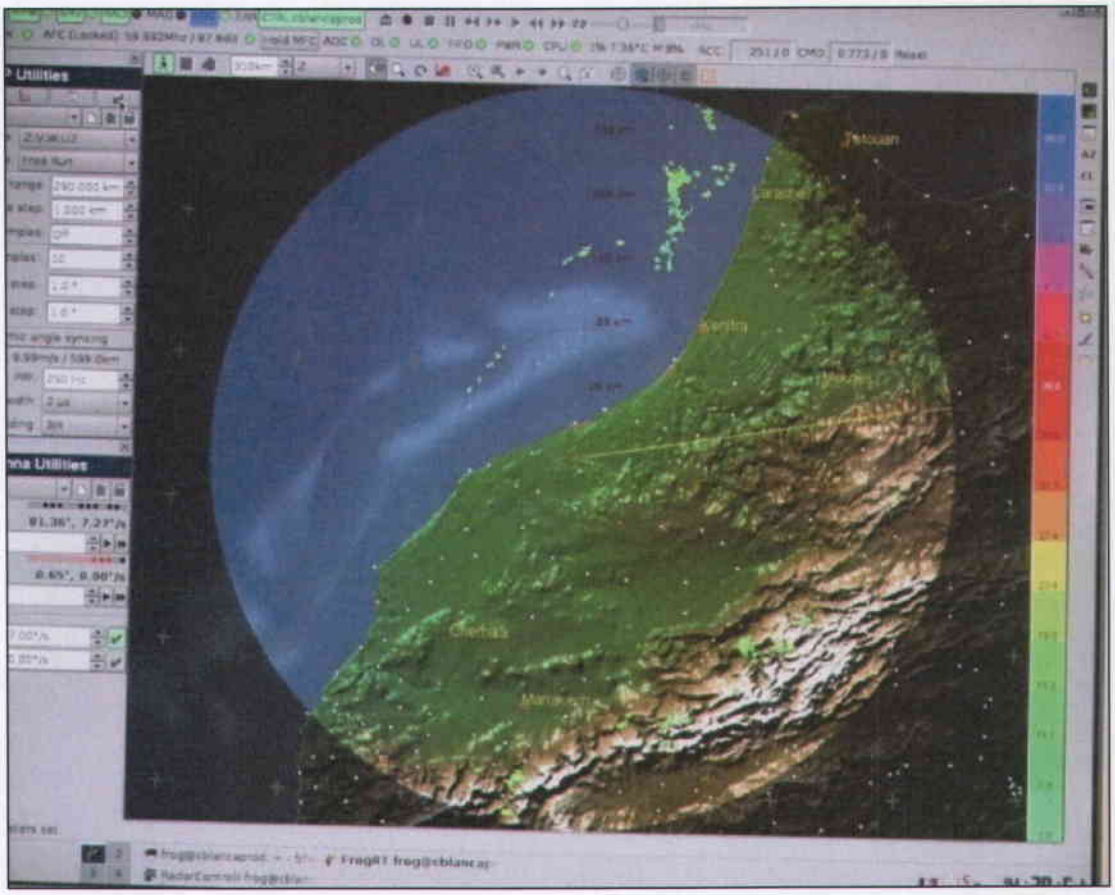
Casablanca Radar Station Site Visit

- This station is not operated continually, but only when a weather system moves into the radar's coverage area, possibly for *economic reasons* (to save money on power and the salaries needed to staff the station 24 hours a day, 7 days a week), and also for *technological reasons*, such as insufficient Doppler signals to produce clear images or wind profiles resulting in lack of significant data to archive.
- Tall trees at the site were partially blocking the lowest tilt scan.
- The radar is not routinely operated in Doppler mode.
- Potential Doppler mode problem as the radar tended to drop out of Doppler mode.
- The operating and display software seemed to be relatively flexible.
- The B&N Team will require full software and hardware documentation.
- The clutter filter was demonstrated and appeared effective in removing the bulk of the ground clutter, but as noted above, the details of the clutter filter are needed.

Figure 2-1 Casablanca Radar Site

- Discussion with local consultant, Mr. El Krimi of the Financial Business Consulting Group (FBCG) – Mr. Krimi was retained to assist in the completion of Task 3 (Economic, Financial, and Socio-Economics). This tasks included quantifying population by political divisions (16 in Morocco), gathering statistics on damages related to floods and other meteorological phenomena and economic losses due to weather phenomena and their geographic distribution, and analysis of data that might be available on agricultural production and estimated losses by storms, floods, etc. A meeting to further define Mr. El Krimi's responsibilities later in the week was agreed upon.

Figure 2-2 Casablanca Radar Scan



Water Resource Management and Flood Forecasting Department Site Visit

The B&N Team met with the staff at the Water Resource Management and Flood Forecasting Department (DRPE) which is responsible for national and regional water planning and resource management. The DRPE completed a flood risk study in 2004 which identifies and describes approximately 400 flood risk sites throughout Morocco. A copy of the three-volume report and

PowerPoint presentation was given to the B&N Team. The presentation included the following information:

- Annual rainfall over Morocco ranges from less than 200 mm (8 inches) in the south to more than 800 mm (32 inches) in the northern Atlas Mountains. 70 percent of the country gets less than 300 mm (12 inches).
- A 2001-02 season flood caused significant loss of life and property and resulted in the creation of the National Flood Protection Plan. For the first time, flood problem areas were identified and inventoried. An analysis of staffing requirements and an action plan were created. 391 flood risk sites were analyzed, put into a database and linked with GIS Sites indicating points that have experienced some type of flooding (streams, local urban, flash floods, poor drainage, etc.)
- Human, societal, infrastructure and environmental characteristics were identified and given a risk level. 56 sites were given a high priority, where levees and other stream management measures may be constructed. The plan is to be implemented over a 15 year period.
- The GIS file of the main Morocco basins could be obtained but it incomplete.
- A record of several decades of flooding events may be acquired from DRPE including daily rainfall data and summaries for 200 stations. Another set of standard rain gauge sites maintained by the DMN will be obtained from Mr. Saouri.

Visit to the Offices of ANZAR (Director, Mr. Azili)

- ANZAR is a hydrology consulting firm specializing in groundwater and environmental problems. The use of their expertise would be determined at a later date.

Fes Radar Station Site Visit

The B&N Team met with the Northeast Region Department of Meteorology (DRM/NE).

The DRM/NE is conducting a hail suppression (cloud seeding) project in an agricultural region in high valleys of the Atlas Mountains to the east of Fes using radar data as one of its criterion for conducting cloud seeding; however, the radar does not adequately cover the project area (the

minimum altitude sampled is about 5 kilometers MSL) due to terrain blockage to the west. This fruit-growing area is highly susceptible to hail damage and, therefore, needs three additional radars installed in the mountains to complete coverage. Clouds are currently seeded with 87 ground-based generators to attempt to suppress hail production in storms; hail events occur 5 to 10 times per storm season with the most common hail size being of 5-8 mm. Images from the Fes radar during storms were not available.

Figure 2-3 Fes Regional Meteorological Office

Figure 2-4 Water Resource Management and Flood Nowcasting Station

While in Fes, the team met with Director Belkheiri and staff at the Sebou Hydrologic Basin. The 48,000 square kilometer basin is prone to flooding, thus radar coverage is critical, particularly in cases of local and flash flooding. Documentation of the floods, stream gage locations, and forecasts is available. Currently, quantitative precipitation forecasting for this area comes from the DMN which is then translated into the basin flood forecast. The current method of obtaining stream gage data is by voice radio link to stream gage sites. Under normal circumstances, the stream level data is radioed to the Sebou Basin office once daily. However, when there is a potential for flooding, the data is sent more frequently.

An automated system of rain- and stream-gage reporting would greatly improve the general flood monitoring and forecasting task of the Sebou office. An automated network of surface observations could then be linked to radar observations to provide a more quantitative estimate of rainfall in regions without gage data. To make more than qualitative use of radar data, even with improved coverage, some detailed radar-rainfall comparisons will be needed at key points in the basin to customize the Fes (or other) radar precipitation algorithm for this region. The

process of data assimilation and modeling for forecasting floods and the incorporation of radar precipitation estimates is a complicated one, but the first step would be to obtain a reliable QPE product for each drainage basin.

Figure 2-5 Sebou Basin Map (Showing Stream Gauges (41) and Rain Gauge Locations)

Fes Airport

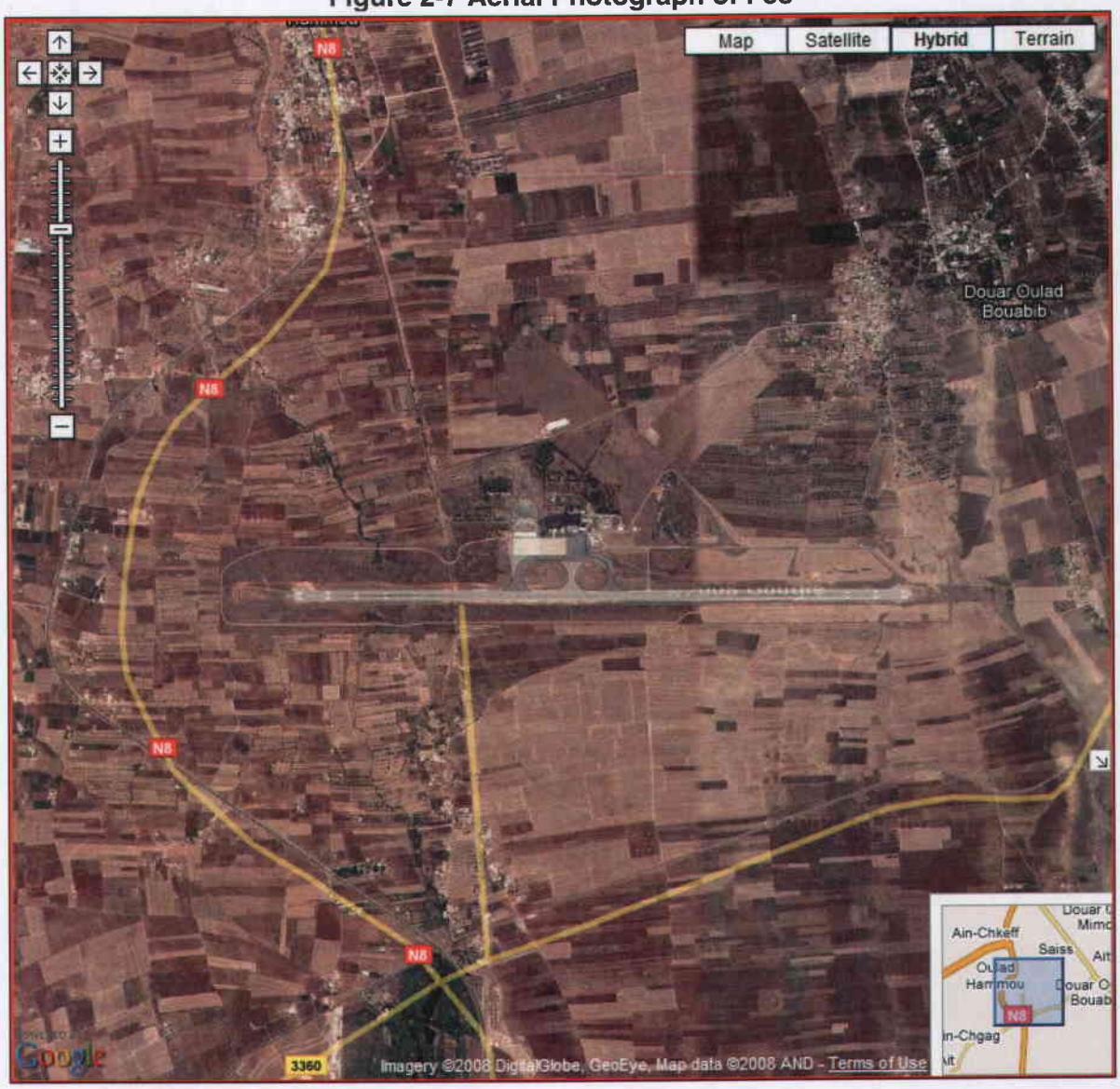
The Fes radar and weather office is located at the Fes Airport. The radar site receives aviation weather forecasts from Casablanca and monitors the radar in real time. The primary function of the radar is to monitor thunderstorm cell locations and track those which move through the approach and departure zones.

Figure 2-6 Fes Airport

This information is communicated from the control tower to incoming and outgoing flights.

Specific Doppler radar algorithms in use on the Moroccan radars, which identify wind shear from microbursts, gust fronts, or other shear producing phenomena, are not apparent. The Fes radar appears identical to the Casablanca radar. Examples of low elevation scans from all Morocco radars during past weather events are required to better define terrain blockage patterns.

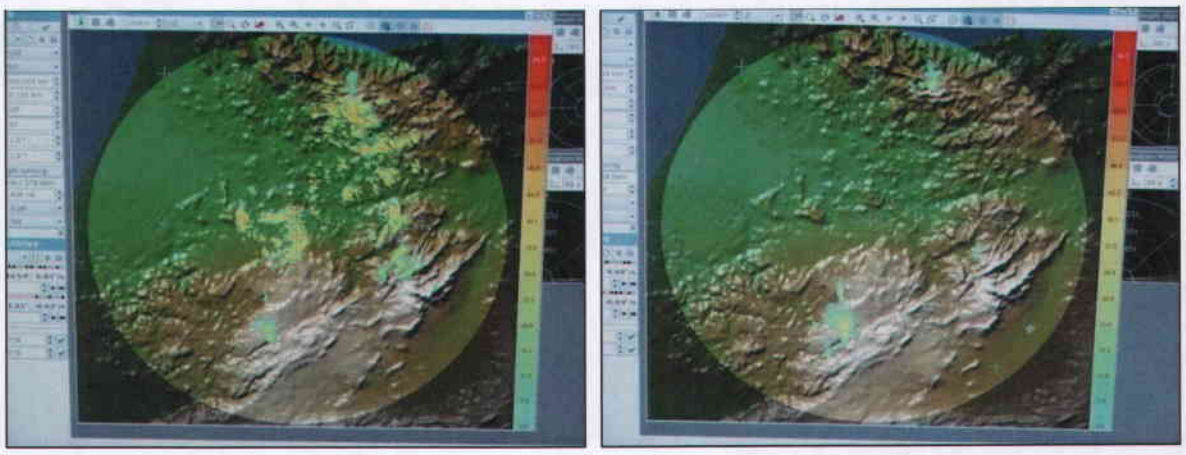
Figure 2-7 Aerial Photograph of Fes



This map shows the area surrounding Fes Airport. The red arrow points to the spot where the Fes radar and airport meteorological station are located.

The Fes radar is in close proximity to the airport runway. In contrast, a Federal Aviation Administration (FAA) Terminal Doppler Weather Radar (TDWR) used to detect wind shear over the Las Vegas Airport in the U.S. is about 15 km from the airport. U.S. TDWRs are operated by the FAA for the specific purpose of hazardous weather detection over airports and, therefore, use markedly different scan strategies (frequently sampling only the lowest layers of the atmosphere) than the National Weather Service WSR-88Ds which are used for severe weather detection and precipitation estimation. This suggests that radars to satisfy specific needs of aviation weather in Morocco may need to be separate from the network of weather surveillance radars. A climatology of wind shear events at airports would be helpful in evaluating the need for such radars. It should also be noted that in dry environments the TDWRs are not nearly as effective in detecting wind shear due to a lack of larger (precipitation) radar targets. In the arid western U.S., surface wind sensor networks and Light Detection and Ranging (LIDAR) systems have been used to augment the TDWR.

Figure 2-8 Ground Clutter Returns



2.5. TRIP WRAP-UP MEETING

The B&N Team met Mr. Geneah, Director of the DMN, and his staff at DMN headquarters to summarize the week's meetings and tour the facility.

Tentative Agreed-Upon Schedule

Moroccan consultants will complete the climatology and socio-economic analysis (Task 3), since they are familiar with the needed contacts and data sources. This Task includes the determination of new radar sites requiring three visits, one for each region where radars could potentially be placed. The B&N Team will make an initial site selection based primarily on

terrain maps and radar occultation programs. The Moroccan consultants will then evaluate the logistical elements such as availability of power, land use, vegetation, road access, etc.
Once Task 3 is complete, the B&N Team returns to Morocco to conduct the radar diagnostic analysis (Task 2) to be completed by the end of October 2008. Diagnostic analysis includes calibrations, transmitter characteristics, Doppler capability, dual-polarization capability, and more.

Additional Data Requested from DMN

- **Radar**
  - Latitude and longitude of all current and proposed radar sites (national network plus proposed hail project sites).
  - 0.5- to 4.0-elevation, angle-tilt images from each site in clear air to show ground clutter and with full echo coverage to show blocked areas.
  - Documentation describing all radar software (algorithm) products, including preprocessing of radar data (occultation corrections, clutter suppression, etc.) and a description of the radar data archiving process, including the format of the archived data.
  - Documentation describing all radar hardware, including the Doppler processor and any dual-polarization hardware that is currently being used.
- **Precipitation/Meteorological**
  - Isohyetal map of annual precipitation with topography, including current radar sites.
  - Isohyetal maps of monthly precipitation with topography.
  - Frequency of significant rainfall events in each main hydrologic basin.
  - Map or table describing frequency of hail events by location.
  - Lightning climatology would be useful.
  - Documentation on frequency of wind shear events at airport.
- **Hydrological**
  - Country map with basins outlined and radar locations.
  - A description of the current method of flood forecasting used by DMN (observational inputs, models used, types and resolution of forecasts issued).
  - Radar coverage shown on basin maps.
  - Flood events by basin and site.
  - Flash flood events by basin and site.

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3. CLIMATOLOGICAL and SOCIOECONOMIC ANALYSIS (TASK 3)

3.1. Methodology

Historical data of every meteorological event during the last 5 to 20 years is not readily available. It is very costly to obtain this kind of data in Morocco and, thus, procurement of such data would have required funding beyond the scope of this project.

All available information regarding damages from National Flood Records was provided by the National Meteorology Department (DMN). The DMN provided all statistics and reports regarding the extreme weather phenomena described in this report. There were difficulties in obtaining information from some institutions in Morocco. In many cases, repeated contact with Moroccan officials of various departments yielded no response. In addition, geographical data was obtained to the extent that was was available. The remaining information was gathered through research using the internet, newspapers, and non-official reports.

The Infrastructure Ministry provided all data with respect to infrastructure damages. However, further information regarding the black spots (uncovered areas) was not obtainable. Climatological data that was able to be freely obtained is included in this report. Further information was obtained by visiting the Agricultural Department, which only produced informal data. Detailed statistics on hail damage and flooding was not available. All relevant data has been included in this report.

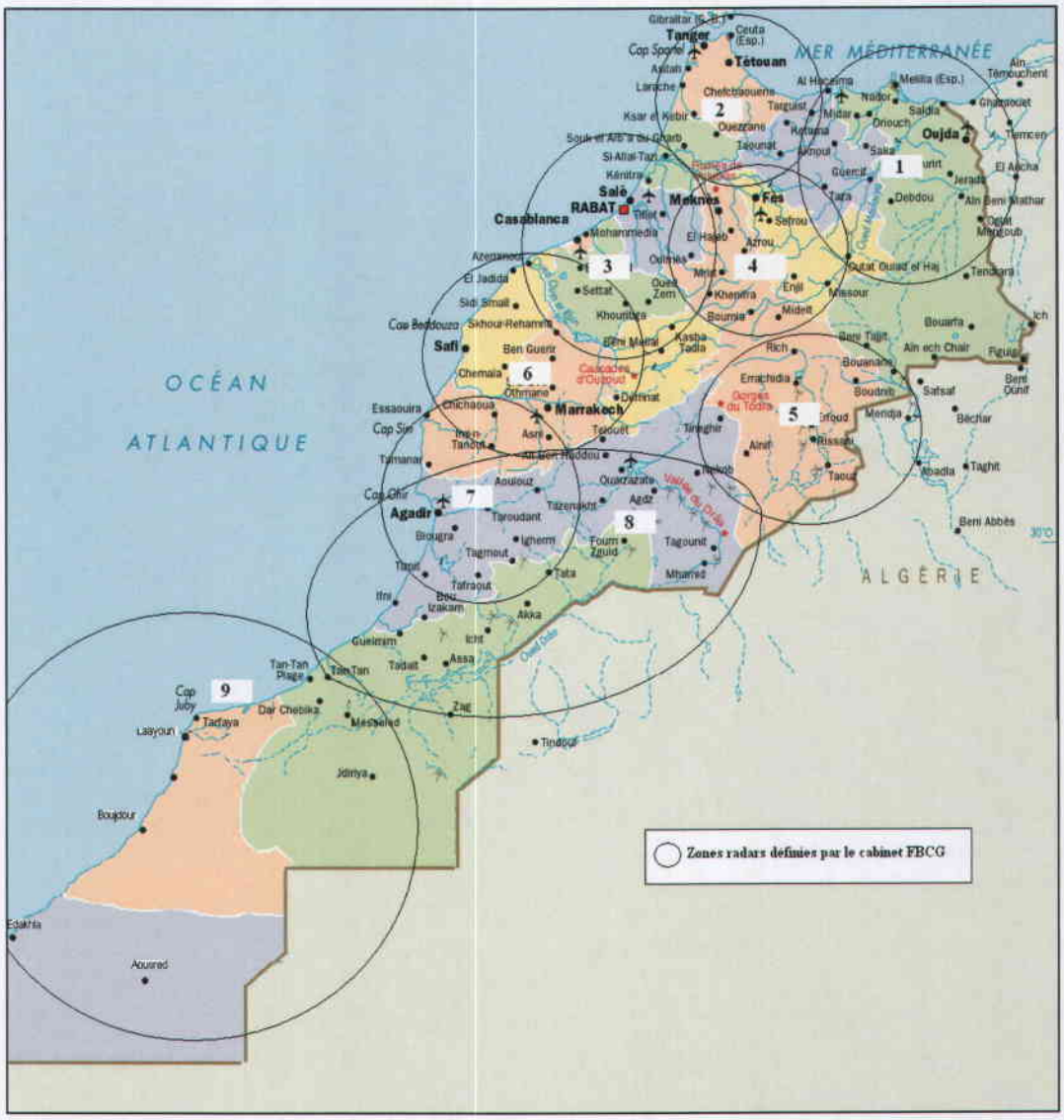
All monetary values referenced in this report are in Moroccan Dirhams (MAD). As of July 17, 2009, the exchange rate is equal to: 1 Moroccan dirham = 0.124749 U.S. dollars.

3.2. Introduction

Despite the arid climate, Morocco is subjected to floods and hail causing devastating effects for both families and the economy. Floods occurred in 1995, 2002, and 2006, to name a few. Dams are often constructed as a means of protection for homes and crops. To date, over 100 projects have been constructed in the effort to insulate against flooding effects, but due to urbanization and deforestation, floods continue to ravage the country which has no warning system to evacuate residents from flood-prone areas.

This *Study* investigates high-risk areas for extreme weather events. Infrastructure was inspected to assess condition and operability. Wet-weather event statistics were analyzed to evaluate the resulting socio-economic impacts. Precipitation, flooding, and other extreme events during the last 60 years in Morocco were evaluated to assess damages and economic losses. This data is categorized according to eightareas which are identified on the following page.

Figure 3.1 – Radar Zones, as defined by FBCG that is part of this Feasibility Study[1]

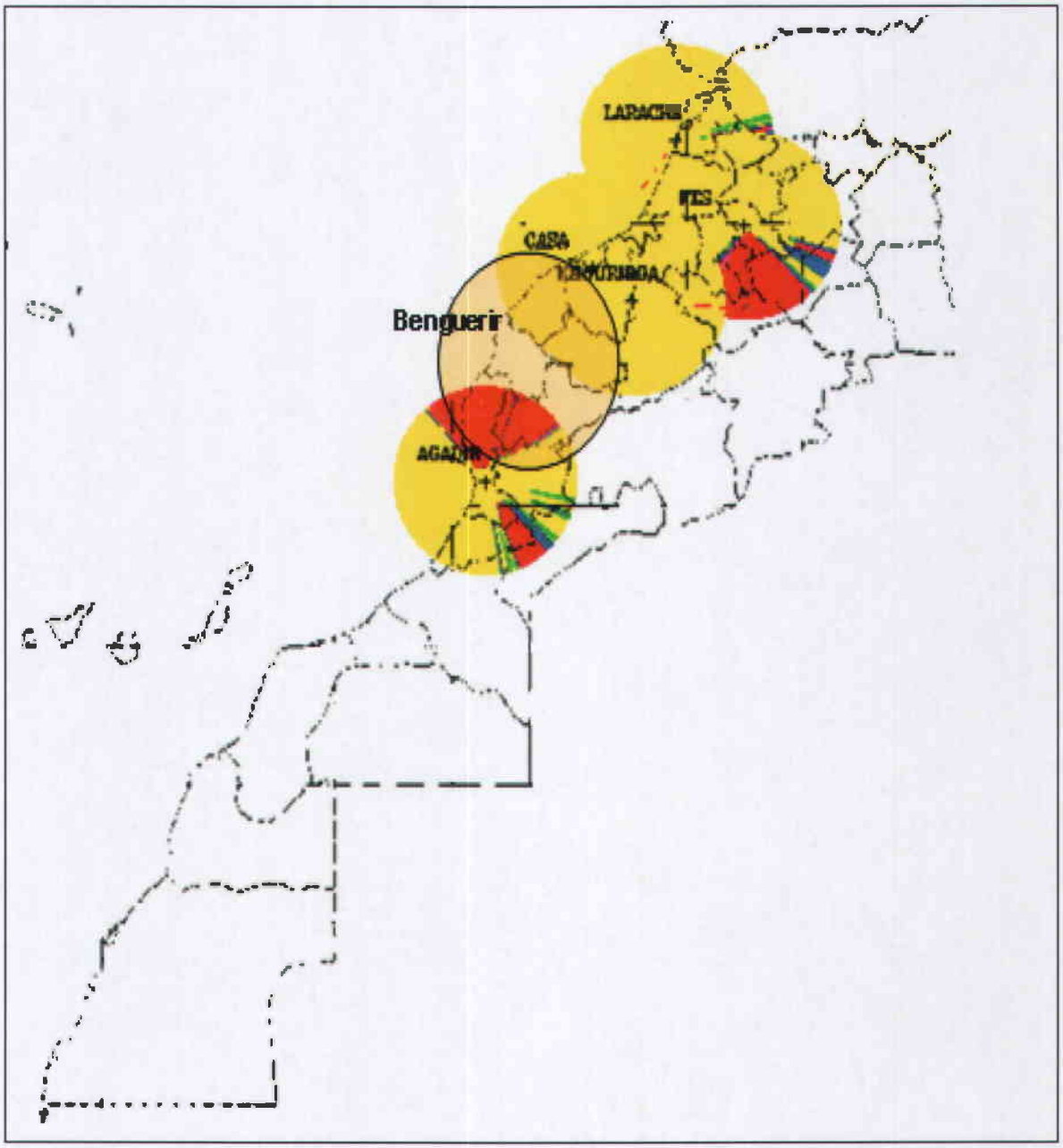


1. Eastern Zone (Oujda, Nador, Hoceima)
2. Tangier Zone (Tangier, Tetouan, Larrache, Chefchaouen, Assila)
3. Casablanca Zone (Casablanca, Rabat, Kenitra, Ben Slimane, Settat, Beni Mellal)
4. Fez Zone (Fez, Meknes, khénifra, Ifrane, Boulmane, Sefrou)
5. Errachidia Zone (Errachidia, Boudnib)
6. Marrakech Zone (Marrakech, El Jadida, Chichaoua, Kalaa Seraghna, Safi)
7. Agadir Zone (Agadir, Essaouira, Tiznit, Taroudan)
8. Ouarazazate Zone (Ouarzazate, Guelmim, Tantan, Zag, Assa)

[1] This figure is property of the Kingdom of Morocco. The figure does not directly reflect or include work completed under the Terms of Reference for this project.

Actual radar coverage, as verified by the DMN, is shown on **Figure 3.2**. The DMN has six radar sites installed at Larache, Casablanca, Fes, Agadir, Khouribga, and Benguerir.

Figure 3.2 – Existing DMN Radar Coverage[2]



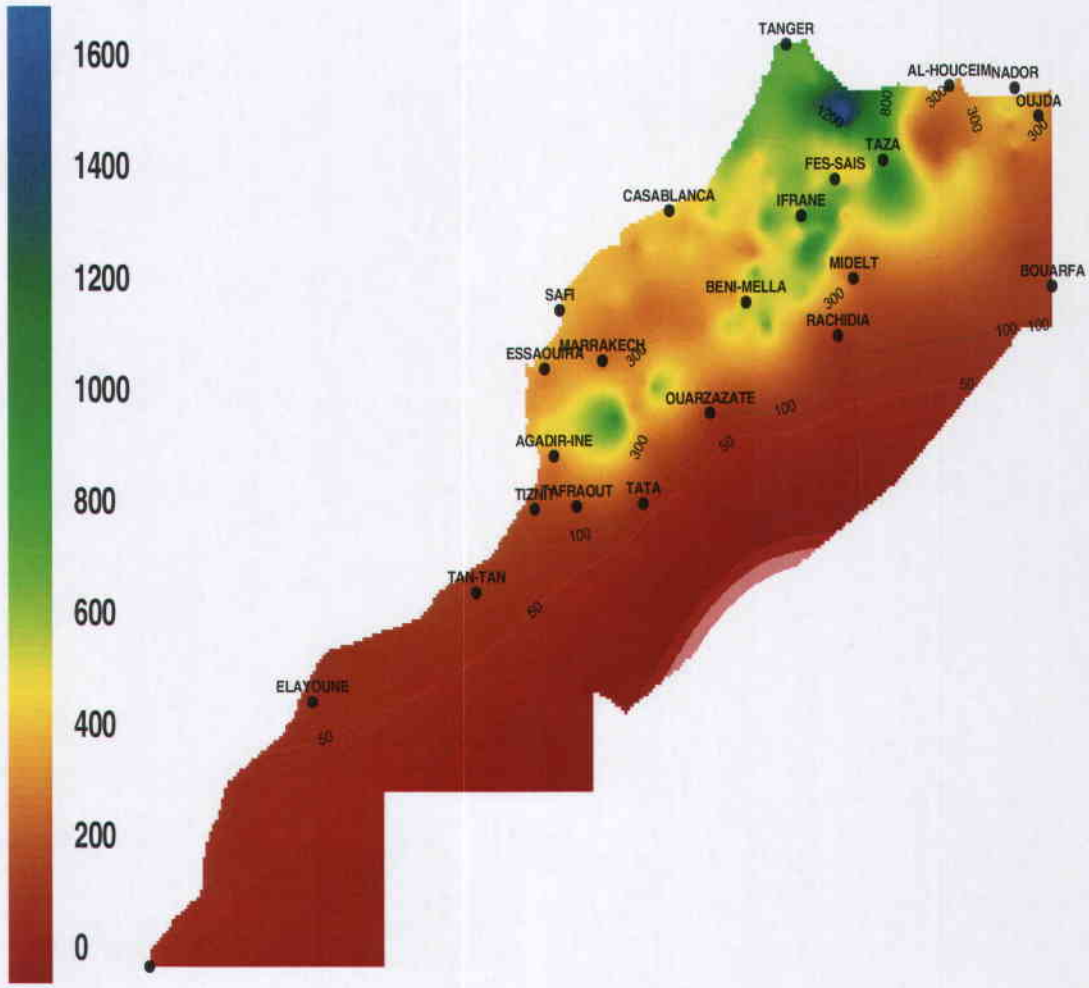
[2] This figure is property of the Kingdom of Morocco. The figure does not directly reflect or include work completed under the Terms of Reference for this project.

3.3. Climate Characteristics

Temperatures

The average annual temperature is approximately 17 to 19 degrees (°) Centigrade (C) with the exceptions of Ifrane with an average of 11° C and Milt averaging 14° C. The average maximum temperature is 20 to 25° C and average minimum is -7 to 14° C. The annual magnitude of temperature (i.e., the difference between the warmest month and the coldest month) is 10° C on the coast and 14° C inland. The wet season is from August through May, and the dry season is from June through September.

Figure 3.3 – Normal annual rainfall (1961-1990)[3]



[3] This figure is property of the Kingdom of Morocco. The figure does not directly reflect or include work completed under the Terms of Reference for this project.

The wet region in the north receives more than 800 millimeters (mm) per annum. The western Rif and Middle Atlas receive the most precipitation which exceeds 1,000 mm per year. The central region receives between 400 mm and 600 mm annually, while the Oriental and Souss regions receive between 200 mm and 400 mm each year. The South Atlas Mountain region is the driest, receiving only 50 mm to 200 mm annually.

The greatest record number of days of precipitation varies greatly by region. According to ***Table 3.1***, Ifrane received an average of 100 days of precipitation per year, while Ouarzazate received only 33 days.

Table 3.1 – Average Precipitation Days by Region

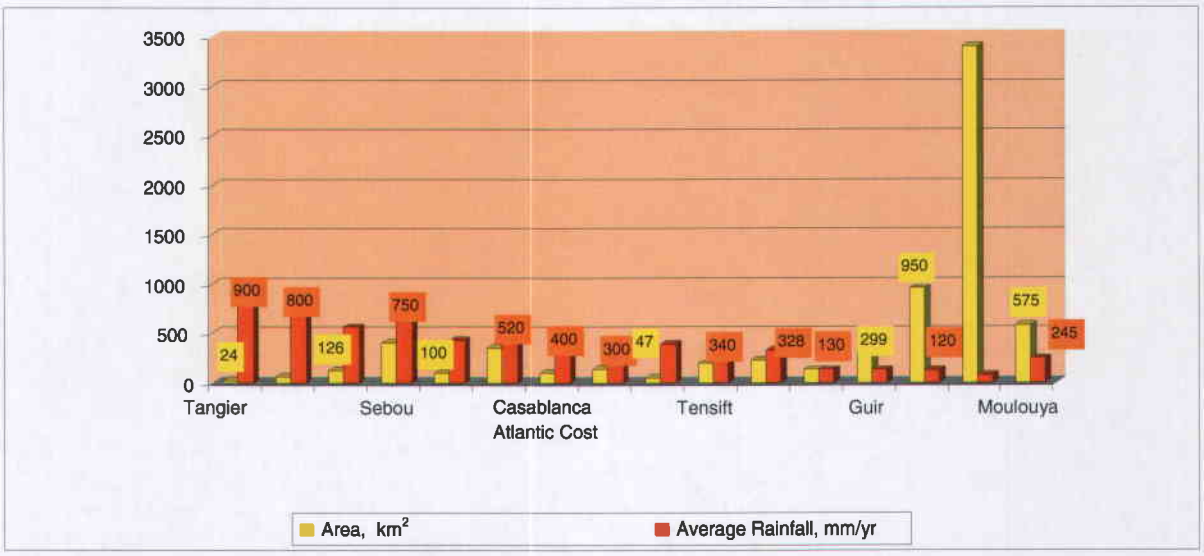
Region	Precipitation (days)
Ifrane	100
Tangier	93
Haouz	34
Souss	34
Ouarzazate	33

Table 3.2 – Average Annual Rainfall by Basin

Wet plains	Size (km^2)	Average Annual Rain (mm/yr)
Tangier	2.4	900
Loukkos	5.6	800
Mediterranean coast	12.6	560
Total North Rif Basins	**20.6**	**680**
Sebou	40.0	750
Bou Regreg	10.0	430
Oum Er'Rbia	35.0	520
Casablanca Atlantic coast	10.0	400
El Jadida, Safi Atlantic coast	13.4	300
Essaouira Atlantic coast	4.7	390
Tensift	19.4	340
Total North and Center Atlantic Basins	**132.5**	**520**
Souss – Massa	22.4	328
Tiznit – Ifni	13.0	130
Total South West Atlantic Basins	35.4	230
Guir	29.9	130
Draa	95.0	120
Total South Presaharian Basins	**124.9**	**125**
Moulouya	57.5	245
Total Oriental Basins	57.5	245
GRAND TOTAL	**313.4**	

Figure 3.4 shows a comparison of region size to amount of rainfall.

Figure 3.4 – Comparison of Region Area and Average Annual Rainfall



Precipitation Case Studies

In September and October 2008, the various weather events and their intensity and associated precipitation was recorded and studied. Four examples are presented below.

- September 17-22, 2008 –
  - In the North and Central regions of the country, a maximum rainfall in 24 hours reached 47 mm at Taza, 31 mm in Marrakech and Errichidia, and 20 mm in Fes.

- September 26-30, 2008
  - This cluster of storms touched the Haut and Middle Atlas regions, the Rif, and the Mediterranean coast. The daily maximum precipitation was 35mm in Nador, 34 mm in Fes, and 30 mm at Chaouen.

- October 8-10, 2008
  - This meteorological situation was characterized by steady rain, storm frequency, down pours, and return periods. For this period, the maximum daily (24-hour) precipitations were: Gourrama – 70 mm, Bouarfa – 62 mm, Tetouan – 51 mm, Nador – 67 mm, and Hoceima – 71 mm.

- October 23-26, 2008
  - The maximum rainfall rate was observed in the North. It rained very heavily on the Rif, Mediterranean coasts, Middle Atlas, and the North-East. This rainfall was greater than any other wet-weather event recorded in Morocco. Daily rain accumulations were: Tanger – 200 mm, Al Hoceima – 129 mm, Nador – 123 mm, and Tetouan – 94 mm.

The cumulative histogram for the precipitation at Tangier is shown below in **Figure 3.5**.

Figure 3.5 – Cumulative Histogram at Tangier on October 23, 2008

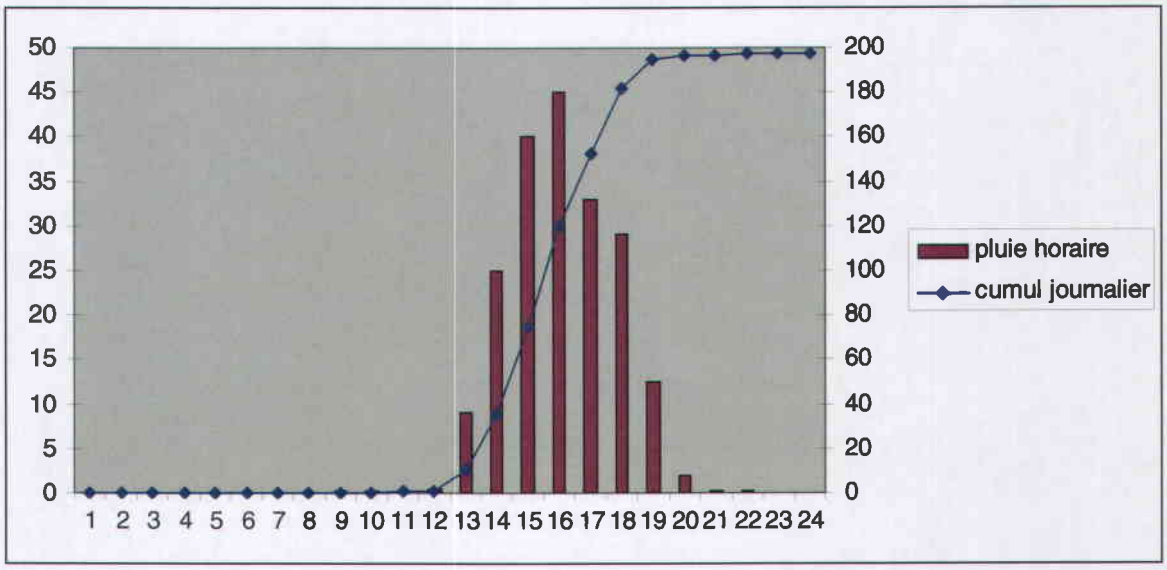


Table 3.3 compares 2008 rainfall accumulation data to historic data (1965-2003). The following table, **Table 3.4**, shows a comparison of maximum daily rain records.

Table 3.3 – Historic Cumulative Rainfall Comparison

Stations	Total rainfall September, October 2008	Maximum previous total
Tangier	345.9 mm	159.4 mm in 1969
Tétouan	304.0 mm	231.4 mm in 1965
Al-Hoceima	388.0 mm	103.7 mm in 1969
Nador	446.4 mm	120.7 mm in 1979
Oujda	122.6 mm	159.4 mm in 1969
Bouarfa	176.8 mm	97.3 mm in 2003
Errachidia	145.2 mm	120.1 mm in 1979
Fès	232.3 mm	163.7 mm in 1979

Table 3.4 – Historic Record Rainfall Comparison

Stations	Old record	New record
Tangier	124.5 mm 10/04/97	199.5 mm 10/23/2008 (4 hours)
Tétouan	86.5 mm 10/06/1984	94.0 mm 10/23/2008
Al-Hoceima	88.3 mm (month) 10/1966	129.0 mm 26/10/2008
Nador	40.0 mm 10/14/1989	123.0 mm 26/10/2008

Table 3.5 – Historic Record of Accumulative Rainfall Comparison

Station	Average	Average accumulation of October over the last
Tanger	54.4 mm	46.3 mm
Tétouan	57.0 mm	47.4 mm
Al-Hoceima	56.4 mm	46.5 mm
Nador	62.2 mm	45.1 mm

Recurrence Frequencies

The return periods vary widely by region, but, in general, have high return periods as shown in ***Table 3.6****. The return period was calculated using the Montana formula. Records of precipitation are now stored in a Geographic Information Systems (GIS) program for all 375 rain gauges, and any return period can be calculated. The frequency of a flood of a certain magnitude corresponds to a risk which will be evaluated in the financial analysis portion of this* report.

Table 3.6 – Return Periods by Region

Region	Precipitation (mm)	Return Period (years)
Tangier	179	100
Nador	102	320
Taounate	67	50

Extreme Weather Events

The DMN conducted detailed research of extreme weather events from September 1950 through June 2008; the complete report is in Appendix B. Extreme weather events affected different regions of Morocco. ***Table 3.7*** lists each event grouped by type. Each event was identified by time, location, intensity, and any pertinent remarks. The following phenomena were identified:

- TS – Thunderstorm
- HP – Heavy Precipitation
- Sn – Snow
- HW – Heat wave or desert wind
- St – Storm
- SnSt – Snowstorm
- SaSt – Sand Storm
- SW – Strong Wind
- CW – Cold Wave

Table 3.7 – Extreme Weather Phenomena[4]

Event	Date	Location
TS HP	9/25/1950	Safrou
CW Sn	Winter 1960	Milt (Aghlala)
HP	5/23/1963	Moulouya
HP	11/5/1965	Tafilalt (ziz), Sebou, Khénifra
HP CW Sn	3/1/1995	Middle Atlas and the East
HP	3/31/1995	Province South, Versants South East, Houz, Sous
TS	4/11/1995	Settat, Er-Rachidia
TS	4/14/1995	Settat El khalaa Seraghna
TS HP	8/17/1995	Marrakech, Ourika
HP	12/15/1995	Souss
HP	12/27/1995	Middle Atlas
HP	1/9/1996	Loukous
HP CW Sn	1/10/1996	Atlas
HP CW Sn	1/12/1996	Sais
HP CW Sn	1/20/1996	Chefchaouen, El Jadida, Safi, Larache, Tangier, Essaouira, Kenitra, Casablanca, Rabat-Salé, Nouasser, Mohamadia, Agadir al Massira, Khouribga, Agadir Inzgane, Tetouan, Taroudant, Ifran, Sidi Slimane, Marrakech, Sefrou
CW Sn	1/30/1996	Sais, Houz, Moyen Atlas
TS	June or July 1996	Azilal
TS	6/17/1996	Province Er-Rachidia
HP	11/11/1996	Mediterranean area, Loukous
HP	12/18/1996	Chefchaouen, Casablanca
HP	12/20/1996	Chefchaouen
TS	4/27/1997	Haouz
HP	11/25/1997	Mediterranean area, sais, Middle atlas
HP	2/1/1998	Chefchaouen, Sous
TS	9/21/1998	Taounate
HW	7/30/2000	All Morocco

[4] This Table is an official table of the Kingdom of Morocco, provided by DMN

Event	Date	Location
HW	8/1/2000	All Morocco
TS	9/12/2000	Taza
TS	9/27/2000	Taza
HP	10/22/2000	Taza
HW	Mar-01	All Morocco
TS	5/18/2001	Taza
TS	5/19/2001	Boulmane, Tetouan
TS	5/20/2001	Tetouan
HW	6/26/2001	All Morocco
HW	10/28/2001	For the seventh day, morocco is under a hot weather specially the Atlantic coast
HP CW Sn	11/9/2001	Oujda, the high and middle Atlas mountains
TS	12/23/2001	The situation of the South West of Sunday 3-10arrakec 23rd , 2001 was Sty
HP	3/31/2002	Situation of the south particularly Souss and the Sahara provinces and Ouarzazate
TS SW CW Sn	11/14/2002	A profound perturbation touched the North of Morocco on November 14 and during November 24 at 06.00 cyclone hit Casablanca Coast
HP	2003	Tan Tan, Nador, Al Hoceima, and Khenifra
HP CW Sn	1/9/2003	The Atlas and the Oriental plains, a week of cold from 10 to 17 January North East
CW	1/19/2003	
HW	8/1/2003	All Morocco
TS	8/12/2003	Tan Tan
TS	8/13/2003	Taroudant
HP	11/15/2003	Return of the North East
HP	12/9/2003	Khenifra, Boulmane, Rabat in Sept, Oct and c 2003
Earthquake	2/24/2004	Al Hoceima
SaSt	3/3/2004	Province sud, versants sud est
CW Sn	12/26/2004	A wave of cold with Sn and strong freezing hit morocco this weekend leading to rain and Sn. The arrival of the polar air Saturday that hit the west of the Mediterranean basin and the Maghreb is the source of this exceptional rain.
CW	1/24/2005	All Morocco

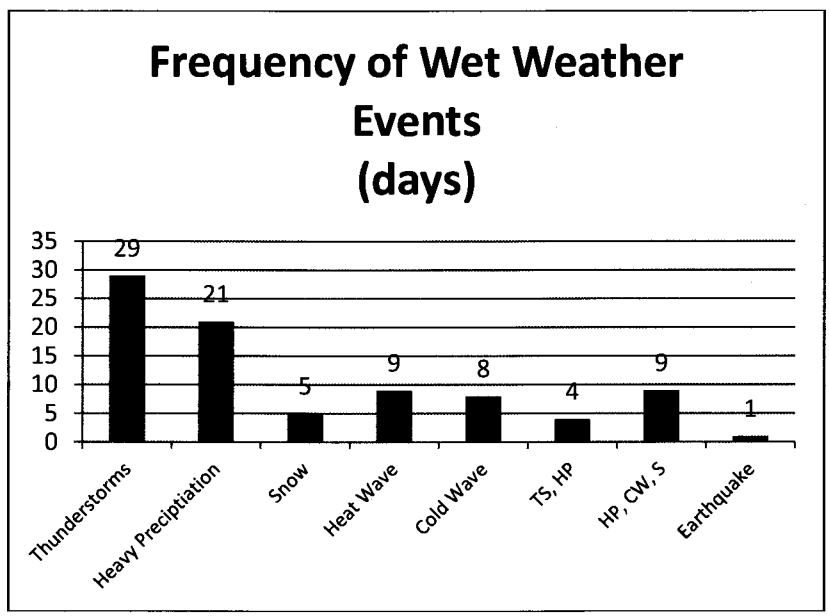
Event	Date	Location
CW Sn	2/7/2005	The provinces of the region of the :Al Houz, Chichaoua, Azilal, Beni Mellal, Khenifra, Ifran, Azrou, Sefrou, Elhajeb, Milt, Taroudant, Ouarzazate, Errachidia, Boulmane, Chefchaouene, El Hoceima, Taounate, and Taza.
CW HP	2/27/2005	Strong wind in : Essaouira, Safi, El Jadida, Chichaoua, Kelaa Seraghna, Settat, Ben Slimane, Khouribga, Khemessat, Casablanca, Mohamadia, Nouasser, Rabat, Temara, Sidi Slimane, Sidi Kacem, Ifran, Fes, Meknes, Kenitra, Larache, Chefchaouene, Tetouan and Taza . Strong rain, West of the Mediterranean
TS HP	3/4/2005	Tangier, Sebta, Tetouan, Chefchaouen, Al Hoceima, Nador, and the north Oujda region
TS HP	5/25/2005	Azilal, Beni Mellal, kassbat Tadla, Khenifra and Khouribga and the North of region of Oujda
CW	6/1/2005	Tangier
TS	6/5/2005	Demnate Ouarzazate
TS	6/11/2005	Casa, Rabat
HW	6/17/2005	sidi slimane, fes, meknes, sidi kacem, larache, kenitra rabat settat khouribga, khasbat tadla beni 3-11arrak 3-11arrakech, cheoun tanger taounate bensliman, kelaaseraghna, khemissat medilt ifran, takerkoust, oukeimn
HW	7/19/2005	Morocco was unr the effect of heat except the regions of oujda, berkane mellilia, nador ; alhoceima tétouan, sebta , the atlantic coast between kenitra and safi,
HW SW	8/3/2005	A wave of heat, with winds of chergui hit all Morocco from August 3 to the August 8th, 2005
TS	8/8/2005	Azilal, the reliefs Al Houz and Kelaa Seraghna, Beni Mellal, Kesbat Tadla, Khenifra, Ifran, Boulmane, Milt, Taza, Al Hoceima (reliefs) and Nador (reliefs)
TS	8/19/2005	Atlas
CW	8/29/2005	Tangier
HP	Sep-05	Province of Jerrada
TS	9/14/2005	Melaline
SnSt	9/18/2005	High atlas

Event	Date	Location
TS SW	11/13/2005	Chefchaouen, El Jadida, Safi, Larache, Tangier, Kenitra, Casablanca, Rabat, Mohammadia, Khouribga, Tetouan, Ben Slimane, Fes, Sidi Kacem, Settat, Meknes, Elhoceima
St	11/29/2005	Center coasts Ined, the tropical St Ita, formed in the middle of north Atlantic on November 23rd 2005, after many days of erratic movement, almost became cyclone. It started moving East; November 28th the cyclone produced a strong tropical St that swept the canary iles. The same night it touched the Moroccan coasts as a Sn St then fainted in the Algerian Sahara.
CW Sn	1/10/2006	Rif, Atlas
HP CW Sn	1/15/2006	Chefchaouen, Al Hoceima, Boulmane Taza Taroudant, Ifran, Beni Mellal, Errachidia, Sefrou, Ouarzazate, Khenifra, Al Houz, Oujda, Bouarfa, Taourirte, Azilal.
HP CW Sn	1/27/2006	Morocco has seen rain falls as Sts, winds and Sn fall on mountains higher than 1200m
CW	2/8/2006	Agadir, Tiznit, Guelmim, Tan Tan
HP	2/10/2006	SMARA ASSAZAG TANTAN GUELMIM et TATA
TS	4/10/2006	Smara, Al houz, Ouarzazate, Beni Mellal, Khenifra
TS	5/24/2006	Er-Rachidia, Figuig, Bouarfa, Missour, Boulmane, Khenifra, Taourirt and Jarada
TS	6/18/2006	Khenifra, Settat, Milt, Alhajeb
TS	8/24/2006	Ifran, Boulmane and Khenifra
TS	8/29/2006	Al Houz, Kelaa Seraghna, Marrakech, Chichaoua, Azilal, Beni Mellal, Khenifra
TS	8/31/2006	Al Houz, Kelaa Seraghna
HP	10/27/2006	Errachidia, Figuig, Ouarzazate, Jerrada, Tata
CW Sn	12/11/2006	Azilal, Beni Mellal, Milt, Al Houz, Boulmane, Ifran, Khenifra, Ouarzazate, Er-Rachidia.
CW Sn	1/1/2007	The middle Atlas, Alfgou in particular, about 200km from Khenifra, and all the region of Tounfite, Aghbala
CW Sn	1/13/2007	The middle Atlas, Alfgou in particular, about 200km Khenifra, and all the region of Tounfite, Aghbala
CW Sn	1/24/2007	The region of Settat, the thermometer varies between 2and 6 grees at night

Event	Date	Location
TS	4/20/2007	Also, SW hit the south of the east with rain in Bouarfa, Er-Rachidia, Ouarzazat.
TS	4/20/2007	Very dark clouds concerned the North of the country caused local important rain, more than 30m/12h.
TS	9/13/2007	Tetouan, Al Hoceima, Nador, Chefchouan
CW HP	11/21/2007	The north of the kingdom
HP CW Sn	2/23/2008	Local TS falls concerned the mentioned areas, more than 30 mm in 06. In addition to impacts now falls concurring the regions of Ouarzazate, Errachidia, Azilal, Al Houz, (relief), Taroudant, Khenifra, Boulmane, Safi, Essaouira, Chichaoua, Ifran, Fez, Alhajeb, Taza, Khenifra, Taounate, Al Houz, Marrakech, Elklaa Seraghna for mountains above 2200 m
CW	4/10/2008	Phosphate plains, Tadla, Houz, Rhamna, verssants South East.
TS	5/8/2008	Ouarzazate and Er-Rachidia
TS	5/10/2008	Ouarzazate and khenifra

The number and types of events are summarized below in **Figure 3.6**:

Figure 3.6 – Wet-Weather Events in Morocco

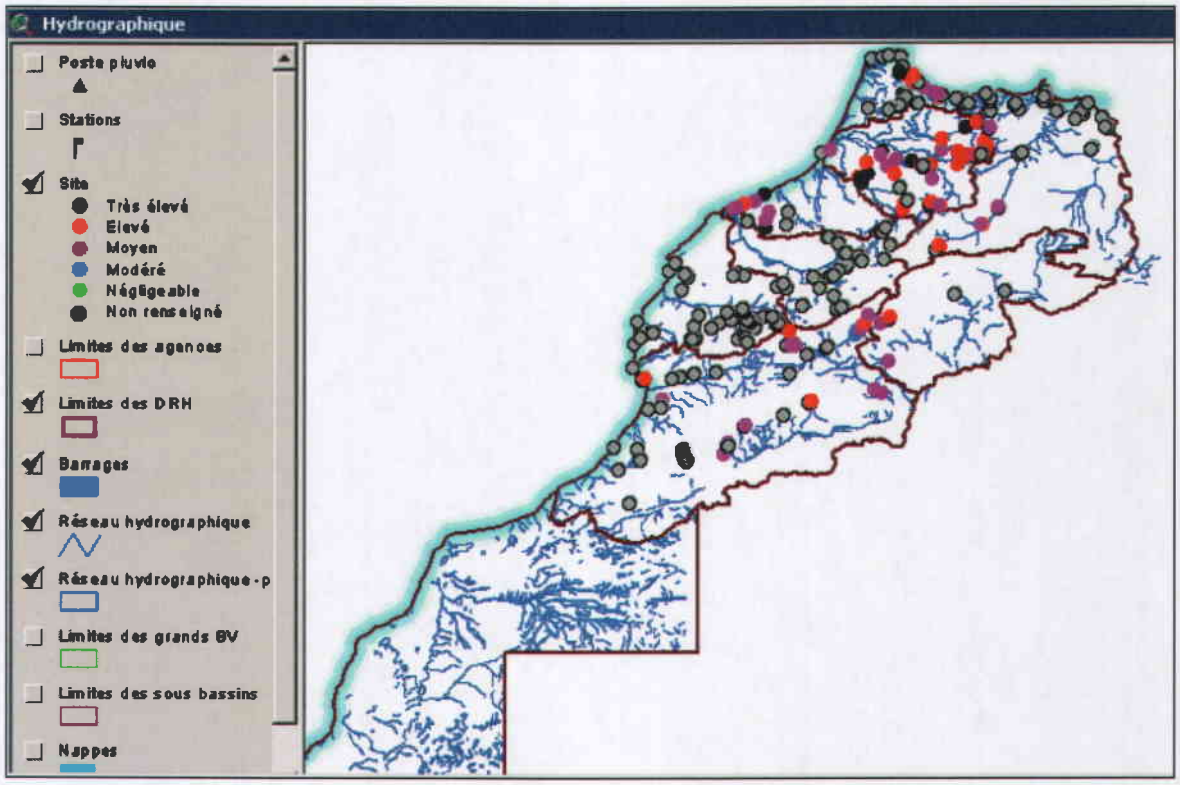


The intensity of the previously outlined events varies. For example, in Moulouya in 1963, heavy rain caused a flood which breached the Mohamed V Dam; a flood in 1965 in Ziz left 25,000 homeless; in 2001, torrential rainfall turned Morocco into a disaster zone, interrupting traffic, causing landslides, destroying homes, and taking lives. Other significant weather events include:

- August 2003 – desert wind – agricultural losses estimated at 100 million MAD as a result of 5 million poultry being lost.
- February 2004 – earthquake – killed 229 and injured countless others.
- May 2006 – thunderstorms – affected 600 families, damaged 355 houses, 114 of which were completely demolished, 347 livestock lost, and 6 dead.
- October 2006 – flooding – destroyed crops in the Errachidia region, hundreds of trees uprooted (date palms, olive, almond, figs, and orchards). Nomadic cattle were lost as well.
- April 2007 – storm – damaged infrastructure destroying a roadway and bridge blocking passage to several parts of the city, home damage, and one death.

3.4. Socio-Economic Losses

Figure 3.7 – Black Spots (Not Covered by Radar)[5]



[5] This figure is property of the Kingdom of Morocco. The figure does not directly reflect or include work completed under the Terms of Reference for this project.

The study includes the following 32 sites:

Martil Tetouan, Chichaoua, Plaine Loukkos, Moulay-Yaouat, Settat Ben Ahmed, Majmaa Tolba, Settat (Amont), Sidi Kacem Kenitra , El Jadida, Milte, El Hajeb Ville, El Hajeb, Ait Hamza, Boudnib, Taza, Boudnib, Tabante, Gorges Todgha, Ait Mhamed, Outerbat, El Kebab, Erfoud Ksar-El Borj, Mrhila, Sidi-Ifni, El Ksiba1, Agafay Ameskroud, rmamate, Guelmim Centre, Ouzoud, Ait Laaza, Marrakech, Aghabalou.
Included in this analysis are various elements used to assess damages caused by natural disaster. The National Flood Protection Program includes eight sections:

- **Human Lives** – It is not customary to put an economic value on a human life in Morocco. The loss of life alone indicates the severity of damages. According to this:
  - The Moroccan GDP (2008) 85.2 billion USD
  - Population 34,435,719
  - GDP per capita 2,474* USD
  - Average Life expectancy for victims 25 years
  - Using this information, a human life is valued at $525,750.
  - A conversion rate is 1USD = 8.50 MAD
- **Affected Persons** – Losses are based on 1,000 MAD per evacuation; lost work days, monetary value based on minimum wage; property damage, based on 6,000 MAD per residence.
- **Employment and Tertiary Activities** – This element takes into account the number of lost working days reported by companies and administrators, damages to stocks and commercial merchandise, and the monetary value of one working day based on minimum wage.
- **Industrial Units** – Damage to industrial units is rare, but important. They are generally evaluated by the employees immediately following the flood. The loss estimates are based on the average production rate in the region and the lost production time.
- **Agricultural Activities** – The sites vary widely and take many parameters into account. The most important criteria is the area flooded, the nature of the crops, the agricultural calendar, as well as the cost per linear meter for infrastructure evaluation, and irrigation culverts and canals. By using the data found on the technical/economic sheets for each plot of agricultural land, it is possible to calculate losses with respect to the flood. For example, when flooding occurs during the winter, the losses correspond to the costs of turning the soil, seeding, and the shortfall in operating income. If the flood destroyed an orchard, the losses are estimated by the amount of time for cultivation, and loss of proceeds from selling the fruit. Damage assessment at the national level is estimated at 40,000 MAD per hectare damaged.
- **Habitat and Building** – Damages are assessed by the number of homes and public buildings destroyed or damaged, the quality of materials used, the height of the flood, and the time the flood waters were present. For the purposes of evaluation and according to the national plan, 150,000 MAD per house demolished is used for economic assessment, regardless of construction method.
- **Property and Equipment** – Both direct and indirect damages are considered. The former counts the destroyed vehicles at 75,000 MAD as well as destroyed public property (i.e. rail service, sports fields, dikes, potable water line). Among the indirect

damages, the impact of interruption of public (rail) services must be considered or lost working days for those using public transport.

- **Roadway** – The impacts of damage caused by road closings, repairing tires, as well as the lost time due to the interruption of transit and tours to avoid the black spots. For 2008, the statistics from the Minister of Transportation were used. Based on this, the estimation of damages at the 32 sites show the total costs in ***Table 3.9*** (following page). Based on information from the Minister of Transportation, damages to roadway as of February 2009 would cost 67,810 KMAD for critical work and 748,500 million MAD for the total work.

Table 3.9 – Monetary Estimation of Road Work

DPE	Place	Petrol	Material	Administration	Indemnisation	Production
Taounate	700	700	400	400	100	11,000
Chefchaouen	160	360	150	120	70	3,300
Sidi Kacem	160	200	500	200	20	14,400
Kénitra	800	400	2000	200	60	4500
Taza	400	300	300	200	100	4,140
Larache	150	100	300	100	50	--
Al Hoceima	170	--	100	50	30	--
Essaouira	300	300	--	100	50	3,000
Khémisset	200	100	150	115	60	1,270
Meknès	200	200	200	100	100	300
Rabat	150	20	100	30	20	10,400
Khouribga	150	80	--	50	30	4,000
Taroudant	--	100	100	30	20	--
Tanger	1000	500	150	100	50	1,400
Tétouan	400	200	400	200	100	9,800
Fès	150	200	100	50	50	300
Total	5,090	3,760	4,950	2,045	910	67,810

The total estimate for roadway repair in the 16 affected provinces is approximately 816,310 million MAD.

Table 3.10 – Estimated Damages by Geographic Location

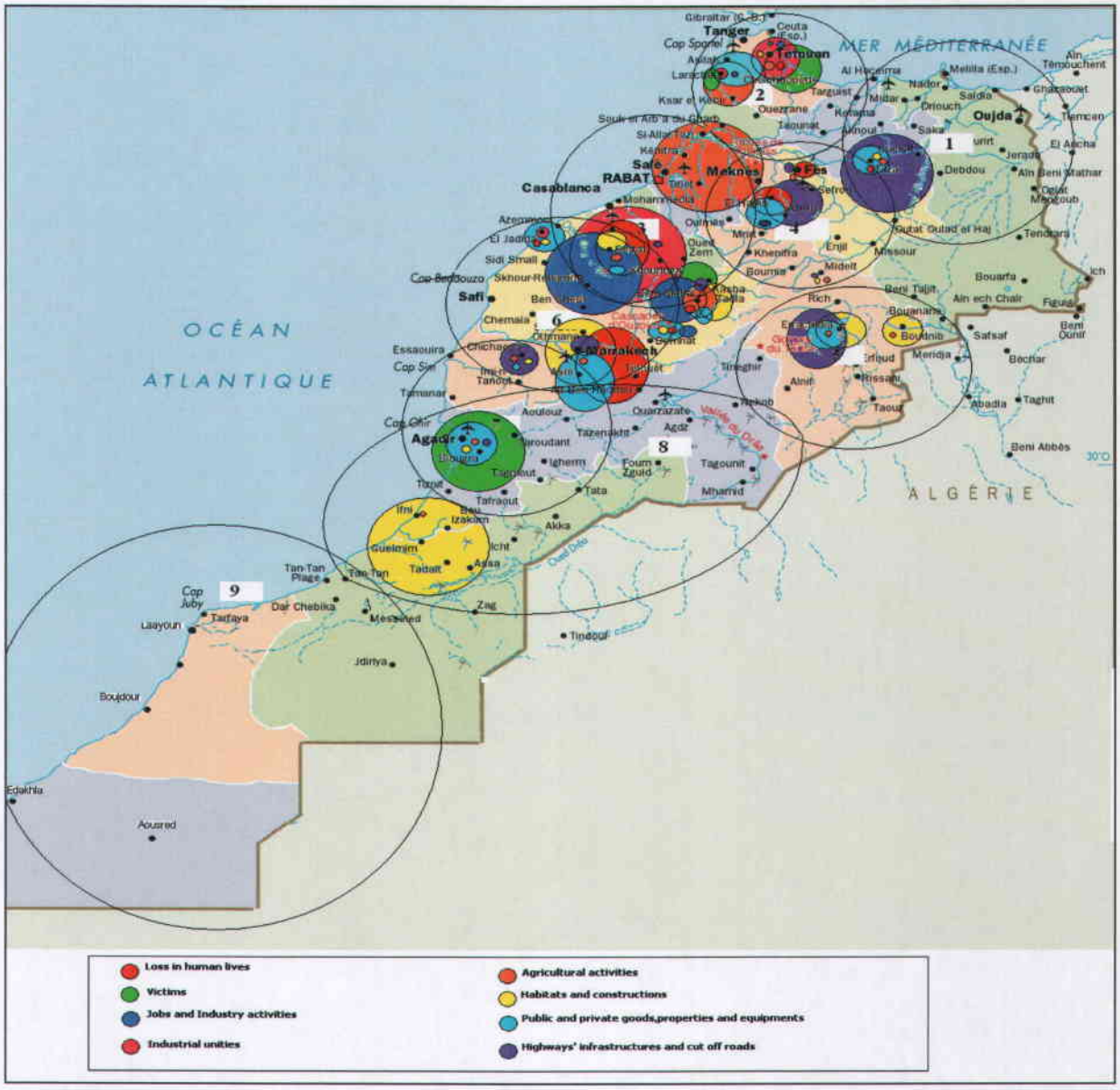
Site Code	PN Name	Date	Human Lives	Damage	Jobs & tertiary activities	Industrial Unit	Agricultural Activities	Homes & Constructions	Public & Private Property	Road & Descriptive Infrastructures	Total
1	Martil Tetouan	Dec 26, 2000	3,085,250	1,651,950	152,000	69,000,000	6,792,930	1,800,000		66,500	82,548,630
5	Plaine Loukkos	Dec 26, 2000		249,140		30,400	82,661,200		12,000,000	9,500	94,950,240
9	Settat Ben Ahmed						350,710				350,710
34	Settat (Amont)	Jan 01	51,215,150		8,550,000	465,750,000		6,360,000	845,600	107,000	532,827,750
38	El Jadida	Jan 96	925,575			100,000		300,000	7,000,000		8,325,575
5	El Hajib Ville	Sept 97	5,244,925		114,000					2,000,000	12,908,925
52	Ait Hamza	Jul 97					11,811,005	90,000			11,901,005
65	Taza	Sept 00	1,851,150				336,600	500,000	2,576,000	6,000,000	11,263,750
87	Tabante	88-89	925,575				25,545,000	180,000	45,500		26,696,075
90	Ait Mhamed	1996			2,000,000			1,400,000	600,000		4,000,000
100	El Kebab	1996						7,328,000			7,328,000
108	Mrhila	1996		304,000	30,400		27,900	150,000			512,300
111	El Ksiba1	1996						800,000	1,700,000	600,000	3,100,000
119	Dermamate	1996		598,500				800,000			1,398,500
120	Ouzoud	1996	1,234,100		1,009,120			1,750,000	7,500,000		11,493,220
137	Merrakech	Mar-97					160,000	21,480,000		780,800	22,420,800
149	Chichaoua	Oct-94					183,680	913,500	515,000	1,480,000	3,092,180
170	Moulay-Yaouat	Jul-95	2,468,200				204,000			220,000	2,892,200
171	Majmaa Tolba	2000	308,525								308,525
178	Sidi Kacem Kenitra						173,000,000				173,000,000
181	Midelte						1,100,000	243,040		152,000	1,495,040
183	El Hajeb	Sept 99	5,244,925						5,550,000		10,794,925
258	Boudnib							8,072,000			8,072,000
259	Boudnib						900,000				900,000
263	Gorges Todgha	Jun 96						300,000	300,000	249,330	849,330
266	Outerbat						1,200,000	600,000	2,000,000	2,000,000	5,800,000
271	Erfoud Ksar-El Borj						252,000	1,800,000	1,200,000		3,252,000
279	Sidi-Ifni						118,000	4,800,000	200,000	22,500	5,140,500
284	Agafay Ameskroud	96 & Dec 00		600,000			1,491,200	120,000	6,000,000	47,500	8,258,700
305	Guelmim Centre	95-96						120,000,000			120,000,000
383	Ait Laaza	96		1,656,325			745,600	600,000	1,800,000		4,801,925
393	Aghabalou	Aug 95	89,163,725				2,268,110	1,164,000	70,000,000		162,595,835
TOTAL			**161,667,100**	**5,059,915**	**11,855,520**	**534,880,400**	**309,147,935**	**181,550,540**	**125,382,100**	**13,735,130**	**1,343,278,640**

Table 3.11 – Summary of Estimated Damages

Elements	Estimation (MAD)	Percent Total Damages
Human losses	161,667,100	12.0%
People touched	5,059,015	0.4%
Employment and other tertiary activities	11,855,520	0.9%
Industrial units	534,880,400	39.8%
Agricultural units	309,147,935	23.0%
Housing and construction	181,550,540	13.5%
Public and private property	125,382,100	9.3%
Road infrastructure and descriptive road	13,735,130	1.0%
TOTAL	**1,343,278,640**	**100%**

Further detailed information regarding socio-economic impacts can be found in Section 6.

Figure 3.8 – Range of Damage Caused by Flooding[6]



Based on the details of the damage and the information discussed above, a recovery of monetary damages has been developed for each event's record. This information is contained in the tables on pages 3-22, 3-23, 3-26, 3-30, and 3-31.

Radar Coverage

Radar coverage allows for forecasting of floods and hail so that measures can be taken in anticipation of a devastating wet-weather event. The DMN has six radars that are located at Laraches, Nouaceur, Fes, Agadir, Khouribga et Marrakech. Each unit has a 240-kilometer

[6] This figure is property of the Kingdom of Morocco. The figure does not directly reflect or include work completed under the Terms of Reference for this project

radius. Despite this coverage, there are certain regions that remain uncovered: The North East including Rif and the Oriental, Midelt, East between Oujda, Rachidia and Ouarzazate, the Region where the High Atlas meets the Anti-Atlas, South side of the Anti-Atlas : Tata, Guelmim. Problems with the radar occur even within the boundaries of the coverage area. Some impediments to proper function of the radar have been found:

- Overlap of coverage at the Khouribga and Casablanca radar stations
- The Casablanca radar is located in a forest
- The radar at Agadir and Fes are surrounded by a chain of mountains that limit coverage.

Before identifying sites for future radar placement, it is important to note all anomalies in the existing system and assess the resulting losses in coverage. Based on the findings from this task, recommendations can be made to expand forecasting abilities. When complete, the radar network will provide a much better forecasting system to warn of heavy rains, risks, and floods.

Damage Reports

Reports are detailed on the next several pages pertaining to storm events at the following locations. The reports include details of the type of event; human, social, agricultural, ecological, and economic losses; and rescue costs. Note that values are best approximations. Monetary estimates are in Moroccan Dirhams (MAD).

- Merzouga (province d'Errachidia), May 25-27, 2006
- Mohammedia, Settat and Ben Slimane, November 2002
- Tata, March 31, 1995
- Ourika, August 17, 1995
- Errachidia Region, October 9 and 10, 2008
- East Region (Nador, Taza, Oujda, Boulamane-Missour, October 2008
- Tangiers Region, October 2008
- Agadir Region, Essaouira, October 2008
- Casablanca Region, Gharb (North Rabat), October 2008
- Marrakech Region, Tensift, Chicaoua
- Fès/Meknes Region

- **Merzouga (province d'Errachidia), May 25-27, 2006**

Type of Event	Stormy rain
Human and Social Losses	6 dead, 355 homes damaged, 114 homes demolished
Agricultural and Ecological Losses	Hydro-agricultural infrastructure losses: *3.3 million MAD*** Damage to 13 acres of agricultural land: *1.8 million* Hydro-agricultural equipment damages: *6 million*
Economic Losses	Agricultural production losses: *2 million* 347 Livestock loss: *0.5 million* Other losses: *13 million*
Rescue Costs	Bivouac, 400 tents affecting 600 displaced families

Pecuniary evaluation of damages

– Hydro-agricultural infrastructure	3.3 million
– Agricultural Production	2 million
– Hydro-agricultural equipment	6 million
– Economic Losses	13 million
– Animal Products Loss	0.5 million
– Human Losses (6 dead)	3,154,500
– 114 demolished homes	17.1 million
Total Damages	**45 million MAD**

- **Mohammedia, Settat and Ben Slimane, November 2002**

Type of Event	Heavy, violent rain causing floods
Human and Social Losses	63 dead, 26 missing, 17 injured, 24 homes demolished, 1,334 damaged, 373 flooded
Agricultural and Ecological Losses	Hundreds of acres of agricultural areas damaged, dozens of animals lost, destruction of dikes on the banks of Oued El Mellah.
Economic Losses	17 industrial units flooded in Berrechid 24 units flooded in Mohammedia *30 million MAD* Fire at Mohamadia petrol refinery, flood, & infrastructure damage. *3 units, Lost production* Road Closures and Infrastructure Damage
Rescue Costs	Agricultural sector *23 million MAD* Infrastructure *20 million MAD*

Pecuniary evaluation of damages

– Industrial losses	30 million
– Human losses (63 dead)	33,122,250
– Agricultural losses	23 million
– Equipment damage	20 million
– Property losses	3,600,000
– Housing loss	10,242,000
Total Damages	**120,108,250 MAD**

- **Tata, March 31, 1995**

Type of Event	Thunder-storms - Akka, Gourjine and OuinSsint streams flood.
Human and Social Losses	Douar Agadir Ou Zrou - 254 damaged homes, 73 demolished homes Douars Elkbaba - 8 damaged homes, 15 demolished homes Ait Antar - 12 damaged homes Akka Centre - 74 damaged homes, 15 demolished homes In Ait Ben Ijja - 10 damaged homes Douar touzouine - 38 damaged homes Douar Agadir Ou Zrou - 6 dead, 2 seriously injured Douar Tagadirt - 8 dead, 3 missing
Agricultural and Ecological Losses	Agricultural - 3,000 acres of crops, 2,000 palm trees Animal losses: 1,300 sheep, 1,500 goats 15 camels
Economic Losses	Businesses on RP12 Tata Road served as a diversion channeled water into construction site damaging materials Materialistic damage 360 homeless families (1,800 people) 655 homes damaged 238 homes destroyed.

Pecuniary evaluation of damages

– Human losses (14 dead)	7,360,500
– Agricultural losses	120,000,000
– Evacuation of 1,800 people	1,800,000
– Home damages	3,600,000
Total Damages	**132,760,500 MAD**

- **Ourika, August 17, 1995**

Type of Event	Stormy rain and floods – 1,000 m^3/s
Human and Social Losses	150 dead, 80 missing
Agricultural and Ecological Losses	No available information.
Economic Losses	Road infrastructure damaged; material losses *80 million*
Rescue Costs	Infrastructure and hydraulics *77 million*

Pecuniary evaluation of damages

– Human losses (150 dead)	78,862,500
– Material losses	80 million
Total Damages	**158,000,000 MAD**

Photographs from the Ourika, August 17, 1995 flood:

Height and devastating effects of the flood.

Home located on the banks of the Ourika river buried by a sediment load.

Photographs from the Ourika, August 17, 1995 flood, continued:

House destroyed by crushing waves.

Dam built on the Tighzirt tributary destroyed by sediment in the flood.

- **Errachidia Region, October 9 and 10, 2008**

Type of Event	Thunder-storms and floods
Human and Social Losses	5 dead, 3 were children, 99 damaged homes, 119 demolished homes.
Agricultural and Ecological Losses	Damage to hydro-agricultural infrastructure Animal losses: 1,500 Fruit tree losses: 35,000 olive, 10,000 apple, 6,000 date palms Agricultural Material Losses *23- 34 million*
Economic Losses	Damage to infrastructure, potable water stations (disruption of supply), damage to power grid Flooding – Gourrama, Boudnib, Douars of Tit N'Ali, Mouguer, Tiouzaguine & Tafendast (CR Gourram), Beni Ouziem, Ksar Gouraâne, Oulad Ali, Ksar Kaddoussa (CR Oued Naâm) Roadblock from Errachidia to Boudnib, Imilchil, Erfou, Tinghir, & Figuig Two vehicles swept away in Goulmima and Tadighoust
Rescue Costs	Road damage: *Total: 849,420 K* Emergency Repair: *51,420 K* Repairs Complete: *798,000 K* February 2009 *Total: 816,310 K* Emergency Repair: *67,810 K* Repairs Complete: *748,500 K*

Pecuniary evaluation of damages

- Human losses 2,628,750
- Agricultural material losses 23-24 million
- Home damages 19,158,000

Total Damages 45,000,000 MAD

- **East Region (Nador, Taza, Oujda, Boulamane-Missour, October 2008**

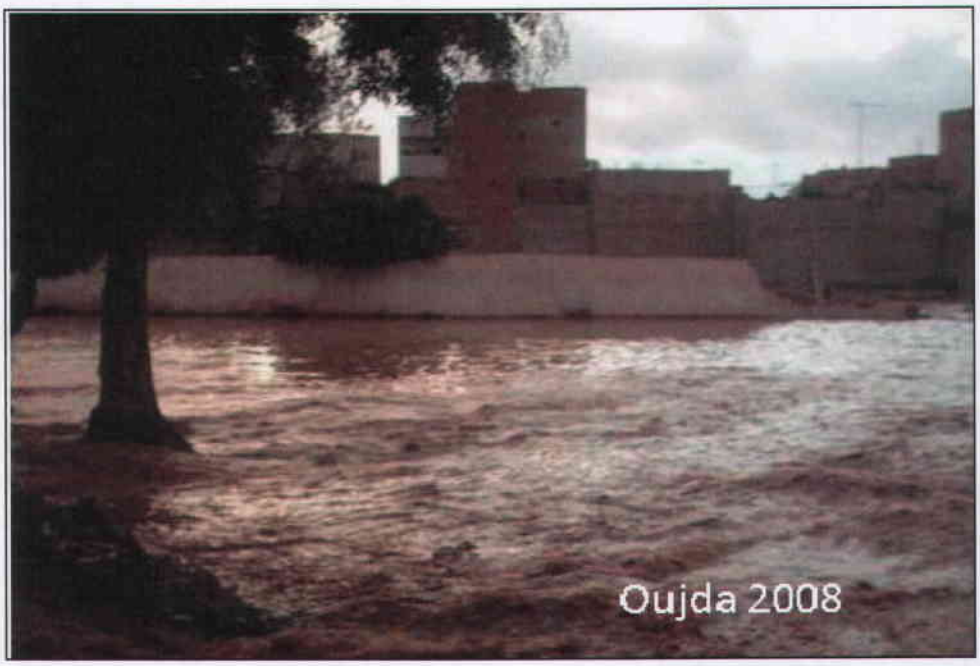
Type of Event	Thunder-storms and floods
Human and Social Losses	11 dead (Nador), 6 dead (Taza), 200 ancient homes demolished (Nador and Hoceima)
Agricultural and Ecological Losses	Flooding – crops, trees uprooted, irrigation canals closed
Economic Losses	Bridges collapsed (Nador and Hoceima) Flooding - Nekkour and Tazourakht Rivers, National Roads (2,10,12) to Hoceima washed away, Nador (Communes of Oulad Stout, Zghenghen, Selouane), Public homes and shops

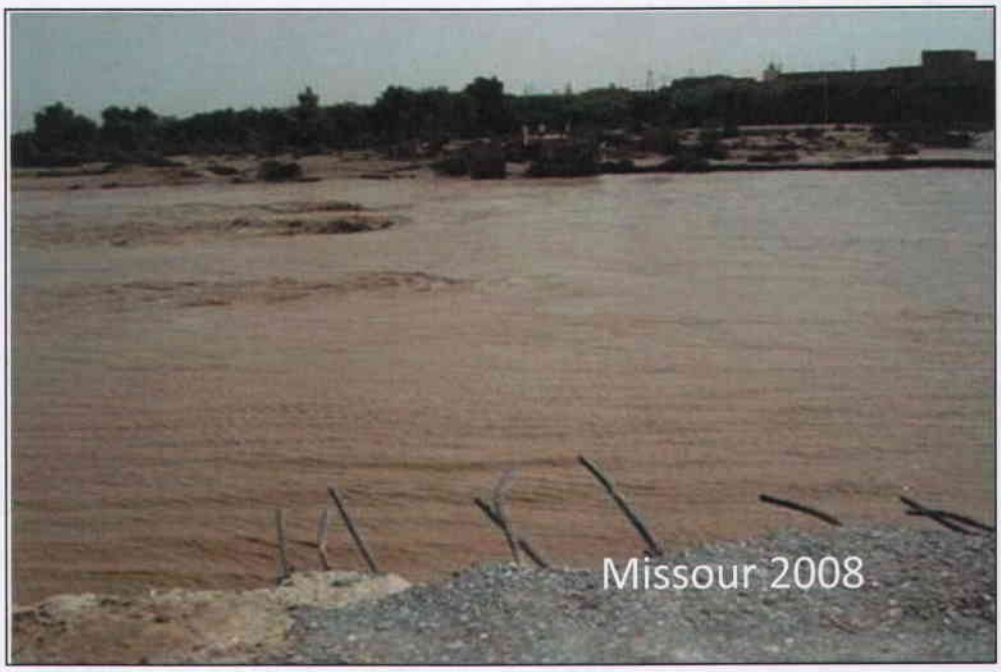
Pecuniary evaluation of damages

- Human losses 8,937,750
- Infrastructure losses 146,040,000
- Home damages 31,200,000

Total Damages 186,000,000 MAD

Photographs from the East Region, October 2008:





Photographs from the East Region, October 2008, continued:

- **Tangiers Region, October 2008**

Type of Event	Thunder-storms and floods
Human and Social Losses	5 dead
Agricultural and Ecological Losses	No information available
Economic Losses	Flooding – Tangiers, industrial region of Mghougha, Fnideg

Pecuniary evaluation of damages

– Human losses	2,628,750
– Infrastructure losses	420,500,000
Total Damages	**423,000,000 MAD**

- **Agadir Region, Essaouira, October 2008**

Type of Event	Thunder-storms and floods
Human and Social Losses	13 children drowned
Agricultural and Ecological Losses	Tree trunks and animal corpses swept into Essaouira by the Qsob River flood.
Economic Losses	No information available.

Pecuniary evaluation of damages

– Human losses	525,750
– Infrastructure losses	36,300,000
Total Damages	**36,850,000 MAD**

- **Casablanca Region, Gharb (North Rabat), October 2008**

Type of Event	Thunder-storms and floods
Human and Social Losses	2,052 homes damaged
Agricultural and Ecological Losses	56,000 hectares in Kenitra flooded resulting in a decrease in harvest volume.
Economic Losses	Dam Damage (Gharb region) Berrechid (industrial region) isolated for 3 days - 31 industrial units were flooded - Many export requests were not delivered - 7,500 unemployed as a result - Losses estimated at more than 25 million - Stocks, raw materials, expensive machinery, and generators damaged - No rail service between Casablanca-Marakech and Rabat-Khouribga for several days due to a landslide

Pecuniary evaluation of damages

– Infrastructure losses	94,900,000
– Housing damage	12,312,000
– Agriculture losses	2,240,000
– Industrial losses	> 25,000,000
Total Damages	**23,720,000 MAD**

- **Marrakech Region, Tensift Chichaoua, October 2008**

Type of Event	Thunder-storms and floods
Human and Social Losses	2 dead, 1 missing
Agricultural and Ecological Losses	No information available.
Economic Losses	Much home damage; many cars and shops damaged; disruption of traffic; damage to utilities: potable water, electricity and telephone systems

Pecuniary evaluation of damages

- Human losses 1,051,500

Total Damages **1,051,500 MAD**

- **Fès/Meknes Region**

Type of Event	Thunder-storms and floods
Human and Social Losses	No information available.
Agricultural and Ecological Losses	Flooding of Gharb plain.

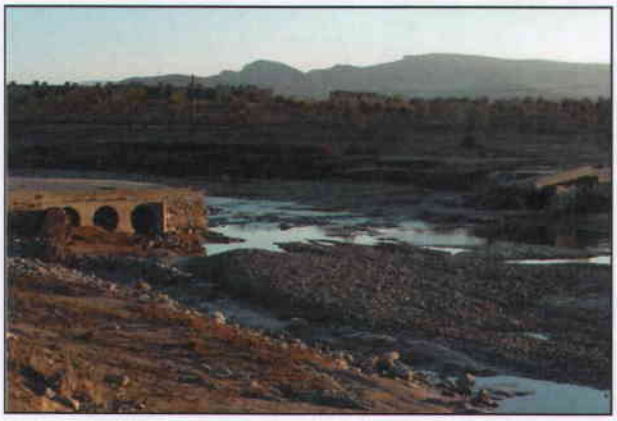
Economic Losses	- Bridge destruction at Mdez, between Sefrou and Adrej
	- Disruption in traffic between Fès and Menzel.
	- Flooding
	  - 2 hydraulic stations (Ain Timedrine-Mz)
	  - Critical damage at Allal Fassi dam
	  - Potable water station
	  - Disruption of water supply in Fez
	  - OULJA in the Sebou valley (downstream of Fez)
	  - Hydroelectric control center in Boulemane

Pecuniary evaluation of damages

- Infrastructure losses 118,570,000
- Agriculture losses 3,200,000

Total Damages **3,318,570 MAD**

Photographs of various devastating flooding events are following:



Photographs of various devastating flooding events, continued:

Photographs of various devastating flooding events, continued:

3.5. Conclusions

As previously illustrated, natural disasters, especially floods, cause considerable damage to the Moroccan economy. These damages affect all facets of socio-economic life in Morocco: human life, infrastructure, industry, tourism, housing, and others. Forecasting is imperative, particularly as the current technology in this area has progressed considerably. As a result, a National Flood Plan has been created to prevent and predict devastating floods. Through this plan, 391 sites throughout Morocco have been identified as flood-prone. The "at risk" areas can exacerbate the effects of flooding by:

- Development of homes in flood areas
- Deforestation
- Lack of maintenance of watercourses
- Under structural design of crossing rivers
- Lack of sanitation
- Insufficient level of prediction and warning

The DMN has coverage of a large part of the country, therefore increasing their forecasting and warning capabilities. However, the extension of coverage to "at risk" areas is crucial for the protection of people and infrastructure and for social and economic development.

The regions of Oujda, Errachidia, Ouarzazate have no coverage and, therefore, are a priority for radar installation. However, smaller regions also remain uncovered. The DMN should cover the entire country using technology appropriate for each situation.

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4. RADAR DIAGNOSTICS (TASK 2)

4.1. SCOPE OF WORK

Pursuant to Task 2 of the Agreement between B&N and DMN, the B&N Team conducted detailed field assessments of identified sites in order to detect failures and insufficiencies in the existing network, propose solutions for upgrading and expanding coverage, and analyze operations and measures for correct operations, training needs, building capacity needs, maintenance, quality assurance systems, and interconnection with network telecommunications. This scope of work includes:

- A field assessment of five radar stations
  - Radar Station **Casablanca** – Mohamed V Airport
  - Radar Station **Fes** – Fes Saiss Airport
  - Radar Station **Larache** – weather station of Larache
  - Radar Station **Agadir** – Agadir Massira Airport
  - Radar Station **Khourigba** – Military Base Hayane
- A field assessment of radar concentrators installed in the weather regional offices (RMSs) at Rabat, Fez, Casablanca, and Agadir
- A detailed field assessment of central radar concentrator of the radar network located in Casablanca
- A field assessment of maintenance and supervision stations in Casablanca
- Summary of radar diagnostics

4.2. FIELD ASSESSMENTS OF FIVE RADAR STATIONS

Reports on the radar station sites (following) are by order of visit, starting with the first location in Casablanca on April 21, 2009. For each site, a new latitude and longitude was recorded for reference. For the regional radar concentrator sites, we were instructed by the customer that a visit to all concentrators was not required. The scope of survey work on the radars was divided into six categories covering the following elements:

- Radar performance characteristics
- Visual inspection
- Operations and maintenance
- Interconnection and telecommunications
- Potential items of interest
- Site summary

Radar Station #1
Casablanca, Morocco

Latitude: 33'22.118'N
Longitude: 07'34.620W
Elevation ASL: 198.2m +-8m

Conducted By: Jeffrey P. Olofson
Date: April 21, 2009

The radar site in Casablanca is located on the grounds near the International Airport, Muhammad V near Casablanca.

- **Radar Performance Characteristics**
  - Transmitter Test – **FAILED**

    The radar located at the Casablanca Site failed to operate in the 2uS pulse width.

    ACTION – Recommend troubleshooting then repairing or replacing the transmitter modulator, power supply or magnetron to solve this issue. A calibration of the pulse widths should also be performed to ensure that they are correctly set.
  - Receiver Test – **PASSED**

    The receiver of the Casablanca radar passed a function check and the test signal generator was operating correctly. Clutter rejection was also functioning correctly. MDS looks acceptable although receiver performance characteristics should be measured and recorded on a regular basis. I was not provided with the receivers initial values for MDS (minimum discernable signal) and dynamic range.

    ACTION – Recommend performing receiver checks semi-annually or annually and documenting the results to ensure correct performance to include MDS, dynamic range, linearity, settings for SDP and settings for matched filters.

- **Visual Transmitter Inspection and Antenna Inspection**
  - Transmitter Visual Inspection – **MARGINAL**

    During the transmitter visual inspection, it was mentioned that work had recently been performed on the system by the technicians. That being said, the building and site were clean but the transmitter panels were not in place upon arrival at the site. The air flow system was designed using a closed circuit system, requiring the panels be in place for proper operation. This also reduces the amount of dust and debris that can get into the transmitter.

ACTION – *Recommend replacing the panels and cleaning the rack semi-annually to reduce possible equipment failure due to dirt and debris.*

- Antenna Performance Test – **PASSED**

  The antenna in Casablanca responded to input commands as expected and moved to specific azimuth or elevation angles with haste and clarity. The pedestal level has not been checked in some time, it is essential to check this as it affects the received data considerably. It was mentioned by the technicians that the pedestal had been recently repaired; however, the access cover for the pedestal elevation motor had been removed and was not replaced after the work. The counter balance for the antenna was also slightly unbalanced. Inside of the radome, several areas of corrosion at this inspection were identified; but these areas at this inspection have been left untreated.

  ACTION – Recommend that repair procedures are followed during and after work. Counter balance of the antenna should be checked annually to ensure there isn't excessive motor 'chatter', which will damage motors. As time passes, it is possible for objects to settle and the antenna level to change. This should be checked bi-annually or annually to ensure the correct level is maintained. A corrosion control program should be generated and followed to identify areas of corrosion and treat them before they become a problem.

- **Operations and Maintenance**
  - Operational Test – **PASSED**

    Upon arrival, I had the technician demonstrate the operational modes of the radar. The system operated in the predefined mode set up at the Radar Central site. This test confirmed that the system will work as defined by the meteorologists' current requirements at the central office.

    ACTION – None required, but a suggestion would be to define more accurately the operational requirements of the radar and allow the meteorologists to use more data from the system. Currently, this radar system is only running one volume scan at a fixed pulse repetition rate and pulse width. By utilizing several types of scans, more data can be collected to provide the meteorologists with more information.

  - Maintenance Practice and Records – **MARGINAL**

    Could not locate historical information in the centralized maintenance database during the inspection of the system. Any information that was obtained was delivered through verbal means from the technicians. Without these technicians available, system history would not be easy to obtain. Several issues could be addressed by establishing an effective preventative and corrective maintenance program. A central maintenance database does exist including maintenance procedures, remote access to system logs, testing control, remote computer monitoring, spare part stock values, spares use and histories information, but it is not currently utilized to its most effective use due to the absence of training on the system.

    ACTION – Recommend using the established maintenance and repair program and completing documentation for all systems. Adherence to routine system status recording at all sites is paramount as an effective long term historical analysis tool.

Historical records of system operation should be governed by a bi-weekly and monthly preventative maintenance. This type of disciplined maintenance program can show trends in system degradation that can be fixed before a catastrophic failure. In addition, a refresher course on the operation/logging techniques should be considered for designated personnel assigned to manage and care for the existing central maintenance database.

- **Interconnection and Telecommunications**
  - Interconnection and Telecommunications – **PASSED**

    Communications was established at the site with Radar Central via a VPN style network. An ISDN backup is being established to supplement the primary communication method. The functionality of the ISDN backup could not be demonstrated while on site. It was brought to my attention that the UPS at the site had not been properly configured.

    ACTION – The entire system depends on communication with Radar Central. If communication is lost, ultimately DMN will not receive data which is as bad for the radar network as the system transmitter failing. A backup system using ISDN has been planned, but not yet implemented. According to the dataset below, the communication link could be improved upon at this location. The UPS should be configured as well.

    DATASET – Using the 'PING' utility in Linux, the following values were recorded.

Pings Sent	Pings Received	Minimum Time	Average Time	Maximum Time	Loss %
125	118	11.75ms	65ms	383ms	5

- **Potential Items of Interest**
  - Item 1 – GenSet

    Located on the exhaust pipe of the GenSet should be a pivoting cover that keeps rain and debris from entering into the exhaust stack. This cover is missing off of the generator at the Casablanca radar site.

  - Item 2 – Waveguide

    The compressor dehydrator is not maintaining adequate waveguide pressure because of a leak somewhere in the compressed line. The line needs to be troubleshot and the leak fixed.

  - Item 3 – Transmitter

    The transmitter will not operate in the 2uS pulse width. Troubleshooting along with repair needs to be performed in order to determine where the problem is located. Then recalibration of the transmitter and receiver must be performed.

  - Item 4 – BITE Status

    Some of the BITE is not working correctly or display the correct status. These sensors are essential to detecting failures at remote radar locations. It is

recommended that DMN reevaluate the sensors usefulness and if required, bring the sensors back to operational status for all monitored sensors. (I.E. Air Conditioner status, Genset status, etc)

- Item 5 – Radome

  During the inspection at this site, it should be noted that on the outside, the radome is excessively dirty and has organic deposits. Things like this can cause attenuation in certain concentrations and degradation of the radar data. It may be possible to clean the outside of the radome and reapply a hydrophobic coating to prolong the life but eventually it could become a serious problem. Also, during the addition of the new obstruction lights, it was brought to my attention that the installation procedure did not seal the obstruction light attachment plates to the radome properly. This caused water leakage into the radome and onto the pedestal; causing antenna/pedestal failures. It should be verified and documented that this deficiency has been corrected and fixed, so no further impact of water intrusion can cause expensive parts failure in the pedestal.

- **Site Summary**
  - Overall System Performance – **PASSED**

    Although there are some issues that could use resolution at this location, the system is operating in the modes currently required by DMN. Data from this site seems to be reliable upon first glance but since calibration hasn't been performed in some time, the data could be inaccurate. The minor problems can be addressed relatively easily and the major problems, such as the transmitter, shouldn't be difficult for a well trained technician to evaluate and repair.

Radar Station #2
Fes, Morocco

Latitude: 33'55.846'N
Longitude: 04'58.442W
Elevation ASL: 573m +-10m

Conducted By: Jeffrey P. Olofson

Date: April 22, 2009

The radar site in Fes is located on the grounds near the Regional Airport, Saiss. It is important to note upon the initial visit, the radar was not functioning due to a GCP failure. After our site visit, the radar was repaired and deemed 'operational' by the maintenance technicians. The system was then re-evaluated remotely from Casablanca Radar Central.

- **Radar Performance Characteristics**
  - Transmitter Test – **PASSED**

    The radar operated with all pulse width and PRF combinations.

    ACTION – A calibration of the pulse widths should be performed to ensure that they are correctly set. Also, a power output check should be conducted to ensure the system meets minimum requirements.

  - Receiver Test – **PASSED**

    The receiver of the Fes radar passed a function check and the test signal generator was operating correctly. Clutter rejection was also functioning correctly. MDS looks acceptable although receiver performance characteristics should be measured and recorded on a regular basis. I was not provided with the receivers initial values for MDS (minimum discernable signal) and dynamic range.

    ACTION – Recommend performing receiver checks semi-annually or annually and documenting the results to ensure correct performance to include MDS, dynamic range, linearity, settings for SDP and settings for matched filters.

- **Visual Transmitter Inspection and Antenna Inspection**
  - Transmitter Visual Inspection – **PASSED**

    The transmitter cabinet at Fes was sealed. The building looked relatively clean, but preventative maintenance must be accomplished to ensure that the equipment is dust and debris free.

    ACTION – *Recommend cleaning the rack semi-annually to reduce equipment failure due to dirt and debris.*

  - Antenna Performance Test – **PASSED**

    The antenna in Fes responded to input commands as expected and moved to specific azimuth or elevation angles with haste and clarity. The pedestal level has not been checked in some time, it is important to check this as it affects the received data drastically. It was mentioned by the technicians that the pedestal had been recently repaired and the access cover was in place and secure. The dual polarization antenna mounted equipment was clean and free of dust and debris inside. The counter balance for the antenna was also slightly unbalanced. Inside of the radome, several areas of corrosion were identified but left untreated.

    ACTION – Counter balance of the antenna should be checked annually to ensure there isn't excessive motor 'chatter', which will damage motors. As time passes, it is possible for objects to settle and the antenna level to change. This should be checked bi-annually or annually to ensure the correct level is maintained. A corrosion control program should be generated and followed to identify areas of corrosion and treat them before they become a problem.

- **Operations and Maintenance**
  - Operational Test – **PASSED**

    After the system had been repaired, I had the technician demonstrate the operational modes of the radar. The system operated in the predefined mode set up at the Radar Central site. This means that the system will work as defined by the meteorologists' current requirements at the central office.

    ACTION – None required, but a suggestion would be to define more accurately the operational requirements of the radar and allow the meteorologists to use more data from the system. Currently, this radar system is only running one volume scan at a fixed pulse repetition rate and pulse width. By utilizing several types of scans, more data can be collected to provide the meteorologists with more information.

  - Maintenance Practice and Records – **MARGINAL**

    Could not locate historical information in the centralized maintenance database during the inspection of the system. Any information that was obtained was delivered through verbal means from the technicians. Without these technicians available, system history would not be easy to obtain. Several problems could be addressed by establishing an effective preventative and corrective maintenance program. A central database does exist including maintenance procedures, remote access to system logs, testing control, remote computer monitoring, spare part stock values, spares use and histories information, but it is not currently utilized due to the absence of training on the system. Also, it was noted that the grass and weeds at the site were overgrown. This can become a potential problem because of pests and animals entering the shelter and damaging the hardware.

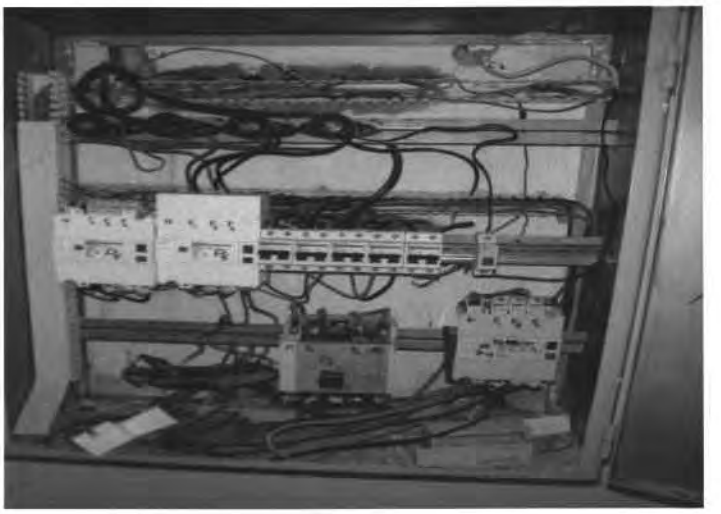
    ACTION – Recommend using the established maintenance and repair program and completing documentation for all systems. Adherence to routine system status recording at all sites is paramount as an effective long term historical analysis tool. Historical records of system operation should be governed by a bi-weekly and monthly preventative maintenance. This type of disciplined maintenance program can show trends in system degradation that can be fixed before a catastrophic failure. In addition, a refresher course on the operation/logging techniques should be considered for designated personnel assigned to manage and care for the existing central maintenance database.

- **Interconnection and Telecommunications**
  - Interconnection and Telecommunications – **MARGINAL**

    The primary power is provided from an airfield line to a building approximately 50m from the radar site. From the building, power is then wired to the radar shelter. Inside of the building a sub-standard job was done on the input wiring and junction box. It is higher recommended for personnel safety issues that proper attention to rectifying the wiring be attended to immediately (See ***Figure 4.1*** below). Also, there were exposed electrical wires to the elements on the outside of the building. (Example: A broken lamp with exposed wires). The UPS at the site had not been properly configured.

ACTION – Personnel safety and equipment safety should be the utmost priority when planning and installing hazardous voltage circuits and maintaining them. It's recommended that a certified electrician and engineer rework the primary power input to the site and bring the existing circuitry up to an acceptable safety standard. The UPS for the radar system should be properly configured as well.

Figure 4.1 – Fes Power Distribution



- Communications was established at the site with Radar Central via a VPN style network. An ISDN backup is being established to supplement the primary communication method. The functionality of the ISDN backup could not be demonstrated while on site. Particularly at Fes, the communication link relies on input power from a source other than the radar building. If input power fails, the link has a potential to go down since it is not located on the same circuit as the GenSet.

  ACTION – The entire system depends on communication with Radar Central. If communication is lost, ultimately DMN will not receive data which is as bad for the radar network as the system transmitter failing. A backup system using ISDN has been planned, but not yet implemented. According to the dataset below, the communication link could be improved upon at this location. It is also recommend that the link be moved to a circuit that receives input power from the GenSet upon failure of commercial power. This would insure the radar and communication link are together for power and during failure of main power will both be GenSet power supplied.

DATASET – Using the 'PING' utility in Linux, the following values were recorded.

Pings Sent	Pings Received	Minimum Time	Average Time	Maximum Time	Loss %
691	691	12.8ms	4.7ms	117.1ms	0

- **Potential Items of Interest**
  - Item 1 – GenSet

    Upon our visit, the Generator was not operational. It is recommended that rectifying this deficiency be taken care of immediately; due to the importance of a backup generator. Power outages are supposedly frequent at this location so that makes it that much more important.
  - Item 2 – Paint and General Practices

    Although not corroded due to the galvanization of the steel, the paint on the tower has started to crack and flake in places. If the paint is merely cosmetic, then there is no urgency required to repaint the tower. Inside of the radome, there was a lot of grease and dust on some of the surfaces of the pedestal. During routine preventative maintenance, surfaces such as this should be wiped down to prevent build up.
  - Item 3 – BITE Status

    Some of the BITE is not working correctly or display the correct status. These sensors are essential to detecting failures at remote radar locations. It is recommended DMN reevaluate the sensors usefulness and if required, bring the sensors back to operational status. (I.E. Air Conditioner status, Genset status, etc)
  - Item 4 – Radome

    During the inspection at this site, it should be noted that on the outside, the radome is dirty and has organic deposits. Things like this can cause attenuation in certain concentrations and degradation of the radar data. It may be possible to clean the outside of the radome and reapply a hydrophobic coating to prolong the life but eventually it could become a serious problem. Also, during the addition of the obstruction lights, it was brought to my attention that the installation procedure did not seal the radome properly and caused water leakage into the radome and onto the pedestal causing failures. It should be verified and documented that this problem was fixed. Most recently a failure occurred when water created a conduction path and caused a high voltage, high amperage signal to short to a low voltage, low amperage input on the Gamic Control Processor.

- **Site Summary**
  - Overall System Performance – **PASSED**

    Although there are some issues that could use resolution at this location, the system is operating in the modes currently required by DMN. Data from this site seems to be reliable upon first testing and inspection but since calibration hasn't been performed in some time, the data could be inaccurate. The biggest problem that was documented was the input power. The system is also in a location that prevents an ideal 360 degree coverage pattern. It is recommended that if greater coverage is desired, an antenna radiation pattern survey be conducted and better locations be scouted for possible system relocation. This is especially true if Doppler information is required for airfield operations.

Radar Station #3
Larache, Morocco

Latitude: 35'09.837'N
Longitude: 06'07.002W
Elevation ASL: 28.9m +-5m

Conducted By: Jeffrey P. Olofson

Date: April 23, 2009

The radar site in Larache is located south east of the city of Larache on government leased land.

- **Radar Performance Characteristics**
  - Transmitter Test – **PASSED**

    The radar located at the Larache Site operated in all of the required pulse repetition frequency and pulse width combinations. It is important to note that during testing, the frequency destabilized abnormally when switching transmitter modes. This signifies that the magnetron is having trouble staying on frequency when it is provided with a different duty cycle. This could be a sign of a deteriorating magnetron.

    ACTION – A calibration of the pulse widths should be performed to ensure that they are correctly set. Also, a power output check should be conducted to ensure the system meets minimum requirements. It is recommended that a technician evaluate the system to determine if the magnetron meets specifications. In this case, the system could potentially be repaired before a significant malfunction.

  - Receiver Test – **PASSED**

    The receiver of the Larache radar passed a function check and the test signal generator was operating correctly. Clutter rejection was also functioning correctly. MDS looks adequate although receiver performance characteristics should be measured and recorded on a regular basis. I was not provided with the receivers preliminary values for MDS (minimum discernable signal) and dynamic range.

    ACTION – Recommend performing receiver checks semi-annually or annually and documenting the results to ensure correct performance to include MDS, dynamic range, linearity, settings for SDP and settings for matched filters.

- **Visual Transmitter Inspection and Antenna Inspection**
  - Transmitter Visual Inspection – **PASSED**

    The transmitter cabinet at Larache was sealed. The building looked relatively clean, but preventative maintenance must be accomplished to ensure that the equipment is dust and debris free.

    ACTION – *Recommend cleaning the rack semi-annually to reduce equipment failure due to dirt and debris.*
  - Antenna Performance Test – **PASSED**

    The antenna in Larache responded to input commands as expected and moved to specific azimuth or elevation with haste and clarity. The pedestal level has not been checked in some time, it is important to check this as it affects the received data drastically. The counter balance for the antenna was acceptable. Inside of the radome, several areas of corrosion were identified but left untreated.

    ACTION – Counter balance of the antenna should be checked annually to ensure there isn't excessive motor 'chatter', which will damage motors. As time passes, it is possible for objects to settle and the antenna level to change. This should be checked bi-annually or annually to ensure the correct level is maintained. A corrosion control program should be generated and followed to identify areas of corrosion and treat them before they become a problem.

- **Operations and Maintenance**
  - Operational Test – **PASSED**

    Upon arrival, the DMN technicians demonstrated the operational modes of the radar. The system operated in the predefined mode set up at the Radar Central site. This means that the system will work as defined by the meteorologists' current requirements at the central office.

    ACTION – None required, but a suggestion would be to define more accurately the operational requirements of the radar and allow the meteorologists to use more data from the system. Currently, this radar system is only running one volume scan at a fixed pulse repetition rate and pulse width. By utilizing several types of scans, more data can be collected to provide the meteorologists with more information.
  - Maintenance Practice and Records – **MARGINAL**

    Could not locate any historical information in the centralized maintenance database during the inspection of the system. Any information that was obtained was delivered through verbal means from the technicians. Without these technicians available, system history would not be easy to obtain. Several problems could be addressed by establishing an effective preventative and corrective maintenance program. A central database does exist including maintenance procedures, remote access to system logs, testing control, remote computer monitoring, spare part stock values, spares use and histories information, but it is not currently utilized due to the absence of training on the system.

ACTION – Recommend using the established maintenance and repair program and completing documentation for all systems. Adherence to routine system status recording at all sites is paramount as an effective long term historical analysis tool. Historical records of system operation should be governed by a bi-weekly and monthly preventative maintenance. This type of disciplined maintenance program can show trends in system degradation that can be fixed before a catastrophic failure. In addition, a refresher course on the operation/logging techniques should be considered for designated personnel assigned to manage and care for the existing central maintenance database.

- **Interconnection and Telecommunications**
  - Interconnection and Telecommunications – **PASSED**

    Communications was established at the site with Radar Central via a VPN style network. An ISDN backup is being established to supplement the primary communication method. The functionality of the ISDN backup could not be demonstrated while on site. It was brought to my attention that the UPS at the site had not been properly configured.

    ACTION – The entire system depends on communication with Radar Central. If communication is lost, ultimately DMN will not receive data which is as bad for the radar network as the system transmitter failing. A backup system using ISDN has been planned, but not yet implemented. According to the dataset below, the communication link could be improved upon at this location. The UPS at this location was also not properly configured for backup power operations. The UPS should be properly configured as soon as possible.

    DATASET – Using the 'PING' utility in Linux, the following values were recorded.

Pings Sent	Pings Received	Minimum Time	Average Time	Maximum Time	Loss %
386	386	11ms	12ms	46ms	0

- **Potential Items of Interest**
  - Item 1 – Corrosion

    Any sea salt air environment can cause corrosion reactions when it comes into contact with untreated metallic objects. This was seen in the inspection of the bolts, waveguide and exposed metal components at the Larache site. These systems metallic elements are not currently protected properly. Inside of the radome, several areas of corrosion were identified but none seemed to have ever been treated. A program of corrosion identification and control should be implemented with a sound preventative maintenance program to treat these areas before they become a problem.

  - Item 2 – Waveguide

    Several pieces of waveguide are starting to deteriorate on the waveguide run from the pedestal base to the tower base. The deterioration does not currently seem to be a real problem, but eventually the waveguide will fail. The waveguide pieces which

have significantly deteriorated should be either treated or replaced before a failure occurs.

- Item 3 – Beam Blockage

  At approximately 310 degrees off of North, there is a prominent structure, a water tower, approximately 500m from the radar site. This structure causes a 2 degree data loss at 150km from beam blockage. This is a known issue, so it is just written here for documentation purposes. The only way to resolve this would be exceed the height of the object (not feasible) or relocate the radar site. The system is in a relatively good location currently; so this may also not be a viable option to consider.

- Item 4 – BITE Status

  Some of the BITE is not working correctly or displaying correct signal status. These sensors are essential to detecting failures at remote radar locations. It is recommended DMN reevaluate the sensors usefulness; and if required, bring the sensors back to operational status. (I.E. Air Conditioner status, Genset status, etc – all monitored signals by the BITE should be considered in this action.

- Item 5 – Radome

  During the inspection at this site, it should be noted the outside, of the radome is excessively dirty and has organic deposits. Things like this can cause attenuation in certain concentrations; thus leading to degradation of the radar data. It may be possible to clean the outside of the radome and reapply a hydrophobic coating to prolong the life; but eventually it could become a serious problem. Also, during the addition of the obstruction lights, it was identified that the installation personnel did not seal the radome properly during the procedure and therefore water leakage into the radome has occurred dripped on the antenna/pedestal causing failures. It should be verified and documented that this problem was fixed.

- **Site Summary**
  - Overall System Performance – **PASSED**

Although there are some issues that could use resolution at this location, the system is operating in the modes currently required. Data from this site seems to be dependable upon first inspection; but since calibration hasn't been performed in some time, the data could be erroneous. A complete re-calibration procedure should be performed at this time, so the operational meteorologists are insured of valid calibrated data collection is reliable for display. The problems at this location right now seem fairly minor, but serious monitoring of the magnetron and waveguide needs to be considered or they could swiftly develop into a major problem.

Radar Station #4

Khouribga, Morocco

Latitude: 32'51.302'N
Longitude: 06'57.367W
Elevation ASL: 32.9m +-2m

Conducted By: Jeffrey P. Olofson

Date: 24 April, 2009

The radar site in Khouribga is located on an old military installation approximately 3km outside of town of Khouribga.

- **Radar Performance Characteristics**
  - Transmitter Test – **FAILED**

    The radar located at the Khouribga site was not operational upon our visit. It was still inoperable upon completion of the site surveys.

    ACTION – The system transmitter was reportedly working before the failure of the GCP. This could not be verified during our visit, and must be confirmed for proper operation by the technicians who perform the repair.
  - Receiver Test – **NOT PERFORMED**

    The receiver of the Khouribga could not be verified to be operational during the visit. The system appeared to receive data before the GCP failure, but this could not be verified on site.

    ACTION – Recommend performing receiver checks semi-annually or annually and documenting the results to ensure correct performance to include MDS, dynamic range, linearity, settings for SDP and settings for matched filters. The receiver will require verification for correct operation after the repair of the control processor.

- **Visual Transmitter Inspection and Antenna Inspection**
  - Transmitter Visual Inspection – **FAILED**

    The transmitter cabinet at Khouribga was not sealed. The building looked relatively clean, but preventative maintenance must be accomplished to ensure that the equipment is dust and debris free. I was informed by the technicians that water had leaked from the radome onto the top of the transmitter rack. This had been verified

by me due to the corrosion and water spots located on the top of the rack. The technician could not confirm whether or not water had actually entered the transmitter rack. He did mention approximately 1-2 inches of water had been standing on the floor.

ACTION – *Recommend cleaning the rack semi-annually to reduce equipment failure due to dirt and debris. Corrosion control and prevention as well as prevention of water entry into the cabinet should be performed.*

- Antenna Performance Test – **NOT PERFORMED**

  The antenna in Khouribga was not tested due to the lack of primary power for the system, along with a control processor to drive the antenna. Counter balance cannot be checked while the pedestal has power removed due to the electromechanical gear lock engaging when power is removed. Corrosion on the antenna is a serious problem at this site.

  ACTION – Counter balance of the antenna should be checked to ensure there isn't excessive motor 'chatter', which will damage motors. As time passes, it is possible for objects to settle and the antenna level to change. This should be checked bi-annually or annually to ensure the correct level is maintained. A corrosion control program should be generated and followed to identify areas of corrosion and treat them before they become a problem.

- **Operations and Maintenance**
  - Operational Test – **FAILED**

    The radar system failed to operate due to maintenance requirements.

    ACTION – Repair of the control processor is required.

  - Maintenance Practice and Records – **FAILED**

    Could not locate historical information in the centralized maintenance database during the inspection of the system. Any information that was obtained was delivered through verbal means from the technicians. Without these technicians available, system history would not be easy to obtain. Several problems could be addressed by establishing an effective preventative and corrective maintenance program. A central database does exist including maintenance procedures, remote access to system logs, testing control, remote computer monitoring, spare part stock values, spares use and histories information, but it is not currently utilized due to the absence of training on the system. The maintenance conducted on the radar seemed to be substandard and inadequately accomplished. This is evident from the lack of attention to detail during the repairs. Several incidents of loose or missing hardware, ignored mess of lubricants and sloppy installation of sealants were present. The system has a history of leaks inside the radome, yet the cover for the electronic components for the elevation axis wasn't re-installed after works performed.

    ACTION – Recommend using the established maintenance and repair program and completing documentation for all systems. Historical records of system operation and bi weekly or monthly preventative maintenance can show trends in system degradation that can be fixed before a catastrophic failure. This system uses

electronic components that are very old, so great care must be taken to ensure that the components function correctly. More attention to detail should be observed during maintenance so future problems are minimized or even eliminated due to proper execution of the maintenance procedures with scheduled time interval regularity.

- **Interconnection and Telecommunications**
  - Interconnection and Telecommunications – **MARGINAL**

    Communications was established at the site with Radar Central via a VPN style network. An ISDN backup is being established to supplement the primary communication method. The functionality of the ISDN backup could not be demonstrated while on site. When the technicians attempted to demonstrate the auto-switching capability of the ISDN, it failed the demonstration. The grounding wire for lightning protection was incorrectly installed. According to the technicians, the proper configuration of the UPS has not been accomplished.

    ACTION – The entire system depends on communication with Radar Central. If communication is lost, ultimately DMN will not receive data which is as bad for the radar network as a system transmitter failing. A backup system using ISDN has been planned, but not yet implemented. According to the dataset below, the communication link could be improved upon at this location. It is also recommended that an engineer re-evaluate the lightning protection ground and have it properly installed to protect the system from hazardous equipment and environmental electrical discharges. Lastly, recommend configuring the UPS.

    DATASET – Using the 'PING' utility in Linux, the following values were recorded.

Pings Sent	Pings Received	Minimum Time	Average Time	Maximum Time	Loss %
378	378	16ms	17ms	34ms	0

- **Potential Items of Interest**
  - Item 1 – Corrosion

    Even though this system isn't located in a strong salt air environment, corrosion is present on many surfaces of the equipment. This is visually apparent when looking at radome bolts, pedestal surfaces and exposed metal components that aren't protected. Inside of the radome, several areas of corrosion were identified but none seemed to have ever been treated. A program of corrosion identification and control should be implemented with a sound preventative maintenance program to treat these areas before they become a problem.

  - Item 2 – Radome Water Leakage

    Unlike the other four systems recently upgraded, this system did not have an aircraft warning lights package installed, yet the radome continues to leak water onto the equipment causing failures. It is recommended that if the existing equipment is going to be used, that a technical team remove the leak protection currently installed on the radome and reinstall new protection to seal the system from environmental hazards.

- Item 3 – Clutter Rejection

  Although the status of clutter rejection could not be verified due to the status of the system, historical data shows poor clutter rejection in distant elevated areas. This could be caused by ground conditions such as snow reflections or moving objects like trees, but it is recommended that once the system control processor is re-installed, the system be calibrated for maximum ground clutter rejection. Based off of the historical data used for the survey, the clutter in the areas described is composited into the national picture causing erroneous and misinterpreted data to be presented to the operators. This can obviously cause numerous forecasting problems if the data is misconstrued as weather returns.

- Item 4 – Air Conditioning

  It was reported by DMN technicians that the air conditioning and environmental control units have failed several times at this location. If the equipment is in a full operational mode and a cooling failure occurs, severe damage can be caused to the equipment. It is highly recommended that the environmental control units by brought into full reliable operations and if possible a backup system be installed to prevent overheating of the equipment should the primary system fail.

- Item 5 – Radome

  During the inspection at this site, it should be noted that on the outside, the radome is excessively dirty and has organic deposits. Things like this can cause attenuation in certain concentrations and degradation of the radar data. It may be possible to clean the outside of the radome and reapply a hydrophobic coating to prolong the life but eventually it could become a serious problem.

- **Site Summary**

  - Overall System Performance – **FAILED**

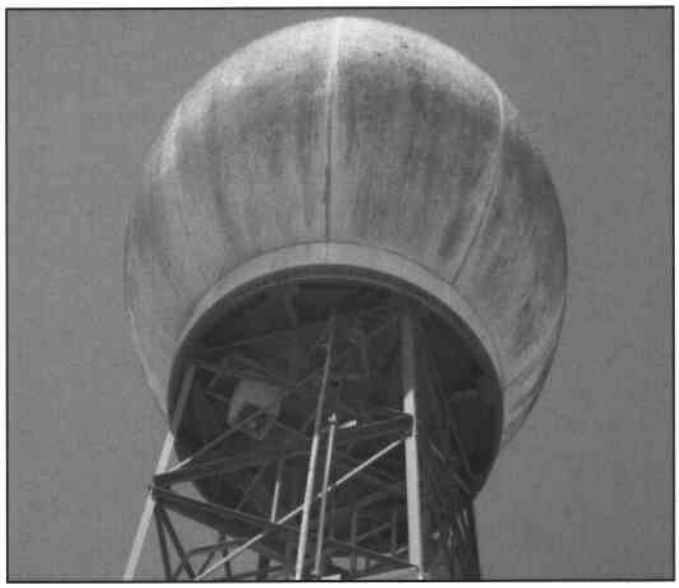
    The pedestal, antenna and radome for this site are very old. There are several problems including drive motor issues, parts procurement and a leaking radome. It is recommended when possible; to replace all three of these items to bring the Khouribga site up to the same standard with the rest of the network. The system would definitely benefit from a larger dish with a narrower beam width. The transmitter, although it couldn't be evaluated, seemed to work before the GCP failure as recorded in the historical data. In addition, the lightning protection grounding needs to be properly addressed from an installation point of view. Currently it is simply draped over the side of the building to a grounding point approximately 10 meters below. It is recommended to properly strap or attach to the building run. Routine maintenance of the building infrastructure such as the air conditioner units, generator should be routinely conducted for operability.

Radar Station #5
Location: Agadir, Morocco

Latitude: 30'19.653'N
Longitude: 09'23.839W
Elevation ASL: 82.6m +-10m

Conducted By: Jeffrey P. Olofson

Date: April 27, 2009



The radar site in Agadir is located on the grounds near the Al Massira Airport.

- **Radar Performance Characteristics**
  - Transmitter Test – **PASSED**

    The radar located at the Agadir Site initially failed to operate at all. The technician remotely changed some parameters, and got the system to run during the visit. Once repaired, the system operated normally as expected in all pulse width and pulse repetition rate combinations. During the testing I discovered that the frequency of the magnetron destabilizes when switching from a long pulse width, low pulse repetition rate to a short pulse width, high pulse repetition rate. This could be a sign of a degraded magnetron.

    ACTION – A calibration of the pulse widths and a power output check should be performed to ensure they are correctly set. It is recommended having a technician evaluate the status of the magnetron and determine whether it meets existing requirements before it causes a critical failure of the system. If deemed necessary, replace the magnetron.

  - Receiver Test – **PASSED**

    The receiver of the Agadir radar passed a functional check and the test signal generator was operating correctly. Clutter rejection was also functioning correctly. MDS (minimum discernable signal) appears acceptable; although receiver performance characteristics should be measured and recorded on a regular basis. I was not provided with the receivers initial values for MDS and dynamic range. Upon arrival, the system showed an SDP error. The technician remotely adjusted some parameters and cleared the SDP error.

    ACTION – Recommend performing receiver checks semi-annually or annually and documenting the results to ensure correct performance to include MDS, dynamic range, linearity, settings for SDP and settings for matched filters.

- **Visual Transmitter Inspection and Antenna Inspection**
  - Transmitter Visual Inspection – **PASSED**

    The transmitter cabinet at Agadir was sealed. The building looked relatively clean, but preventative maintenance must be accomplished to ensure that the equipment is dust and debris free.

    ACTION – *Recommend cleaning the building and rack semi-annually in a documented preventive maintenance action to reduce equipment failure due to dirt and debris.*

  - Antenna Performance Test – **PASSED**

    The antenna in Agadir responded to input commands as expected and moved to specific azimuth or elevation angels with haste and clarity. The pedestal was not level and it was apparent that the pedestal level has not been checked in some time. It is extremely important to insure the pedestal is leveled; as it affects the received data considerably. The counter balance for the antenna was also slightly unbalanced. Inside of the radome, several areas of corrosion were identified but appear to be left untreated. The radome fan was not functioning.

    ACTION –Counter balance of the antenna should be checked to ensure there isn't excessive motor 'chatter', which will damage motors. As time passes, it is possible for objects to settle and the antenna level to change. Antenna balancing should be checked bi-annually or annually to ensure the correct level is maintained. A corrosion control program should be instituted and performed routinely to identify areas of corrosion and treated before they become a problem. Recommend the radome fan be repaired.

- **Operations and Maintenance**
  - Operational Test – **PASSED**

    Upon arrival, I had the DMN technician demonstrate the operational modes of the radar. After some small troubleshooting and repair, the system operated in the predefined mode set up at the Radar Central site. This means that the system will work as defined by the meteorologists' current requirements at the central office.

    ACTION – None required, but a suggestion would be to define more accurately the operational requirements of the radar and allow the meteorologists to use more data from the system. Currently, this radar system is only running one volume scan at a fixed pulse repetition rate and pulse width. By utilizing several types of scans, more data can be collected to provide the meteorologists with more information.

  - Maintenance Practice and Records – **MARGINAL**

    No historical information was available in the centralized maintenance database during the inspection of the system. Any information obtained was delivered through verbal means from the technicians. Without these technicians available, system history would not be easy to obtain. Several problems could be addressed by establishing an effective preventative and corrective maintenance program. A central database does exist including maintenance procedures, remote access to system logs, testing control, remote computer monitoring, spare part stock values, spares

use and histories information, but it is not currently utilized due to the absence of training on the system. A good level of cleanliness was not maintained inside of the radome as there was trash and debris inside of the dome.

ACTION – Recommend using the established maintenance and repair program and completing documentation for all systems. Historical records of system operation and bi weekly or monthly preventative maintenance can show trends in system degradation that can be fixed before a catastrophic failure. The issue of cleanliness can be managed by effective preventative maintenance as well.

- **Interconnection and Telecommunications**
  - Interconnection and Telecommunications – **PASSED**

    Communications was established at the site with Radar Central via a VPN style network. An ISDN backup is being established to supplement the primary communication method. The functionality of the ISDN backup could not be demonstrated while on site. It was brought to my attention that the UPS at the site had not been properly configured.

    ACTION – The entire system depends on communication with Radar Central. If communication is lost, ultimately DMN will not receive data which is as bad for the radar network as a system transmitter failing. According to the dataset below, the communication link could be improved upon at this location. The UPS should be configured as well.

    DATASET – Using the 'PING' utility in Linux, the following values were recorded.

Pings Sent	Pings Received	Minimum Time	Average Time	Maximum Time	Loss %
2951	2950	15ms	19ms	281ms	0

- **Potential Items of Interest**
  - Item 1 – Obstruction Light Power cable

    Located in radome is the power cable for the obstruction lights. This cable carries voltage to power the lights when they are turned on. This cable is not properly secured. It hangs down enough for the antenna to rub against the cable when in high elevation positions. Although this is not the primary operation position for the antenna, it is still a concern and safety hazard. Recommend that this cable be properly secured.

  - Item 2 – GenSet

    The generator set in Agadir is not operational. It is recommended this be addressed as soon as possible as this is the only secondary power provided to the radar system. In the event of commercial power loss, the UPS will not be sufficient to maintain the system for a prolonged period of time without the generator.

  - Item 3 – Radome Fan

    The radome fan is not functioning. It is deemed necessary to have a radome fan in functional order, due to environmental conditions. It is recommended the radome fan

be repaired or replaced. This could potentially help with the condensation and organic deposits on the radome by circulating air throughout.

- Item 4 – Corrosion and Condensation

  Inside the radome, corrosion and condensation are present on many surfaces including the pedestal. There are areas of corrosion which have caused the paint treatment to bubble and flake off. Outside of the radome, the waveguide has started to corrode and the surface treatment is flaking off. The tower paint is starting to flake off in spots. Corrosion can weaken metal and cause failure of critical system components if left unchecked. It is recommended a program of corrosion identification and control be implemented with a sound preventative maintenance program to treat these areas before they become more serious problems.

  Condensation inside the radome is apparent by traces of water droplets around the inside edge of the dome as well as the corrosion present on many different metallic surfaces. This problem could potentially be fixed by repairing the ventilation fan, but it must be monitored to ensure that the condensation build up is not too severe.

- Item 5 – Pedestal leveling

  The pedestal at this site is not level. It is recommended to perform a pedestal leveling procedure to correct the problem. This should be checked bi-annually or annually to ensure the correct level is maintained.

- Item 6 – BITE Status

  Some of the BITE is not working correctly or displaying the monitored signal's correct status. These sensors are essential to detecting failures at remote radar locations. It is recommended DMN reevaluate the sensors usefulness and if required, bring the sensors back to operational status. (I.E. Air Conditioner status, Genset status, etc – <u>all monitored signals)</u>

- Item 7 – Radome

  During the inspection at this site, the radome outside is excessively dirty and has organic deposits. Things like this can cause attenuation in certain concentrations and degradation of the radar data. It may be possible to clean the outside of the radome and reapply a hydrophobic coating to prolong the life but eventually it could become a serious problem.

- Item 8 – Site Location

  The location at Agadir seems to have been a problem since installation. DMN requires the data to the west and south of the location but also requires the information to the east and north. In the east and north direction, the radar site is surrounded by mountains. It is recommended to consider, if possible, relocation of this system to a location where there would be less beam blockage due to ground clutter for full radar beam coverage. Optimization of the overage might be governed by infrastructural availability, but consideration to site the radar to a site which can provide optimized coverage in the full radars 360 degree surveillance could be beneficial.

- **Site Summary**
  - Overall System Performance – **MARGINAL**

    There are some issues that could use resolution at this location but the system is operating in the modes currently required by DMN. Data from this site seems to be reliable upon initial inspection, but since calibration hasn't been performed for some time, the data could be erroneous. Some of the minor problems identified above could escalate at a later date at this location to more serious issues if they're not addressed at all. This radar system may benefit from scouting additional locations and relocating the radar equipment to a more optimum coverage site if possible.

4.3. FIELD ASSESSMENT OF MAINTENANCE AND SUPERVISION STATIONS IN CASABLANCA

This system is a complete maintenance and supervision workstation that has the capability to track and document the following information with little effort from the technicians:

- Repair actions and preventive/corrective maintenance actions
- Intervals for preventative maintenance
- Preventative maintenance instruction
- Monitoring of the centralized database for maintenance
- Spares and spare part stock values
- Log files from the computers at the radar locations which can be downloaded
- Remote access to the computer terminals
- Total radar control

The greatest problem with the system seems to be its lack of use possible due to a lack of training. In-depth inspection revealed:

- Preventative maintenance was not documented.
- Spare part levels are not monitored or updated.
- Log files are not stored.

It is recommended that DMN that detailed training be conducted for the responsible personnel. The training should include solid procedures for documenting and centralizing maintenance actions and knowledge of the radar network. With proper documentation, the maintenance manager could report the current status of the entire network, recent preventative actions, and other viable system monitoring parameters. DMN could then be alleviated from the current countless hours of surveys, from locating maintenance personnel and sorting through multiple accounts of the same event.

Severity Action Table

Consult attached Radar Site Analysis Severity Table.

Table 4.1 – Radar Site Analysis Severity Table

SITE NAME	DATE OF VISIT	ITEM OF INTEREST	SEVERITY** (Scale 1 to 3, 5 INOP)
Casablanca	21-Apr-09	Transmitter will not operate in 2uS pulse width	2.3
Casablanca	21-Apr-09	Generator Set Exhaust cover not in place	1.8
Casablanca	21-Apr-09	Waveguide is leaking pressure	2.0
Casablanca	21-Apr-09	Bite Status does not correctly display status	1.4
Casablanca	21-Apr-09	Radome Dirty, potentially leaking	1.0
		OVERALL SYSTEM STATUS* see note 1	1.7
Fes	22-Apr-09	Generator Set is not operational	5.0
Fes	22-Apr-09	Peeling Paint and Dirty Pedestal	1.0
Fes	22-Apr-09	Bite Status does not correctly display status	1.4
Fes	22-Apr-09	Radome Dirty, potentially leaking	1.5
		OVERALL SYSTEM STATUS* see note 1	2.2
Larache	23-Apr-09	Magnetron has frequency drift issues	1.5
Larache	23-Apr-09	Corrosion on bolts, waveguide and exposed metal	1.3
Larache	23-Apr-09	Waveguide starting to deteriorate	1.0
Larache	23-Apr-09	Beam Blockage from nearby structure (May be acceptable)	1.7
Larache	23-Apr-09	Bite Status does not correctly display status	1.4
Larache	23-Apr-09	Radome Dirty, potentially leaking	1.0
		OVERALL SYSTEM STATUS* see note 1	1.3
Khouribga	24-Apr-09	System is not operational due to equipment failure (GCP)	5.0
Khouribga	24-Apr-09	Corrosion on bolts, waveguide and exposed metal	1.5
Khouribga	24-Apr-09	Radome Water Leakage onto equipment	2.5
Khouribga	24-Apr-09	Clutter Rejection doesn't appear to function or be set correctly	2.0
Khouribga	24-Apr-09	Air Conditioner has had previous failures, no backup system installed	1.5
Khouribga	24-Apr-09	Bite Status does not correctly display status	1.4
Khouribga	24-Apr-09	Radome dirty, potentially leaking	1.5
		OVERALL SYSTEM STATUS* see note 1	2.2
Agadir	27-Apr-09	Generator Set is not operational	5.0
Agadir	27-Apr-09	Obstruction light power cable rubs against antenna	1.8
Agadir	27-Apr-09	Radome Water Leakage onto equipment	2.5
Agadir	27-Apr-09	Radome fan is not functioning	1.5
Agadir	27-Apr-09	Corrosion and Condensation present inside of the radome / on tower	1.3
Agadir	27-Apr-09	Radome dirty	1.5
Agadir	27-Apr-09	Bite Status does not correctly display status	1.4
Agadir	27-Apr-09	Site Location is problematic due to ground clutter beam blockage	2.0
		OVERALL SYSTEM STATUS* see note 1	2.1

* Note 1 - Overall system status is rated from 1 to 3. 1 is the ideal, 100% operational status and 3 requires immediate attention. Anything above 2 should be evaluated as soon as possible.

** Note 2 - SEVERITY is measured from 1 to 3. 1 is the idea, 100% operational status and 3 requires immediate attention. 5 means the equipment or software listed in the ITEM OF INTEREST is NON OPERATIONAL and requires an immediate maintenance action.

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5. NEEDS ASSESSMENT (TASK 4)

5.1. Introduction

Based on the results of Tasks 1 through 3 presented in Sections 2 through 4 of this report, this section presents a further analysis of social, geographic, and climatologically data and provides a prioritized determination of needs to the existing radar network. The goals of this section include:

- Determining equipment needs to upgrade existing radar stations
- Determining the number of additional radar stations needed, equipment required, and the geographic locations
- Providing justification for the additional station locations and their suitability
- Providing technical specifications, quantities and requirements for equipment, and identify prospective US sources of supply.

Several factors were considered in prioritizing the siting of new radars that would optimize the current network and expand coverage to the areas of greatest need. Relocation of existing radar was also considered. The same social-economic criteria were used in evaluating the relocation of existing radars or the siting of new radars. This criteria, in order of importance, is outlined below:

Criteria No.	Criteria Description
1	Areas currently without radar coverage where the addition of a radar would improve public safety in the event of a weather related disaster; e.g., estimation of precipitation over key drainage basins where flooding has been common and resulted in loss of life.
2	Areas without coverage where a new radar would improve short-term forecasts and warnings that could result in a decrease in economic loss to urban areas, industry, and agriculture; e.g., as in 1, but where damage is more related to infrastructure or crops rather than people.
3	Areas without coverage where radar could generally improve the forecasts issued by the Department of Meteorology (DMN); generally filling in the gaps found in the current coverage, or extending coverage to offshore areas.
4	The addition of radar to improve warnings related to aviation safety (strong winds, wind shear, heavy precipitation, etc.).
5	The addition of radar to aid specific projects such as hail suppression programs and snow enhancement programs (e.g., hail algorithms to detect hail-bearing storms).

The criteria outlined above are used later in this Section to assist in prioritizing potential radar sites.

Radar coverage in Morocco along the Atlantic coast from the city of Tangier southerly to the city of Agadir is generally adequate, while the region east of the Atlas Mountains from the Mediterranean south through the Southern Provinces of Morocco is nearly devoid of radar coverage (see **Figure 5.1**).

Figure 5.1 – Location of Existing Radars with Hydrologic Basins

This Needs Assessment presented herein includes a detailed analysis of radar coverage using Shuttle Radar Topography Mission (SRTM) high resolution terrain data (90 meter DEM) and a radar beam occultation analysis program (Shipley, 2008), that:

- works within Google Earth, and
- permits plotting of beam height and occultation patterns over terrain, geographic boundaries, hydrologic basins and a variety of other data bases.

Use of this program requires accurate radar locations. Radar locations were determined using the high resolution terrain data, and visual observations of the radar locations in Google Earth. **Table 5.1** presents the accurate locations of the current radars.

Table 5.1 – Locations and altitudes of sites in the current Morocco radar network

Radar Site	Latitude (N)	Longitude (E)	Altitude (m)
Agadir	30.32752	-9.39767	72.0
Casablanca	33.36862	-7.57687	200.0
Fes	33.93077	-4.97022	572.0
Khouribga	32.85518	-6.95680	785.0
Larache	35.16347	-6.11670	72.0
Ben Guerir	32.13171	-7.92104	459.0

Analysis of new radar site locations with WxAnalyst software provides results that address the major concerns of the DMN. These specific applicable results are as follows:

1. A beam tilt and occultation analysis was performed using fine scale terrain data (90 meter). The Google Earth visual map allows for the identification of other possible barriers such as buildings and vegetation.

2. The radar products can be overlaid on any other maps, such as watersheds, that can be formatted as ".kmz" Google Earth files. The hydrologic basins and provinces of Morocco are shown on all the products of this analysis.

3. The basic plot used in this report is one that shows the height of the lowest radar beam tilt that clears the terrain out to a range of 150 km. Mosaics showing the beam height above terrain from multiple radar sites were used to develop new radar siting maps for the entire country.

4. Specific DMN concerns related to possible poor radar coverage, such as that in the areas around Tangier-Tetouan, the eastern Saharan provinces, and the Figuig-Bouarfa regions, have been addressed.

The radar coverage analysis provides proposed coverage of the country of Morocco that actually exceeds the coverage currently in the United States, and in most countries of the world.

5.2. Discussion of Weather Radar Technology and Application to Monitoring Weather Events in Morocco

The B&N Team has reviewed both a comprehensive description of hazardous weather events in Morocco and the characteristics of the technology used in the current radar network of Morocco in order to recommend a radar technology for an expanded radar network. The current radar characteristics are described in the report, "Reseau radar de la Meteorologie", compiled by the Direction de la Meteorologie Nationale (DMN). The hazardous or damaging weather events are described in a report compiled by Mohamed El Krimi . The El Krimi report was prepared as part of the overall B&N/USTDA project, and is summarized in Section 3 of this document.

The review of hazardous weather events indicated that the most frequent event was a storm that produced a high-intensity rainfall (like that accompanying a thunderstorm). The next most frequent event was a storm that produced a high precipitation amount, where the rainfall rate

might have been lower than the first event type, but the accumulation over 24 hours was very high (at times 50-200 mm). Other extreme weather events such as high winds and snowfall were 5-10 times less frequent. In addition, if events that combined heavy precipitation and high wind are included in the first two categories, then the two most frequent categories would include 75% of all extreme events documented in the report. Some of the other events included extremely hot or extremely cold weather episodes, and radar would be of little use in documenting either of these situations.

Therefore, the highest priority for the design of a radar for the national network of Morocco must be the capability to detect and quantify the hazardous storms with the greatest likelihood of producing harm to the citizens of Morocco, or damage to property and infrastructure. This would incorporate the events in the first two storm categories and make the estimation, or short term prediction, of precipitation amount the highest priority of the Morocco network. The second priority would be the ability to quantify wind speed, necessitating Doppler capability.

The radars recommended for the expansion of the current Morocco network should be configured as closely as possible to the technology currently in use. We believe the characteristics of the current C-Band (5.4 – 5.7 GHz) radar are adequate. Some of the primary transmitter/receiver characteristics are repeated in Table 5.2. For some weather applications there are advantages to using smaller (shorter wavelength) radars (X-Band), such as their greater sensitivity to small particles and ice particles (at lower transmitted power), similar spatial resolution (with a much smaller antenna) and lower overall cost of hardware. However, some disadvantages are that there is significantly greater attenuation in heavy rainfall (resulting in rainfall estimate errors), and a large reduction in the maximum scanning range. Since the primary application is detection and estimation of significant rainfall events, the current 5-cm system is a better choice. At longer wavelengths, such as the 10-cm wavelength that is used in the U.S. NEXRAD network, attenuation is negligible in even the heaviest rainfall and sensitivity to small particles and ice can be compensated for with much greater transmitted power (NEXRAD radar peak power is 750 KW). The price differential between a C-Band and an X-Band is minimal. However, using both radar systems would cause the program's cost to increase as additional personnel training and warehousing of parts and equipment for two radar systems would be required. For example, to attain a similar 1° beam dimension (as with the current Morocco system) requires a 10-cm antenna that is nearly twice as large (NEXRAD antenna diameter is 8.5 m).

There is also a disadvantage to having a national network with widely varying radar system characteristics, both in hardware component compatibility and in signal processing and radar output products. As will be noted in the subsequent analysis of new radar sites, complete coverage of problematic hydrologic basins and critical flood assessment areas will require simultaneous use of rainfall estimates from multiple radars. This is best accomplished with a network of radars that is completely compatible, and where all key radar parameters and calibration factors are closely monitored. For these reasons a network of 5-m radars with similar characteristics is recommend.

Table 5.2 – Characteristics of radar used in the current Morocco network

Wavelength/Frequency	~5 cm / ~5500 MHz
Peak Transmitter Power	Adjustable from 250 to 350 KW; 250 KW currently used
Antenna	2.4 m diameter for Khouribga; 4.8 m diameter for all others
Pulse Width	0.4, 0.8, 1.0 and 2.0 µsec
Pulse Repetition Frequency (PRF)	Adjustable between 100 to 2,000 Hz
Receiver Sensitivity	-112 dBm (at 1.0 and 2.0 µsec);114 dBm (at 0.4 and 0.8 µsec)
Receiver Dynamic Range	92 dB (at 1.0 and 2.0 µsec); 96 dB (at 0.4 and 0.8 µsec)

5.3. Description of the WxAnalyst Program

The WxAnalyst program was developed in consultation with the B&N Project Team specifically for the Moroccan Weather Radar Modernization Feasibility Study. Initially GTOPO30 DEM data was used, but the data was determined to be too course, and actually very inaccurate in many locations in Morocco. The GTOPO30 data is 30 arcsec data, or approximately 1 km resolution. It was decided during the course of development of the software for this project to use SRTM data, which is 3 arcsec data providing a much finer resolution of 90 m. Higher resolution DEM data has diminishing returns because of the quality of finer resolution data that is available. We will however utilize 30 m DEM data within 30 km of the radar as warranted. The characteristics of the radar and a variety of scanning patterns are used as input to the program. Some of the more important radar input parameters are the vertical beam dimension (1° was used), the maximum range (150 km was used), the angle of the lowest tilt (0.5° was used), and the height of the radar antenna center above the ground (18 meters was used). For the analysis of occultation by terrain, the beam tilts from 0.5° to 3.0° in 0.5° steps were processed. (This varied with location and the amount of terrain blockage encountered.) The primary output product is a map of the minimum beam height above the terrain (termed floor height), determined by processing each azimuth angle in 0.5 km range steps out to 150 km. The minimum height at each range is determined by stepping up in tilt until the beam clears the terrain. An example plot is shown in **Figure 5.2** for the current Larache radar site. For optimal scanning of meteorological events for the purpose of precipitation estimation, beam-to-terrain heights less than 1000 m are preferable. The effect of earth curvature (which is unavoidable) increases the distance to the ocean surface (west of Larache) to greater than 1000 m beyond about 130 km range. Where terrain rises with range, such as east of Larache, the distance from lowest useable beam to the terrain first decreases (as to the southeast), then dramatically increases beyond the highest terrain where a higher tilt is needed to clear the highest mountains at about 75 km range. We will however utilize 30 m DEM data within 30 km of the radar as warranted. The characteristics of the radar and a variety of scanning patterns are used as input to the program. Some of the more important radar input parameters are the vertical beam dimension (1° was used), the maximum range (150 km was used), the angle of the lowest tilt (0.5° was used), and the height of the radar antenna center above the ground (18 meters was used). For the analysis of occultation by terrain, the beam tilts from 0.5° to 3.0° in 0.5° steps were processed. (This varied with location and the amount of terrain blockage encountered.) The primary output product is a map of the minimum beam height above the terrain (termed floor height), determined by

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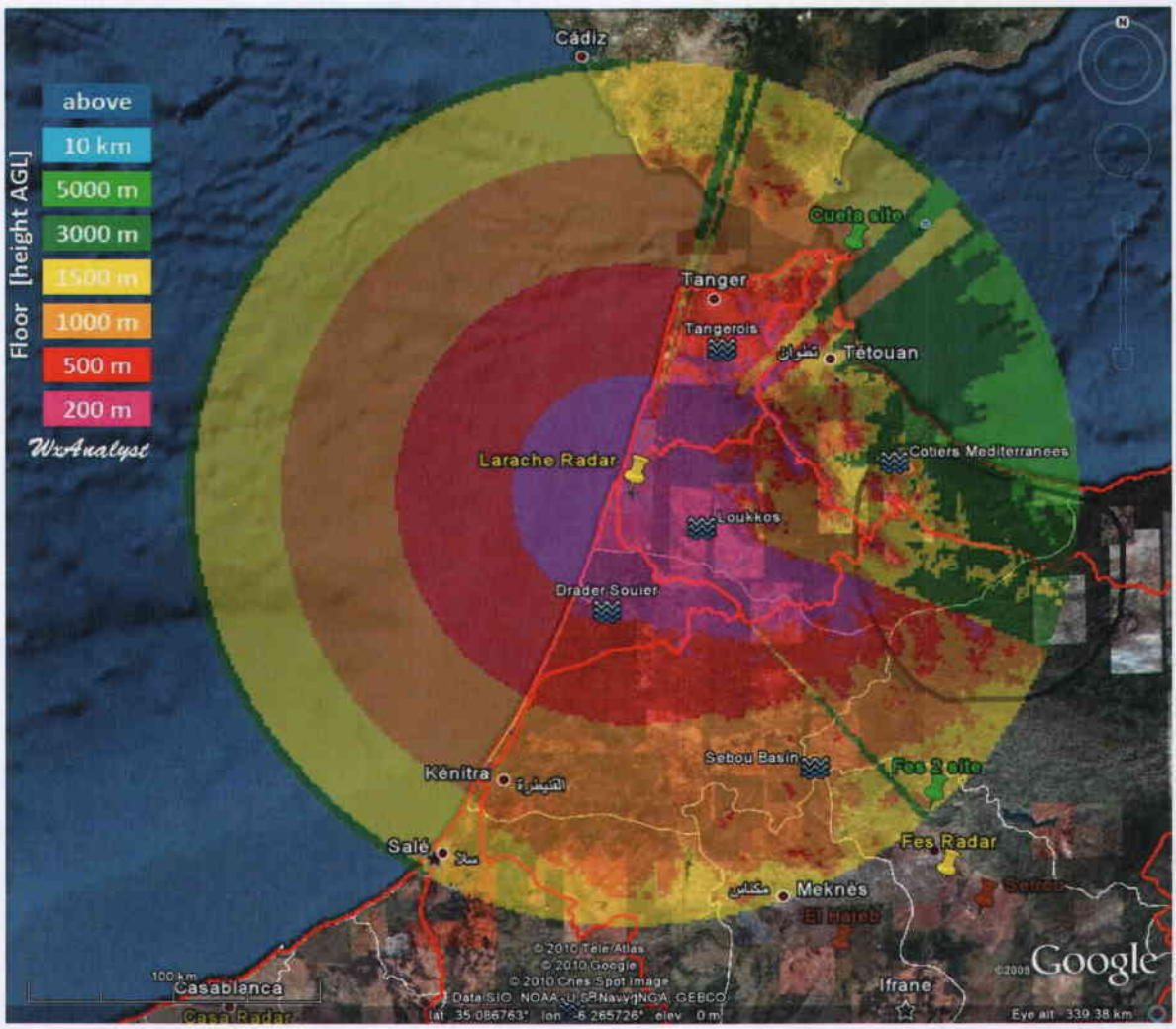


Figure 5.2 – Example of a Floor Analysis plot showing lowest beam height above terrain (floor height) for the 150 km coverage area **of the Larache radar**. The pattern is one of concentric circles over a surface of constant height like the Pacific Ocean to the west. Due to terrain blockage to the east of Larache, the beam height to coastal terrain and the Mediterranean Sea increase to greater than 3000 meters. Watersheds are outlined in red and provinces in white. The region outlined in black has the greatest annual precipitation in Morocco.

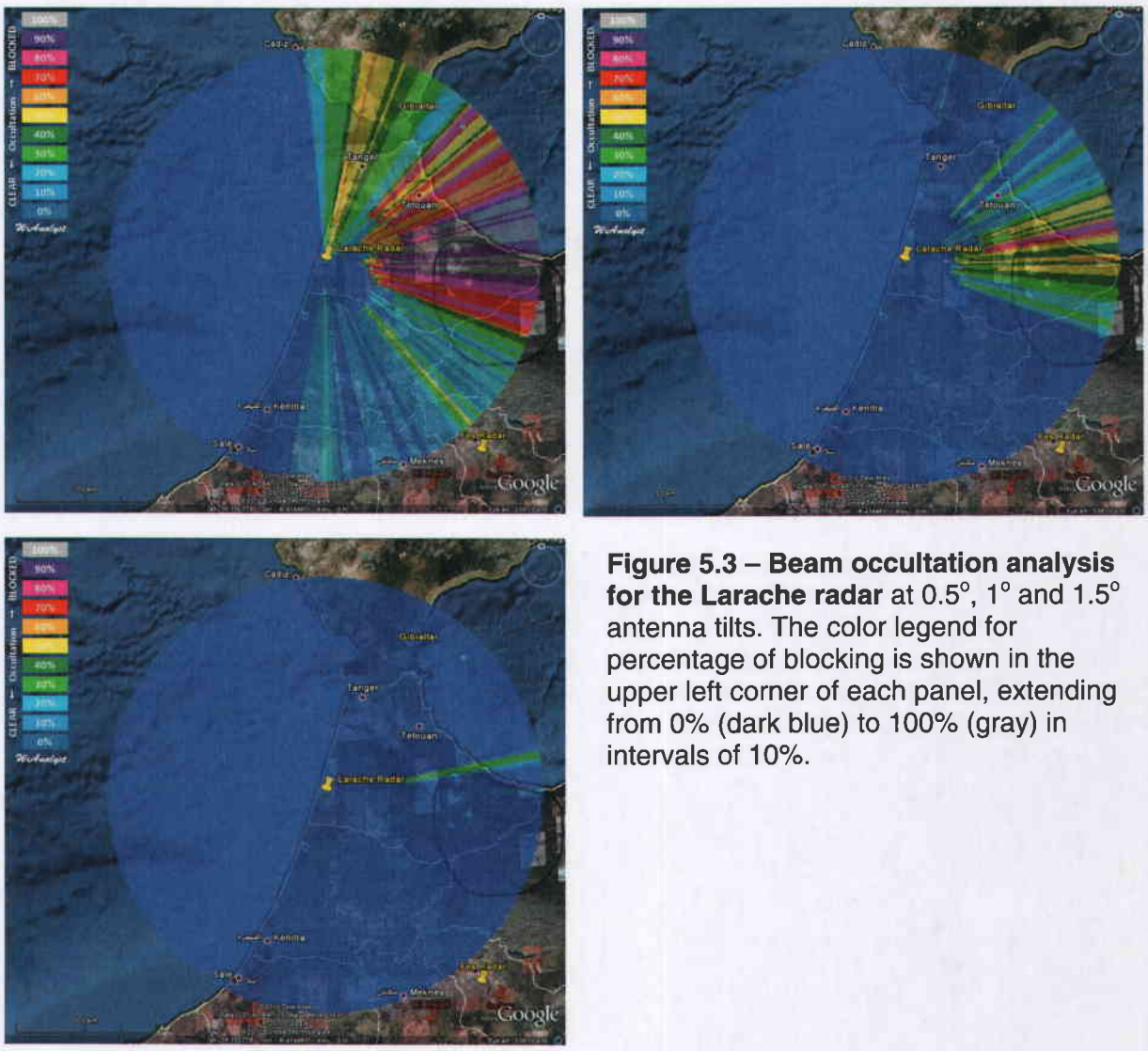


Figure 5.3 – Beam occultation analysis for the Larache radar at 0.5°, 1° and 1.5° antenna tilts. The color legend for percentage of blocking is shown in the upper left corner of each panel, extending from 0% (dark blue) to 100% (gray) in intervals of 10%.

The floor height maps and the beam occultation analyses shown in **Figure 5.3** were used to identify problem areas at all the current and proposed radar sites in the Moroccan radar network. **Figures 5.2** and **5.3** indicate that the main occultation problem in the Larache area is in the azimuth sector from about 45° to 110° at ranges beyond about 85 km. This area includes part of the precipitation maximum just south of the coast, and also the flood prone area around Tetouan which was indicated as a coverage priority by DMN staff. On the other hand Larache appears to cover the flood prone area around Tangier quite well at tilts above 0.5°. To optimize the radar network the gap to the east needs to be compensated for by an existing radar or by siting a new radar to the east of the high terrain, somewhere along the western coast of the Mediterranean Sea.

The analysis used for this study is further explained in a White Paper provided in **Appendix 5C** of this section.

5.4. Detailed analysis of radar coverage in Morocco

5.4.1. Summary of Coverage by Existing Radars

Floor and beam occultation maps are provided for the five radars. The first of the five existing radars to be examined is the radar at Casablanca. The floor and beam occultation is shown in **Figures 5.4** and **5.5**.

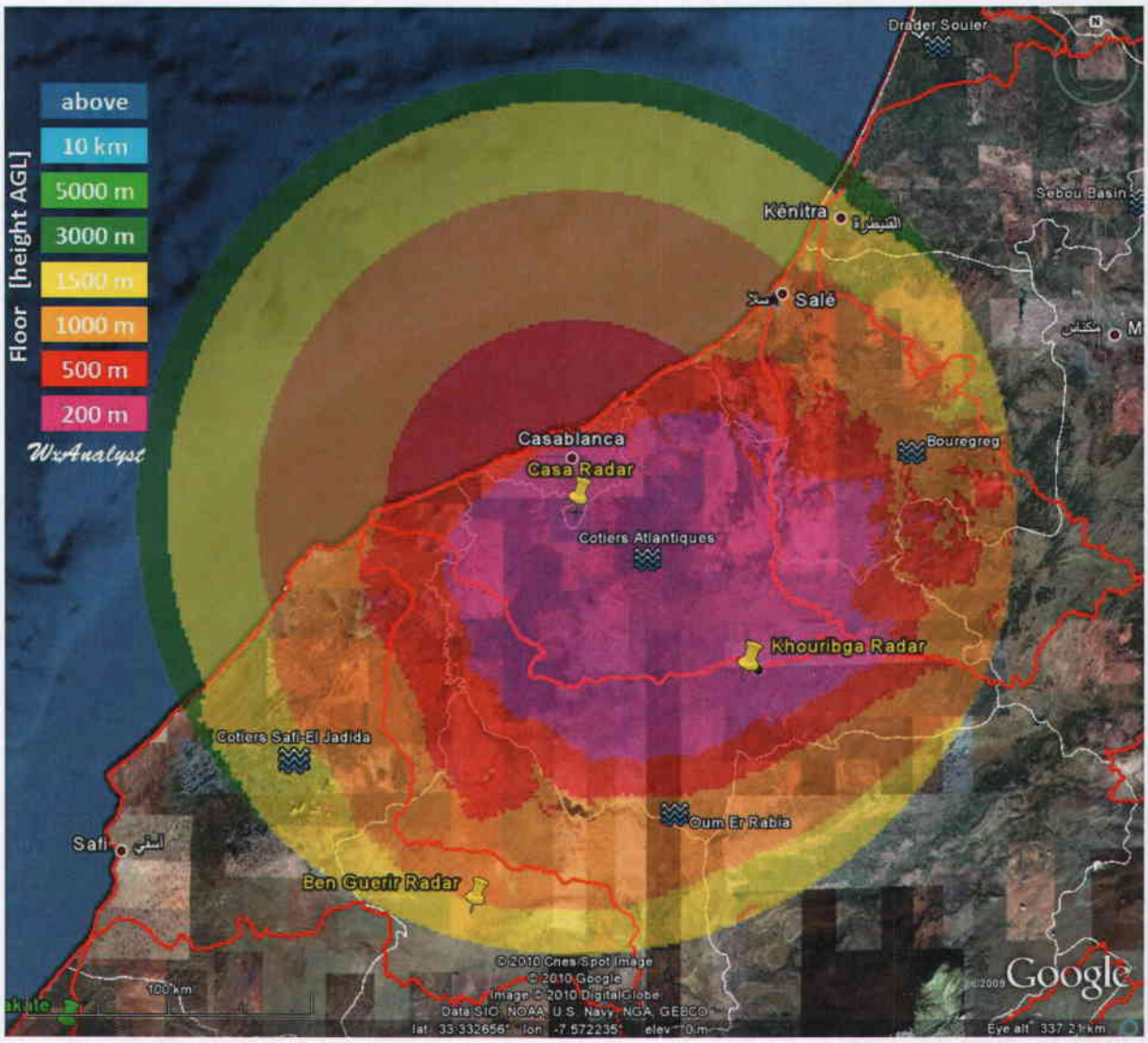


Figure 5.4 – Floor height plot for the coverage area of the Casablanca radar. Note the very gradual rise in terrain inland considerably broadens the coverage of the <500 m terrain clearance, without blocking the lowest tilts. The locations of the Khouribga and Ben Guerir radars are shown for reference. Occultation analysis appears in **Figure 5.5**.

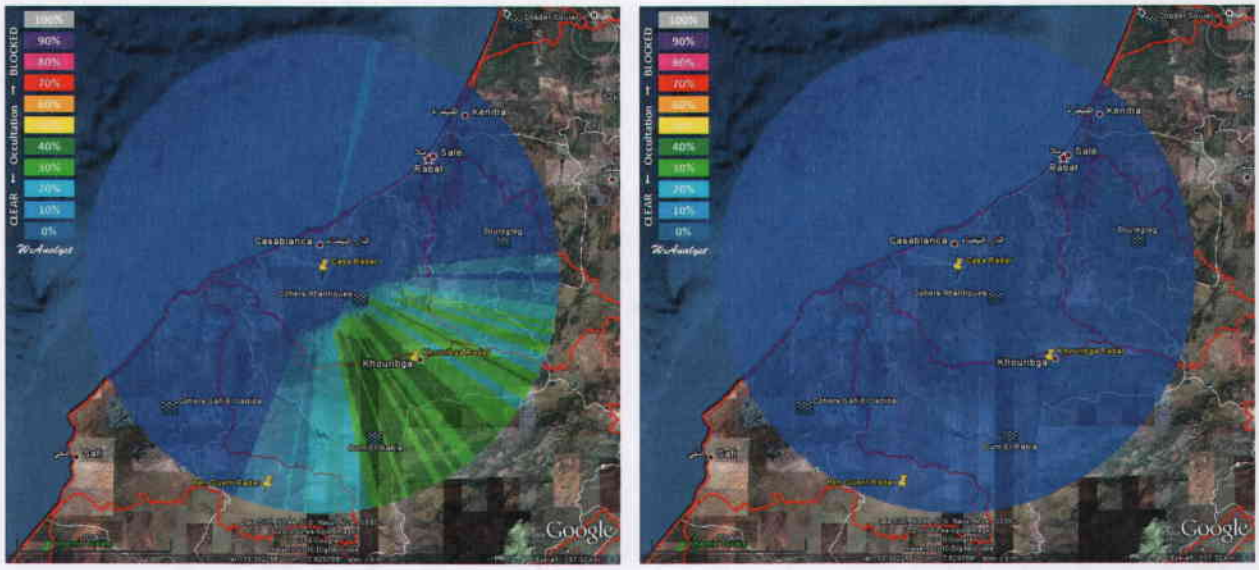


Figure 5.5 – Beam occultation analysis for the Casablanca radar at 0.5° and 1.0°

The Casablanca Radar shows partial blockage to the east due to the gradually rising terrain. This does not compromise the radar observation, as **Figure 5.4** shows excellent surveillance at the lowest levels above the ground.

The Khourigba Radar beam occultation is shown in **Figure 5.6**. The floor analysis is alternatively shown in **Figure 5.7**.

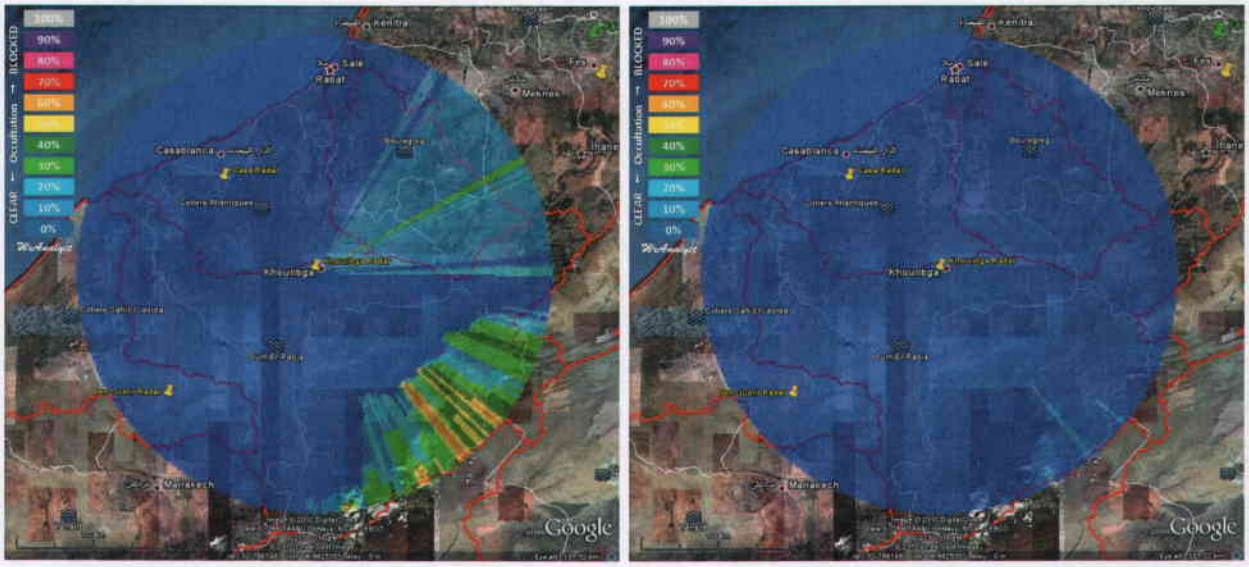


Figure 5.6 – Beam occultation analysis for the Khourigba radar at 0° and 1° antenna tilts.

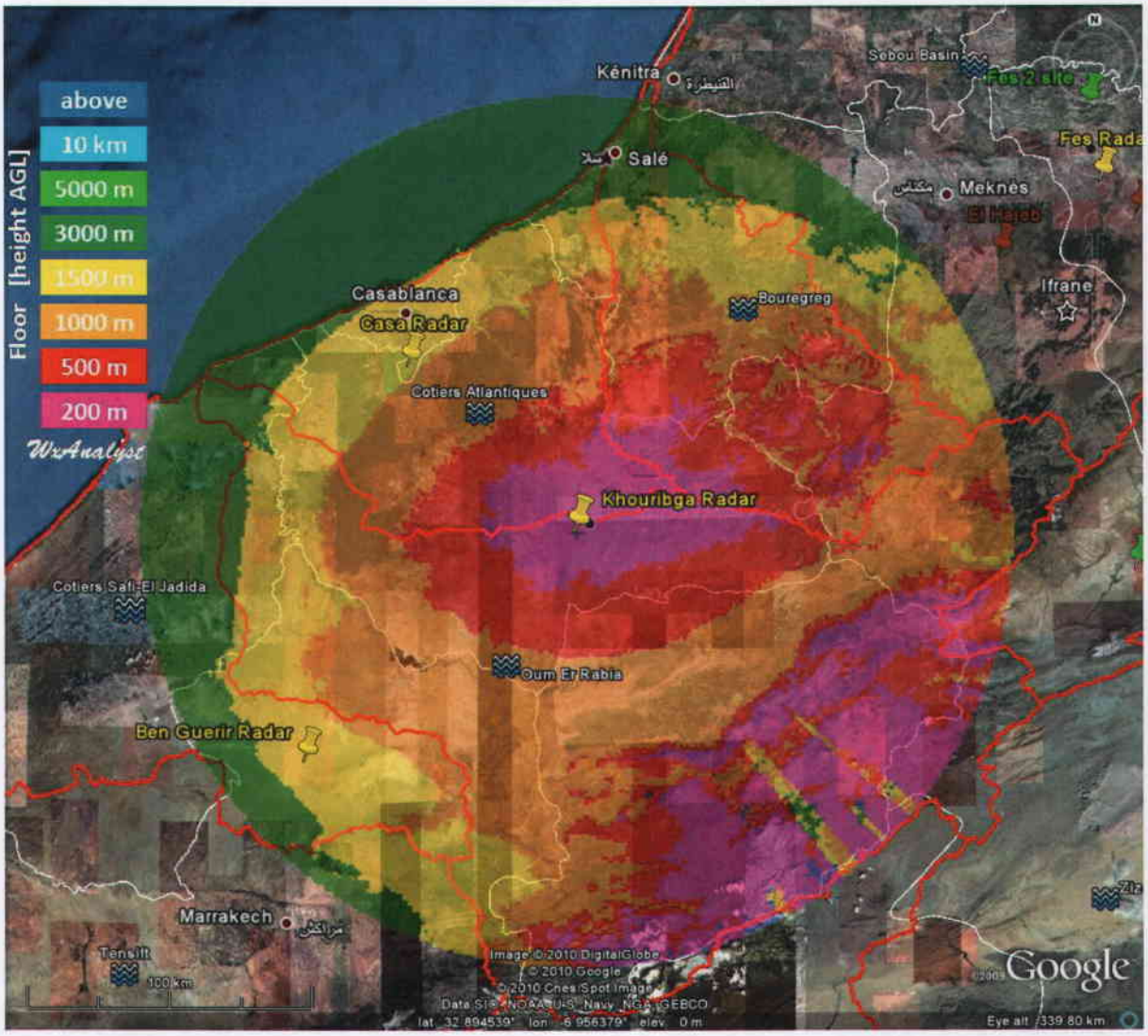


Figure 5.7 – Floor height plot for the coverage area of the Khouribga radar. Note the High Atlas Mountains to the southeast rise up to decrease the radar beam to terrain distance to generally less than 200 m between about 75-150 km range. The locations of the Casablanca and Ben Guerir radars are shown for reference. Occultation analysis appears in **Figure 5.6**.

The Khourigba Radar provides excellent coverage especially capturing the layer of atmosphere close to the ground over the Atlas Mountains with only minor blockage. This radar appears to be very well located.

Figures 5.8 and **5.9** show the floor analysis and occultation for Ben Guerir Radar. This radar was not operational at the start of this study. This radar brings coverage to such important areas as Marrakech and other areas to the south and southeast that have experienced recent flooding.

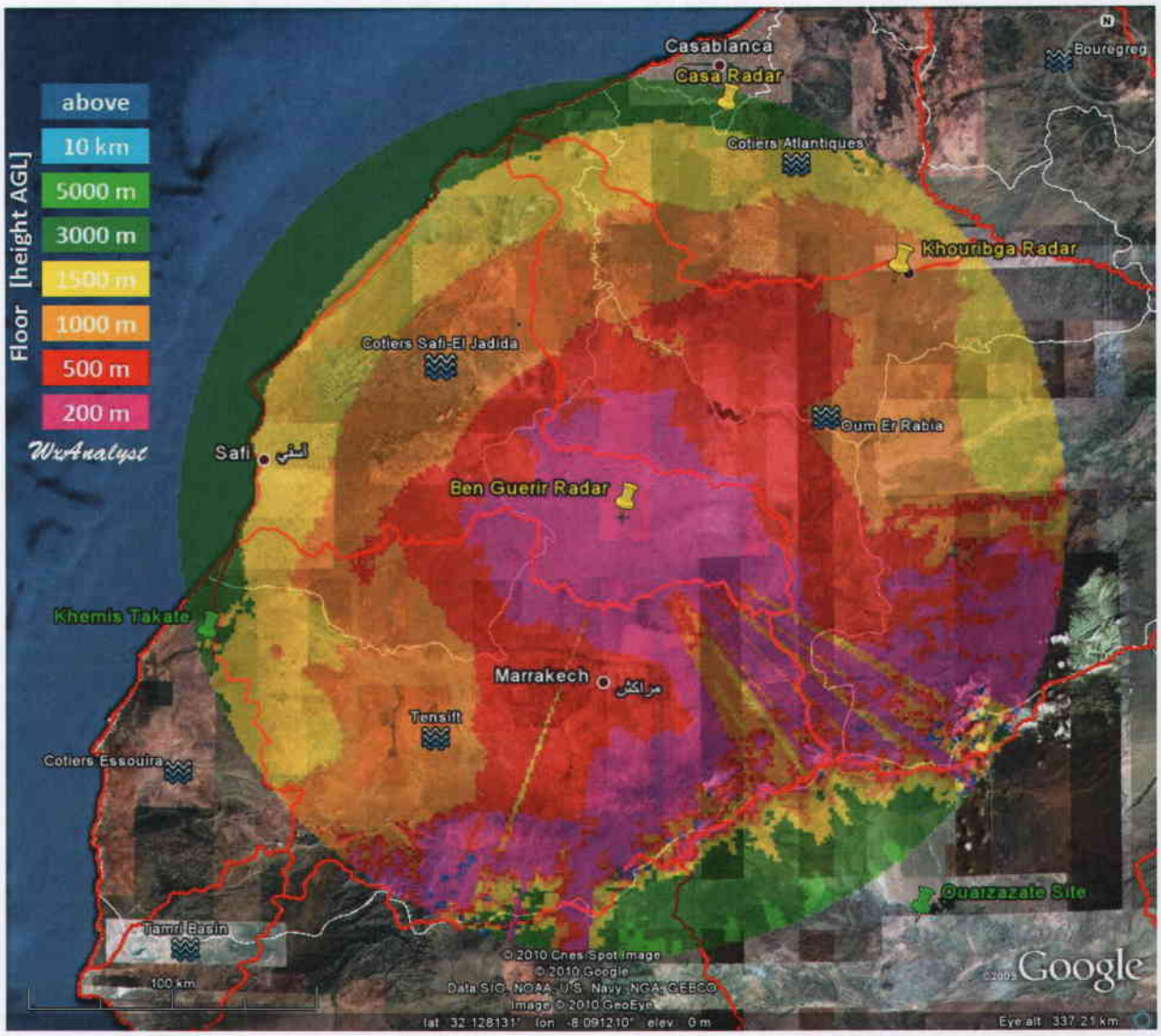


Figure 5.8 – Floor height plot for the coverage area of the Ben Guerir radar. The coverage over the High Atlas Mountains to the east through south is good except beyond about 125 km where the highest mountains block the lowest beam tilts and create a region where the beam to terrain distance is 1000-3000 m. The locations of the Casablanca and Khouribga radars are shown for reference. Occultation analysis appears in **Figure 5.9**.

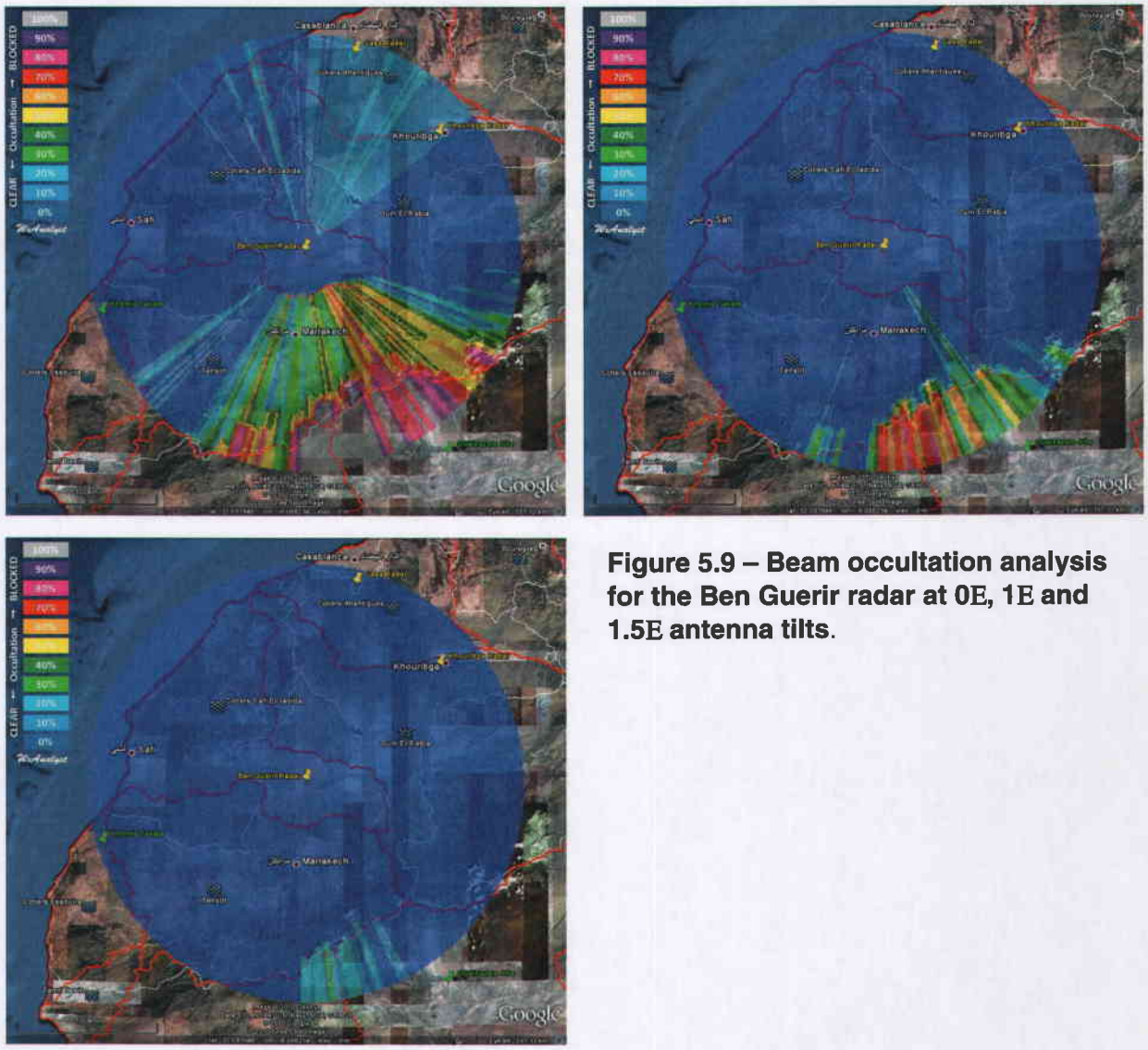


Figure 5.9 – Beam occultation analysis for the Ben Guerir radar at 0E, 1E and 1.5E antenna tilts.

Fes and Agadir radars have the worst beam occultation problems.

The floor and occultation maps shown in **Figures 5.10** and **5.11** reveal that the Fes radar covers the northern and western parts of the Sebou Basin quite well, but that coverage is relatively inadequate for sampling weather systems over the mountainous regions to the east through west-southwest of the site (southern part of the Sebou Basin). The beam occultation problem (**Figure 5.11**) extends to the 2.5° antenna elevation angle, or higher, to the south-southeast, where the blocking terrain is 10-20 km from the radar.

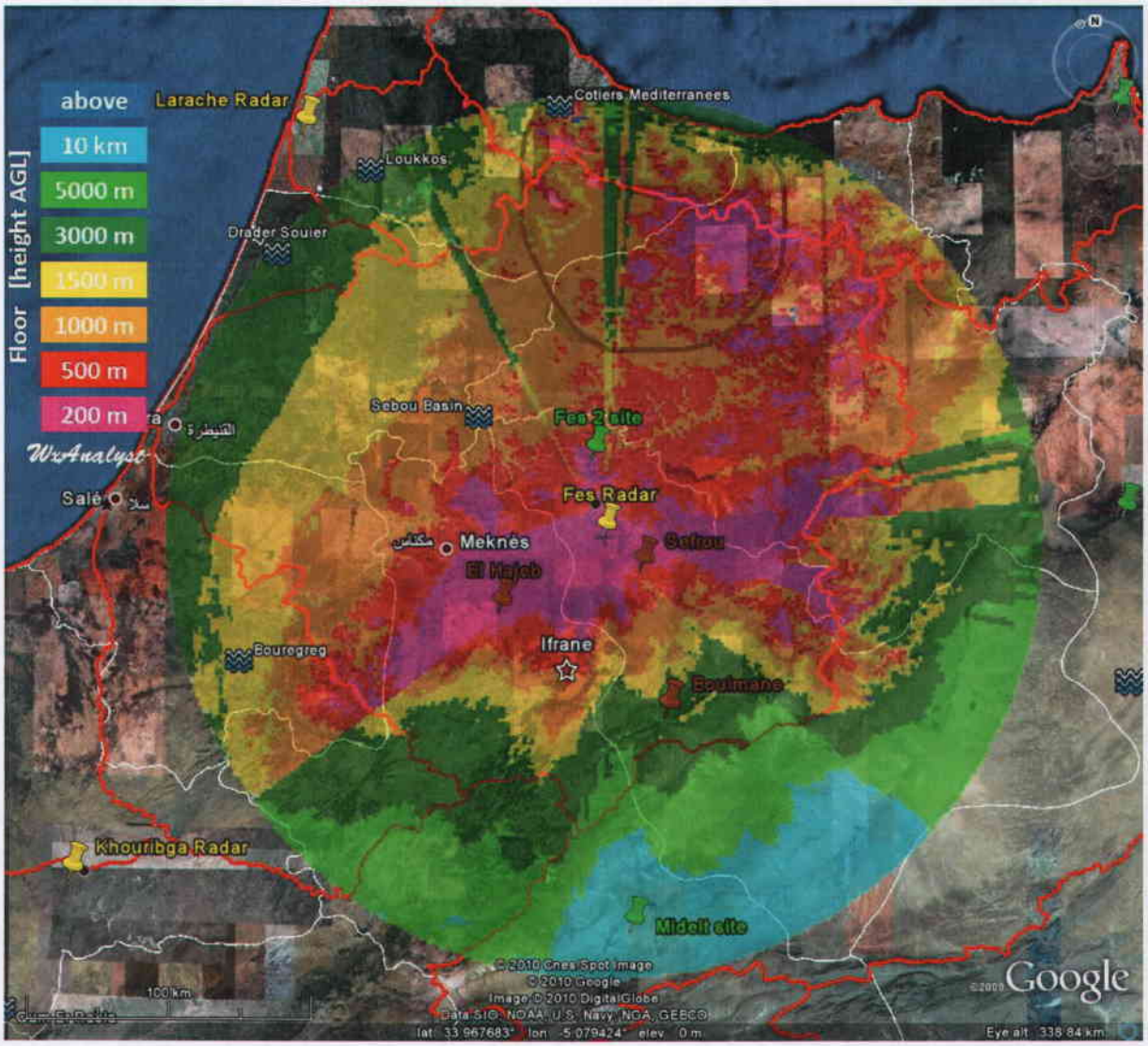


Figure 5.10 – Floor height plot for the coverage area of the current Fes radar. The area outlined in black to the north of the radar represents a climatological maximum in precipitation (>1200 mm per annum). The region around the sites marked by brown pins is an important agricultural area that is prone to hail storms. As indicated by the map Fez represents a radar in the current network with multiple coverage problems, the most pronounced being over the high terrain area south of the radar. The location of the Larache radar is shown for reference, as are a possible new site for the Fes radar (Fes 2 site), and three other possible new sites to the northeast (Nador), east (Debdou) and south (Midelt) of Fes.

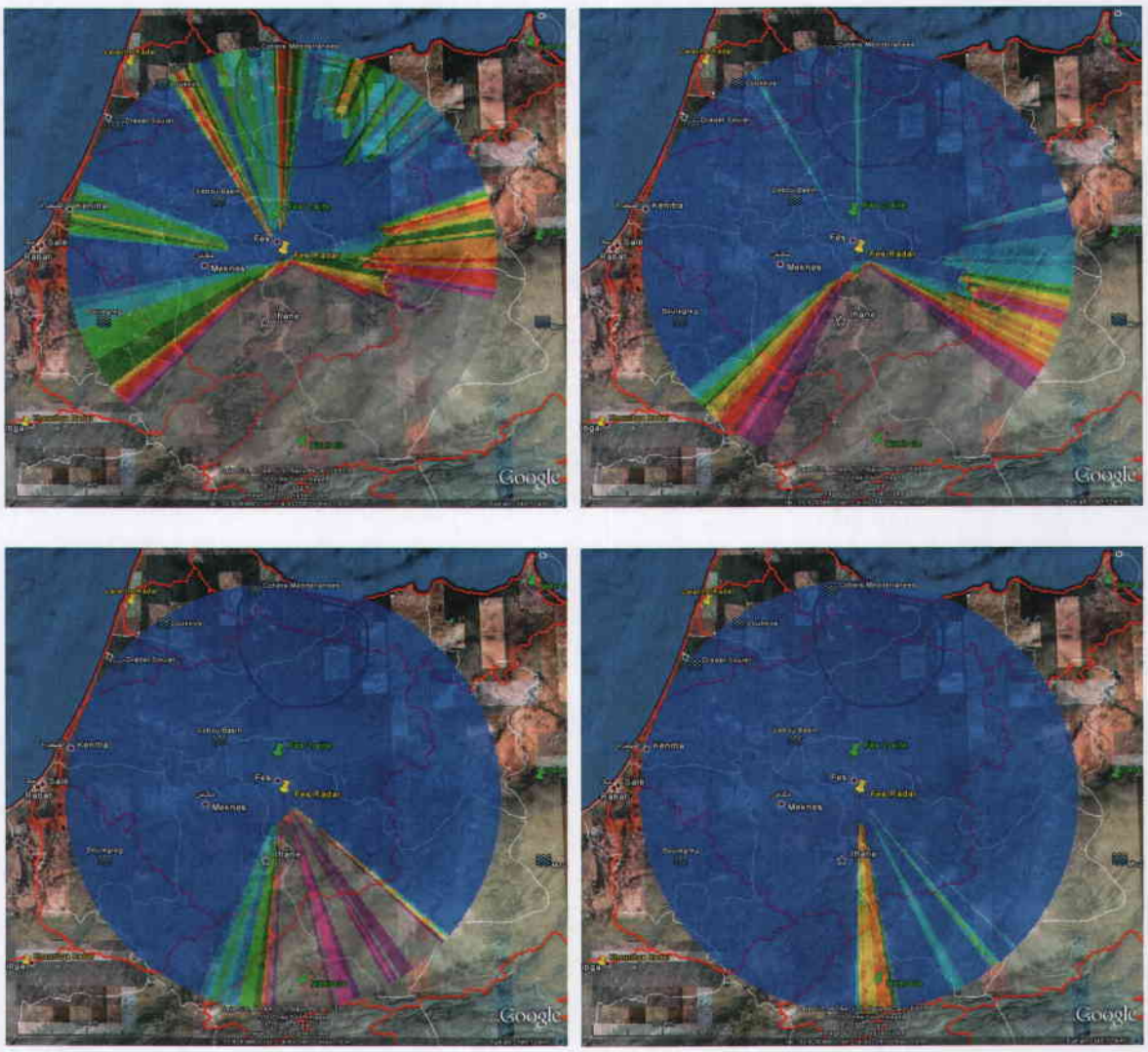


Figure 5.11 – Beam occultation analysis for the Fes radar at 0.5°, 1°, 2.0° and 3.0° antenna tilts.

This is further illustrated in **Figure 5.12** where beam heights are plotted on a terrain cross-section for three specific azimuths from the southeast to the southwest. The terrain blockage prevents coverage of storms below 1500 m AGL over several of the important agricultural regions south of Fes, and is the main reason why the Fes radar is of limited value to the hail suppression projects near Ifrane and Boumane.

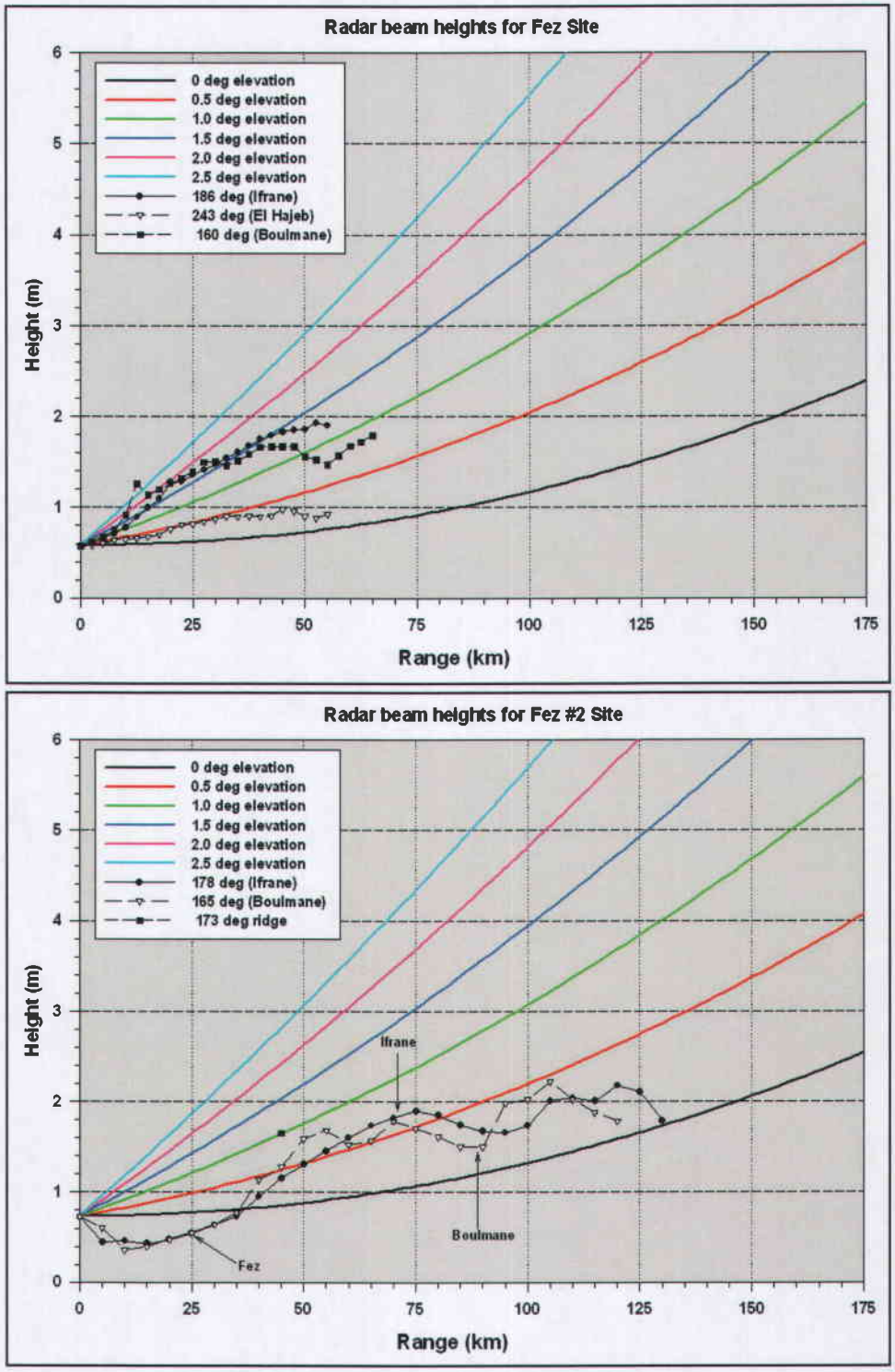


Figure 5.12 – Radar beam heights and terrain profiles for the current Fes radar site (top) and for a potential site (Fes #2) about 25 km north of the current site (bottom). In the bottom panel the location the current Fes site and two hail suppression areas are noted on the terrain profiles.

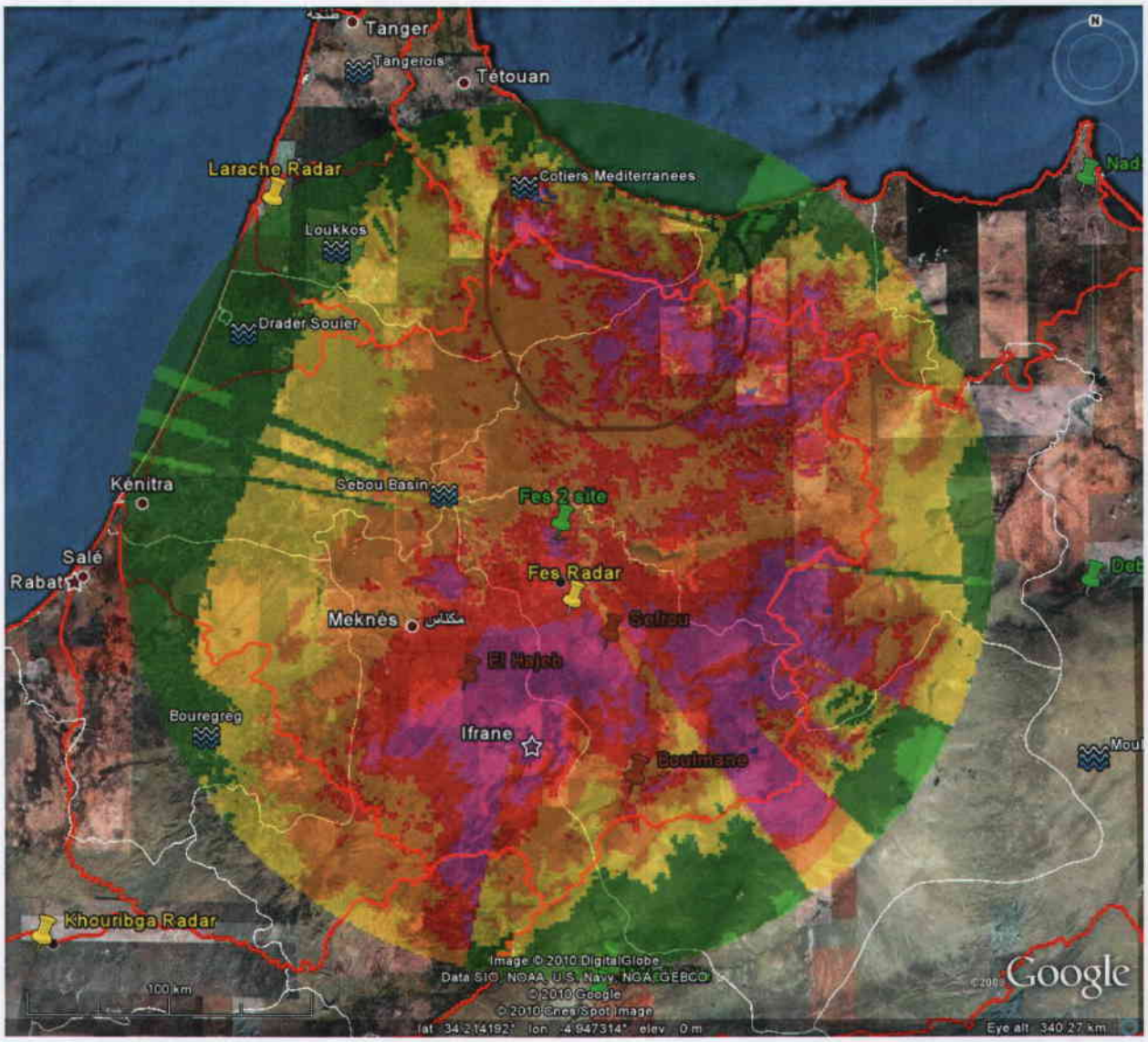


Figure 5.13 – Floor Analysis for a potential new radar site at Fes (labeled Fes 2 site). Color height scale as in Figure 5.2. Sites marked by brown pins are near important agricultural areas.

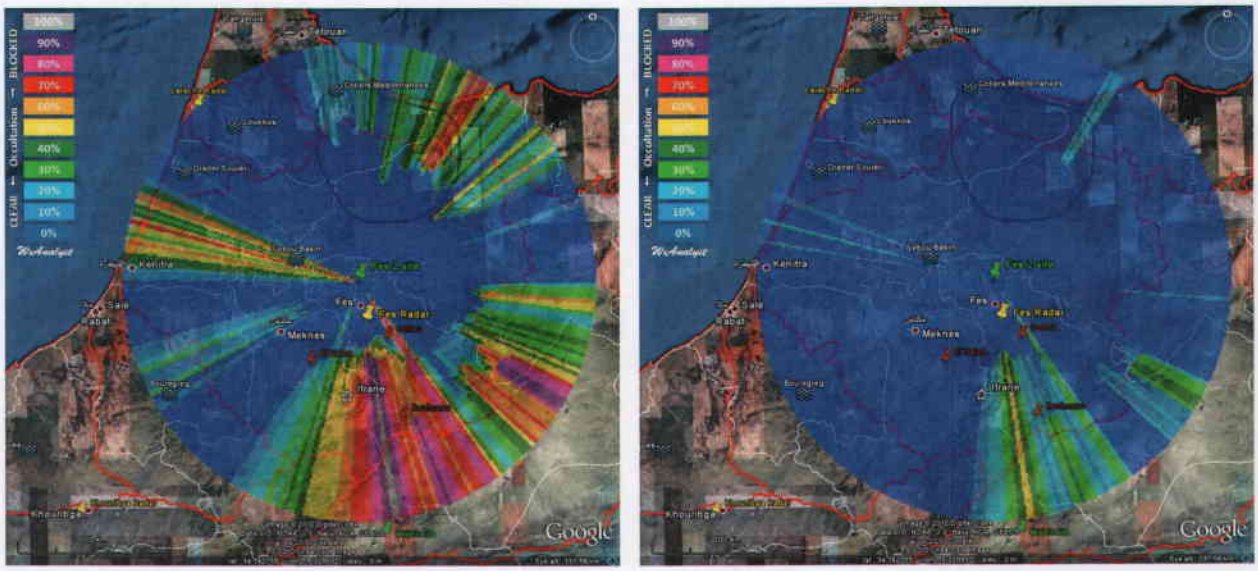


Figure 5.14 – Radar beam occultation plots for the Fes 2 site at 0.5E and 1.0E. Higher tilts are not shown since there was no blockage at and above 1.5°. Sites marked by brown pins are near important agricultural areas. Area outlined in black north of Fes represents an annual precipitation maximum.

A potential solution to the blockage and beam height problem would be to move the Fes radar to the north to a somewhat higher site where the lower beam tilts would clear the problem terrain. Floor and occultation analysis for one possible site (Fes 2) are shown in **Figs 5.13 and 5.14**. Because the Fes 2 site is higher than the current airport site the beam is somewhat higher over the center of the Sebou Basin, but still generally below 1000 m AGL in the upper part of the basin. Coverage to the north is similar to the original site, but Fes 2 now samples the high precipitation region (**Figure 5.13**) at beam heights mostly below 500 m. **Figure 5.14** shows that the 1.5° tilt beam would be relatively unaffected by terrain to the south, and beam coverage below 500 m would extend across the agricultural area and significantly improve the detection of hail producing storms in the vicinity of Ifrane and Boumane. Additional detail on terrain clearance at specific azimuths is shown in **Figure 5.12**. This new site would provide an improved monitoring of hazardous weather directly over the Fes Airport and provide better coverage over the flood prone regions, including the important Sebou Basin. Close-up views from the Fes 2 site are shown in **Figure 5.15**. These images revealed a main road crossing the higher terrain, and several minor roads branching off to higher points that could potentially serve as radar sites. Communication should be available from sources near Fes and power is likely available, at least along the main road.

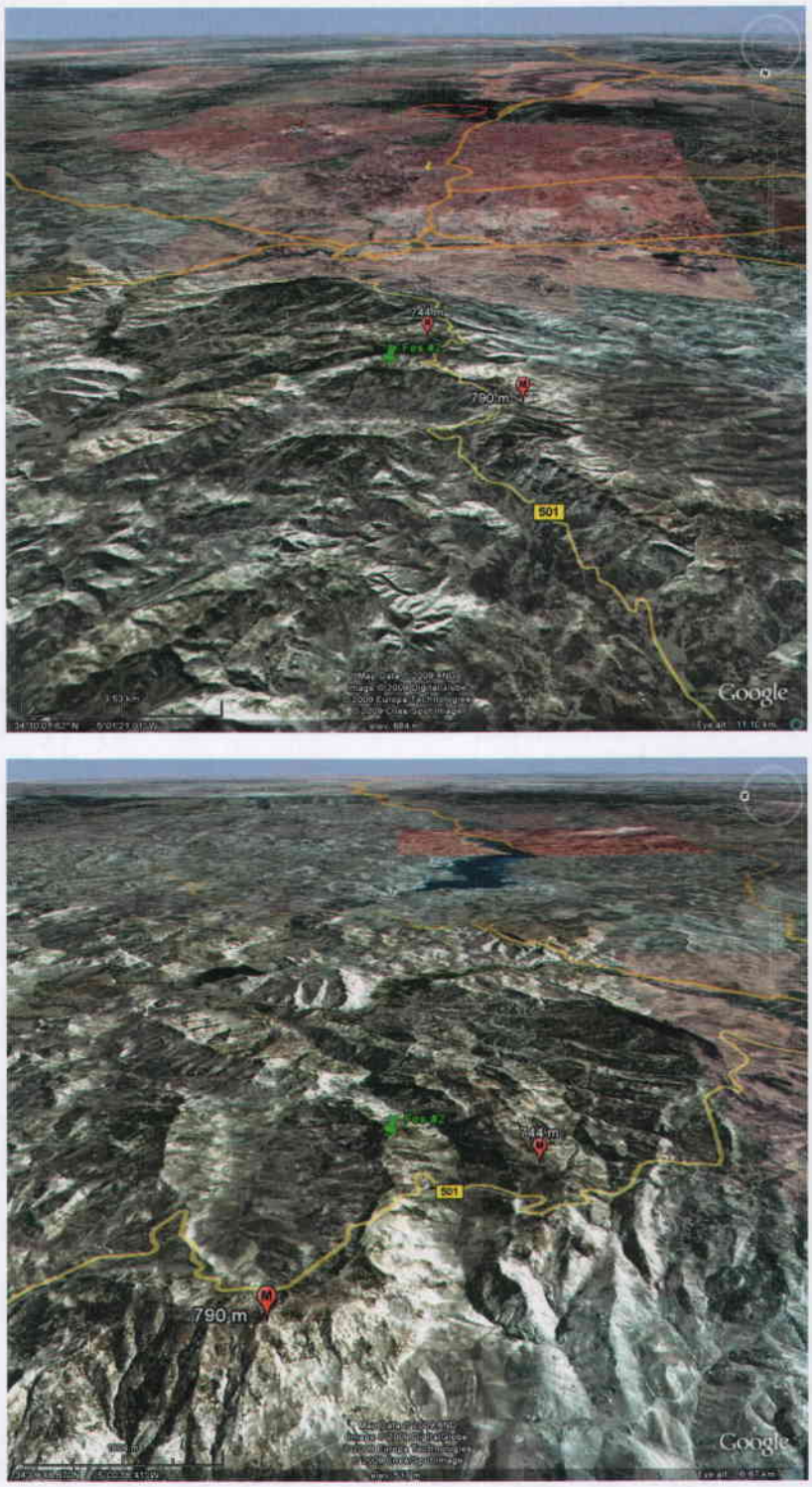


Figure 5.15 – Views of the alternate Fes 2 site. Top panel is a view from the north-northwest looking out over Fes and bottom panel is a view from the west.

Floor and occultation plots for the other current site (Agadir) with severe terrain blockage problems are shown in **Figures 5.16** and **5.17**. Coverage with beam heights below 1000 m includes most of the Souss and Massa Basins and the north tip of the Cotiers Guelmim-Tiznit. The high terrain north of Agadir effectively blocks tilts below 2.0° to the north-northwest through northeast, resulting in beam heights above 1500 m over a large portion of Tamri Basin and the Cotiers Essouira. A potential solution to the blockage problem at Agadir is the addition of a new radar at a site near Khemis Takate (shown in **Figure 5.16**). An analysis of a new radar at Khemis Takate will be discussed in more detail in Section 5.5.

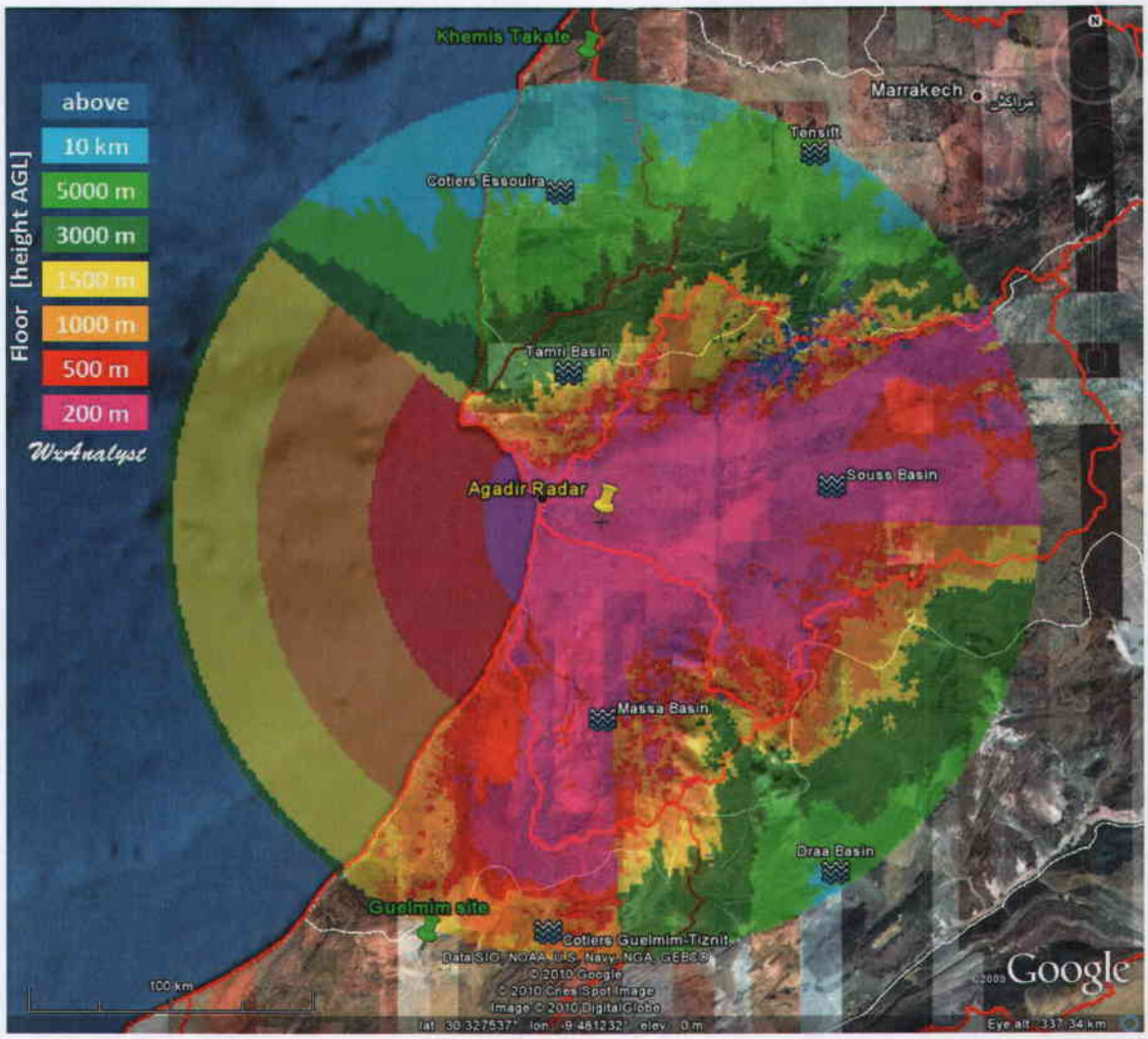


Figure 5.16 – Floor height plot for the coverage area of the current Agadir radar. The Agadir radar has good offshore coverage from northwest to southwest and covers the Souss Basin quite well. North of Agadir an east-west ridge forces higher beam tilts for coverage of regions to the northwest through northeast. In this area beam to terrain heights are generally above 3000 m. The lower tilts are also blocked beyond about 75 km in the southeast quadrant leading to beam heights above 1500 m over the Draa Basin.

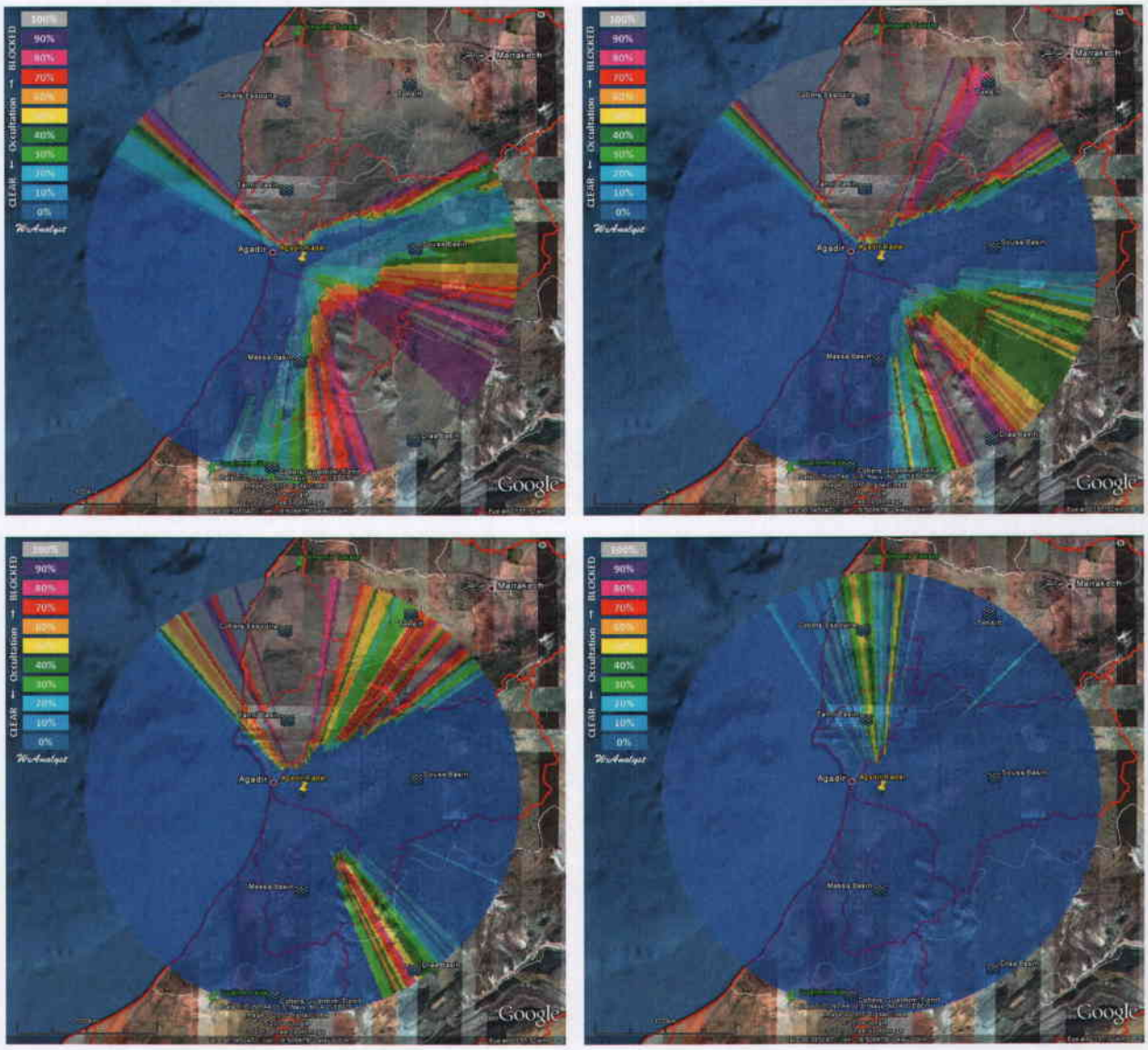


Figure 5.17 – Beam occultation analysis for the Agadir radar at 0.5°, 1°, 1.5° and 2.5° antenna tilts.

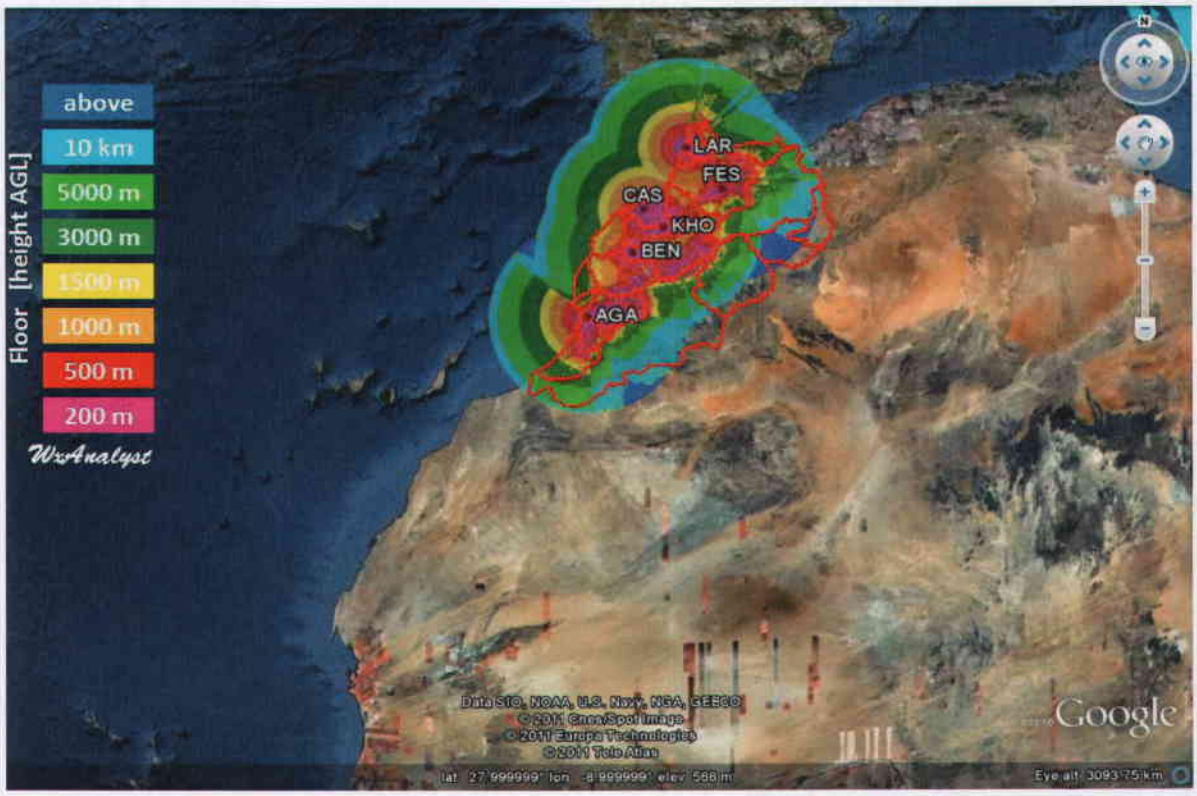


Figure 5.18 – A floor analysis mosaic constructed from the floor analysis data at individual radar sites in the current Morocco network. For overlapping areas the Floor Analysis program selects the range bin with the lowest radar to terrain height. Hydrologic basins of the study area are outlined in red. The six existing radars are indicated by the three letter abbreviation.

Figure 5.18 shows a mosaic constructed from the individual floor analysis plots for the current Morocco radar network, with the exception that the proposed new Fes 2 site is represented in the mosaic instead of the original Fes Airport site. The mosaic clearly shows the current problem areas with specific radars and the general lack of coverage east of the Atlas Mountains and south of the Agadir coverage area. New radar locations will be discussed in the following section starting with the region north of Agadir, then working south from the Mediterranean region to the Draa Basin east of the Atlas Mountains.

5.4.2. Summary of National Coverage of Existing Radar Network

National radar coverage of the existing radar network was calculated using the floor analysis. With the floor analysis we can determine the coverage of a specific radar, or network of radars, by altitude above the ground. The floor analysis provides the elevation of the radar beam in 8 increments; 0-200, 200-500, 500-1000, 1000-1500, 1500-3000, 3000-5000, 5000-10000, and above 10000 meters above ground. A calculation of how many pixels occurred in each altitude range was then determined for the existing radar network. If two radars covered the same area,

the radar that provided coverage at the lowest altitude (AGL) was used in this analysis. Radar coverage was analyzed over 300 km range even though the study team realizes that radar data at 300 km is not desirable.

The results of the coverage for the existing five radar network indicate that approximately 76% of the study area was covered by one of the five radars, leaving 24% without radar coverage. Coverage by altitude (AGL) is as follows:

Table 5.3 – Radar coverage percentages and cumulative Percentages for existing radar network in the study area.

Altitude m (AGL)	Percentage	Cumulative Percentage
≤ 200	14.5%	14.5%
200 to 500	9.7%	24.2%
500 to 1000	11.5%	35.8%
1000 to 1500	5.9%	41.6%
1500 to 3000	10.8%	52.4%
3000 to 5000	11.7%	64.0%
5000 to 10000	11.6%	75.6%
> 10000	0.4%	76.0%
no coverage	24.0%	100.00%

About 64 percent of the study area has radar coverage at or below 5000 m, which is usually assumed be the approximate level of non-divergence vertical velocity serves as the mechanism for synoptic cloud development and otherwise is important in monitoring the dynamics of weather systems. This, however, leaves a 36 percent of the study area without radar coverage.

5.4.3. Equipment Required to Upgrade the Existing Radar Stations and U.S. Sources of Equipment

Based on the extensive Field Assessments performed under Task 2 of the Agreement (see Section 4 – Radar Diagnostics). A conclusion of the field assessment was that the existing equipment does not need to be replaced for the radar network to function properly. However, several suggestions are recommended, which would improve the performance and uptime of the radar network substantially. Many of recommendations are not expensive, but fall under the category of improved maintenance policy.

Several observations recorded during the Field Assessments are considered vital for the success of DMN's mission to save lives and property. These recommendations will fall under the following categories:

A. Power Environmental, and Communications Infrastructure
B. Mandatory Repairs Required
C. Scheduled Maintenance and Documentation

D. Radar Technician and Radar Operator Training
E. Recommended Hardware Upgrades

5.4.3.1 Power, Environmental, and Communications Infrastructure

Per the Field Assessment Report on Task 2 (see Section 2 – Initial Visit), it was noted that power and communications were not optimal at several radar sites. It is recommended that the standby generators and UPS systems be maintained to the highest level of performance, especially maintaining a full supply of fuel, to run the generators for a long enough period to outlast a power outage. It is very detrimental to radar electronic and high voltage components to have the power suddenly removed while the radar is transmitting, and then have power suddenly re-applied to the system.

It is also vitally important for the air conditioning systems to be fully operational at all times, as radar equipment can rapidly overheat when in transmitting mode. It is recommended that a spare air conditioning unit be kept at every radar site

Per communications, it was noted that DMN has plans to provide a backup ISDN connection to each of the radar sites. The B&N Team wholly concurs that this is required in order to operate a mission critical radar network, where lack of data communications from a given radar site leaves a blind spot in the coverage area observed at Radar Central.

5.4.3.2 Mandatory Repairs Required

During the Field Assessment it was noted that at least 2 of the radar failures were due to leaking radomes and/or radar buildings. Eliminating these leaks must be a high priority, because it appears that the two radar failures may have been prevented if the radomes had not leaked into the transmitter cabinet or pedestal.

Concerning the leaks, it would appear that there are two causes. One is a function of installing aircraft warning lights, and the other cause is from lack of proper sealing of the joints in the radome. Corrosion also seems to be a factor in several of the radomes inspected, which, if left unchecked can lead to leaking.

The B&N Team recommends that for leaks of the first type that the installations be done very carefully and methodically, inspected by a separate individual as a function of quality assurance, and tested thoroughly, including pouring water over the outside of the radome, with the radar powered off, and the antenna\pedestal or transmitter cabinet covered up, before leaving the site.

Leaks due to sealant failures are generally visible from the inside of the radome. Every effort should be made to identify and re-seal radome leaks as soon as possible. Radomes should be visually inspected on a periodic basis, to protect the sensitive and expensive equipment inside.

This same concept applies to radar shelters and buildings.

5.4.3.3 Scheduled Maintenance and Documentation

Another conclusion of the field assessment is that DMN has an excellent maintenance tracking software but the software is not being fully utilized. The B&N team recommends that DMN conduct refresher training for all radar technicians on the maintenance software, and that a policy be implemented requiring all repairs and scheduled maintenance activities be logged into the maintenance software. The scheduled maintenance should include periodic visual inspection of radomes, towers, buildings, for leaks or corrosion, as well as periodic leveling of the antenna pedestals, and re-balancing the counterweights on the pedestal arms.

If DMN does not feel that its staff is completely comfortable performing this level of scheduled maintenance, then the B&N Team recommends that a highly qualified 3rd party company be utilized, or refresher training be provided to all radar technicians, as vacancies can exist, due to promotions and retirement of radar personnel.

5.4.3.4 Radar Technician and Radar Operator Training

DMN is not utilizing the capability of the radar systems to their fullest extent, as there appears to be only one scan strategy deployed. The B&N Team recommends that all radar technicians and radar operators, on site and at Radar Central receive refresher training on radar operations, and particularly on the radar software. This is to compensate for vacancies that are created in the workforce due to, career changes, internal promotions, and retirements.

5.4.3.5 Recommended Hardware Upgrades

This section will concentrate on two recommended upgrades, the first being a hardware upgrade to a specific radar site, and the second recommendation being conceptual for the entire radar network.

During the field assessments, it was noted that the Khouribga radar site had a smaller antenna and a smaller radome than the other radar sites. It is the B&N Team's considered opinion that an upgrade should be made to the antenna, and by extension, the radome, at this site for several reasons.

- This would bring this site into conformity with the rest of the radar network, in terms of observed data, especially reflectivity values.
- A larger dish would reduce the beam width, from an estimated 2 degrees down to 1 degree, which will improve the resolution of the radar output.
- A larger dish would also increase the gain of the system from an estimated 35db to approximately 44db, which will result in better MDS (minimum detectable signal) performance.

The radome has to be increased in size; because the larger antenna would require more room inside the radome. One other consideration would be to determine if the existing pedestal is capable of supporting the larger antenna. If not, it should also be replaced. The cost of upgrading these components is much more economical than the cost of a new radar system.

The second recommended hardware/software upgrade, which has the potential to greatly improve the performance of the entire radar network, is an upgrade to dual polarization technology. Dual Pol has now become an accepted world standard in technology for the field of Doppler Weather Radar. See **Appendix 5E** for more explanation of the benefits of this technology.

A dual pol upgrade to existing radar will require, at a minimum, modification or upgrading of the following components:

- Antenna – additional waveguide must be attached
- Rotary Joints – must be upgraded to dual channel
- Slip Rings – must be upgraded to handle dual pol additional signals, if spare rings are not already available.
- Potentially, the Transmitter/Receiver, if it does not have capability to be upgraded to Dual Pol
- Digital signal processor/ radar control processor/software will require upgrading to handle the additional signaling and processing of the dual pol moment data

DMN should decide on the cost benefit ratio of performing these upgrades. The B&N Team recommends a separate study be performed to determine exactly which components would be affected by this upgrade, on a site by site basis.

The following is a list of radar manufacturers in the United States:

- Baron Weather Solutions
- EWR Weather Radar Systems
- Aero Express, Inc.
- Ambient Weather
- Eastern Avionics International
- Enterprise Electronic Corporation
- Radtec Engineering, Inc.
- Advanced Designs Corporation

Appendix 5F presents a listing of the potential manufactures and contact information.

The B&N Team makes no guarantees as to the capabilities of any of these manufacturers, and makes no particular recommendation. Each manufacturer must stand on its own merits and capabilities. DMN should decide, as in the past, which radar supplier can meet all of the requirements for performing upgrades to existing radar stations.

5.5. Analysis and Justification for Additional Radars

Figure 5.19 presents the approximate existing and proposed radar locations that are evaluated in Section 5.5. These locations are superimposed over mapping of the major river basins in the study area to aid in the discussion concerning new radar locations.

Figure 5.19 – Existing and Proposed Radar Locations in the Study Area

5.5.1. Power and Communications Considerations

Power and communications are essential in evaluating new radar locations. Communication does not appear to be a problem because of the excellent wireless telecommunications infrastructure in Morocco. In situations where terrestrial telecommunications are not possible, solutions are available to transmit data by way of satellite, such as VSAT. VSAT is not desirable to DMN because of the high cost of telecommunication charges. At most, if not all, telecommunications at the proposed radar locations will be handled by terrestrial based providers.

Power availability is more of a concern. Power availability was examined as part of the analysis of potential radar sites. Optimum radar sites do not always coincide with power availability, and power may need to be extended approximately 1 km to some proposed radar sites. This is more of a problem in mountainous terrain where optimum radar sites are more difficult to select.

Road access is also a key concern. Access is generally required for the site to be considered to be part of the national radar network.

An optimum radar site should not be avoided because of power and/or communications challenges. Even the lack of access to an excellent site is something that can be overcome. A radar site will serve the public safety and commercial interests of a country for the rest of time, so an agency implementing a radar network should not dismiss potential sites or compromise radar surveillance by choosing a lesser site that provides less meteorological information in exchange for power, communication, or access.

5.5.2. Assessment of Regions Where Weather Radar Coverage is Lacking

Based on the assessment criteria outlined in Section 5.1 and the capabilities of the current radar network, new radar locations were evaluated to improve the overall coverage of Morocco. Other physical and logistical criteria (such as terrain blockage, power availability, access to a communications link, etc.) were considered in the evaluation. The reports of Mr. Mohamed El Krimi are considered in the discussions. Several of Mr. El Krimi's maps depicting the occurrence of floods and the damage caused by floods are contained in **5B**.

5.5.2.1 New Potential Site North of the Current Agadir Site

The occultation analyses in **Figures 5.16** and **5.18** indicate significant beam blockage at 0.5° and 1.0° antenna tilts north of Agadir. Flood damage assessment maps (**Figures 5.B3, 5.B4** and **5.B5**) show that this is a key region for radar coverage. An airport at Agadir adds to the need for a radar to assess weather events to improve air safety. Repositioning the radar could improve the coverage at low tilt angles; however, an inspection of the terrain north and south of Agadir shows few if any sites that might offer the required logistical support. One option that would improve coverage over the mountainous region to the northwest through east of Agadir is to add a new site near the coast north of Agadir and west-southwest of the current Ben Guerir radar site. The site identified as Khemis Takate in **Figure 5.16** is a good possibility.

Floor and occultation analyses for the Khemis Takate site are shown in **Figures 5.20** and **5.21**. These plots show that beam blockage will not be a problem at this relatively high altitude site. Only some of the higher peaks in the Atlas Mountains to the east will result in ground clutter, but there should be no significant blockage by terrain close to the radar. A close inspection of the region displayed in **Figure 5.22** shows a minor road branching off of the main road that follows the ridge line and terminates at some type of facility at the top of the ridge (~709 m altitude). This suggests that power is also likely available. If the required logistical support is available this would be the preferred site for a new radar installation.

The new site would fill the current coverage gap north of Agadir with very good low altitude coverage of the Tamri, Cotiers Essouira and Tensift Basins. These basins appear in the damage assessment maps (**Figures 5.B4** and **5.B5**) and document losses of human life, highways, habitats, private industry and agriculture. The site therefore satisfies criteria 1, 2 and 3 from Section 5.1. A new radar at Khemis Takate would provide good offshore coverage not currently available from Bengrir and good coverage over the mountains north through east of Agadir (where the Agadir beam in currently blocked).

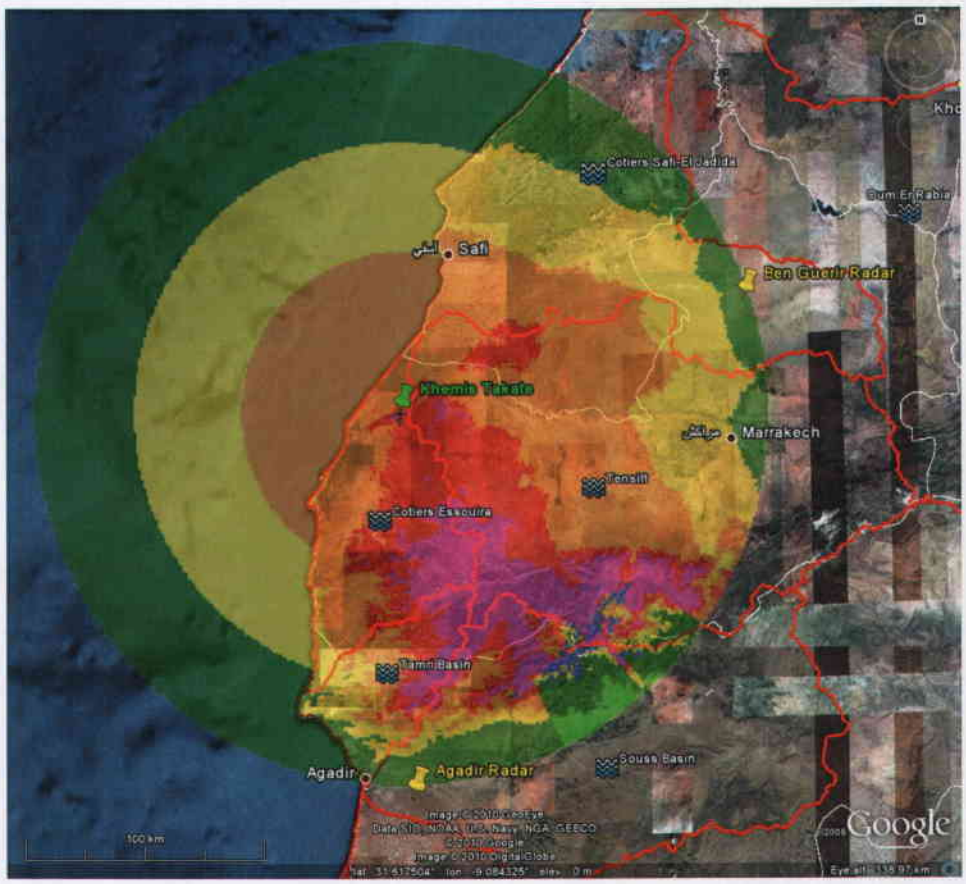


Figure 5.20 – Floor analysis for a proposed site near Khemis Takate. The current Agadir and Ben Guerir radar sites are shown.

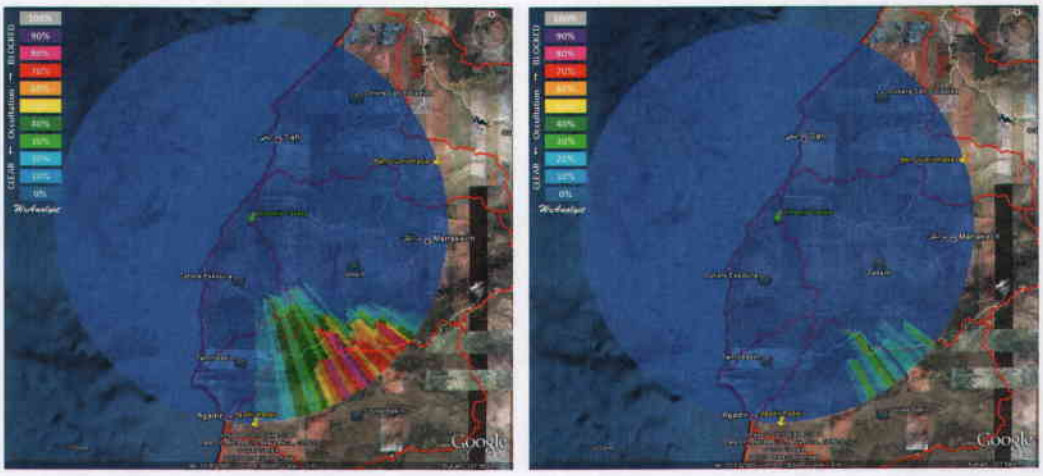


Figure 5.21 – Occultation analysis plots at 0.5E and 1.0E for the proposed Khemis Takate site north of Agadir

Figure 5.22 – Close-up view of the Khemis Takate site (orange symbol near image center) from the northeast. Site is at the top of a mountain ridge a short distance from the coast.

5.5.2.2 Potential New Sites for the Mediterranean Coast and Moulouya Basin

The next regions considered are the Mediterranean coastal region, including the cities of Nador and Oujda, and the Moulouya Basin. As shown in **Figure 5.18**, radar coverage is currently lacking in this area. This area has been assessed by DMN as an important region and a new radar near Debdou is being developed. The western parts of these regions have relatively high annual precipitation (> 600 mm) while the eastern area along the Moroccan border is quite arid (< 200 mm annually). A national flood assessment based on historical data indicates that numerous sites in this region have experienced flooding that resulted in loss of life, property and agriculture, and government infrastructure (**Figure 5.C3**). Also, storms in September and October 2008 broke longstanding rainfall records at Nador, Taza, and Oujda, and produced extensive flooding with loss of life and economic losses of about $23M.

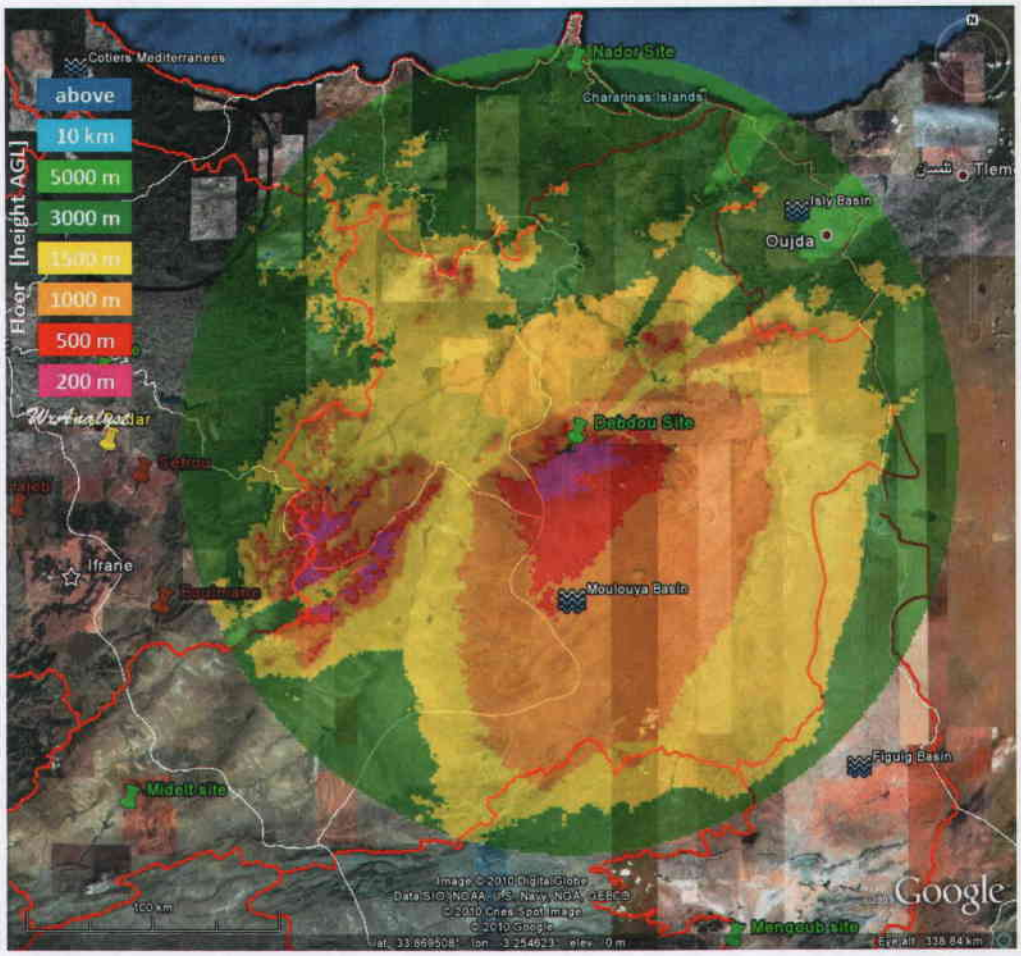


Figure 5.23 – Floor analysis plot for a site near Debdou. The current Fes site is shown as are potential sites at Nador, Midelt and Mengoub.

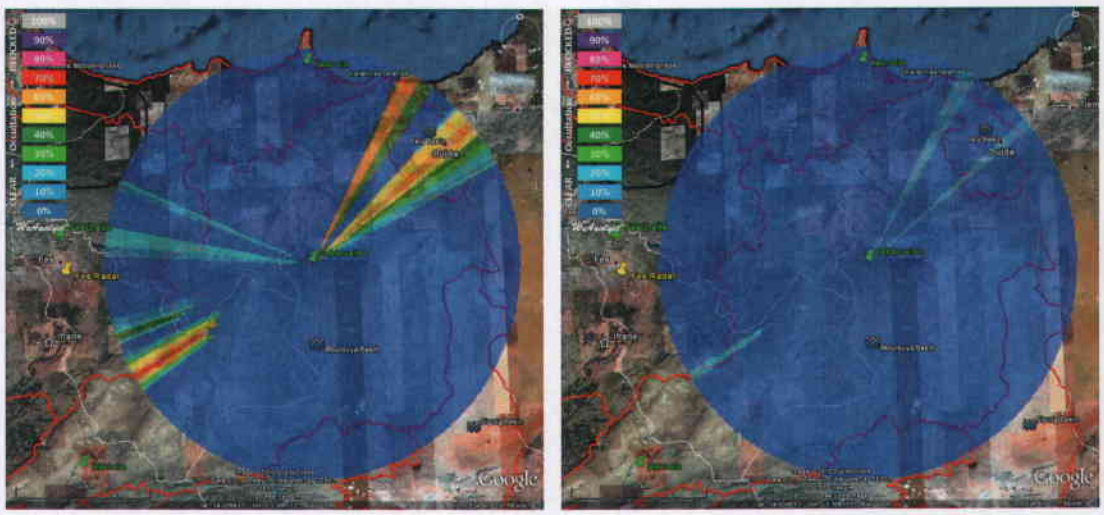


Figure 5.24 – Occultation analysis plots at 0.5E and 1.0E tilts for the proposed Debdou site east of Fes and south of Nador.

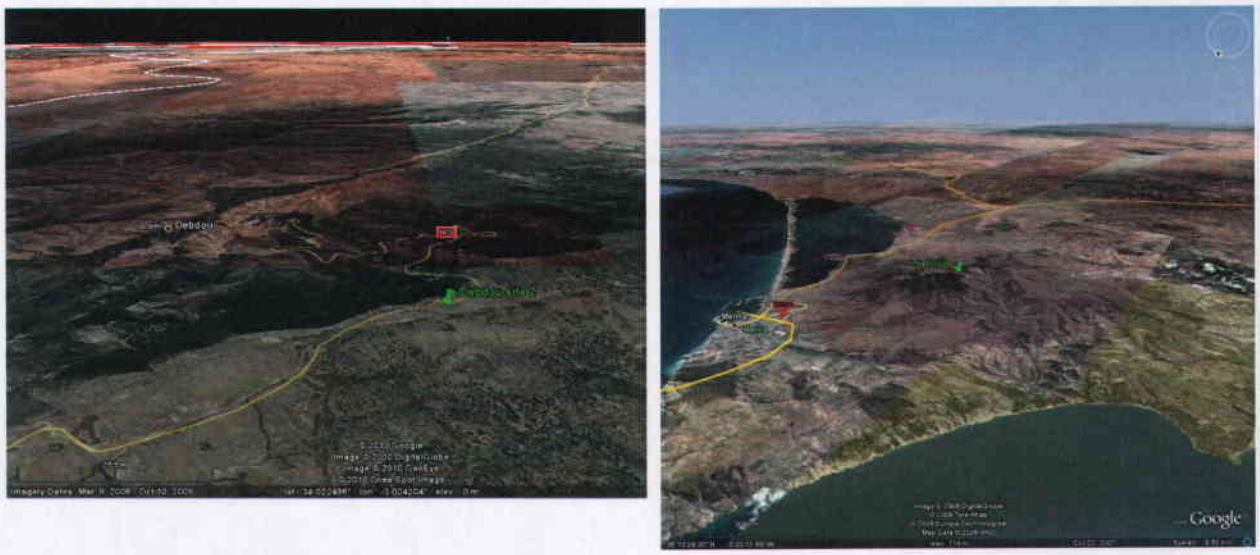


Figure 5.25 – Close-up views of two potential radar sites in the Mediterranean and Moulouya Basin regions. Left: View from the south of the Debdou site. **Right:** View from the north-northwest of a possible coastal site (green pin) near Nador on a hilltop (862 m altitude) that would have an unobstructed view in all directions.

The Debdou site is one of the highest priorities for a new site, primarily because of satisfying Criteria 1 and 2. The Debdou site provides improved surveillance of weather systems approaching Morocco from the Mediterranean and some improvement to forecasts for coastal regions (Criteria 3 from Section 5.1). However because of the height of the proposed site (1628 m) detection of shallow cloud systems would be marginal since the 0.5° elevation beam would be above 3 km AGL near the coast. This is illustrated by the floor and occultation plots in **Figures 5.23** and **5.24**. The Debdou site would provide only marginally useful coverage over the airports at Nador and Oujda, because the lowest beam tilts would be 3000 m or higher over these cities and provide no useful data on low level wind shear. For better offshore radar surveillance and support of airport activity, a coastal radar site would provide more effective coverage.

Figures 5.23 and **5.24** show that the proposed Debdou site has only minor blockage and good low level coverage over the mountains west of Debdou. Low elevation scans from Debdou would greatly improve the detection of storms in the mountainous regions of the Moulouya Basin, and the bulk of the Moulouya Basin south of Debdou would be well covered with beam height to terrain distances generally less than 1500 m. Because terrain drops off rapidly to the north through northeast of Debdou, the beam to terrain distance exceeds 1000 m beyond about 50 km range. Over the Isly Basin and the area around Oujda beam heights exceed 3000 m AGL.

A close-up view of the Debdou site is shown in the left panel of **Figure 5.25**. There appear to be no local obstructions such as vegetation or buildings and the site is quite close to an existing road. The town of Debdou is visible in the valley below the site.

In the Mediterranean coastal region a potential radar site near Nador is shown in the right panel of **Figure 5.25**. The site is on an isolated hill with a road leading to a facility at the summit. The floor and occultation plots for the Nador site are shown in **Figures 5.26** and **5.27**. The site would improve the radar network in several ways, and satisfies four of the five criteria for assessing site priorities. It would cover a region noted with numerous damage assessments from extreme flood events, including loss of life (**Figure 5.B5**), and also would cover several specific sites assessed with high flood risk (**Figure 5.B3**).

Figure 5.26 indicates the coverage of the coastal regions, including Oujda and the Isly Basin, and the northern part of the Moulouya Basin, would be at beam to terrain heights generally below 1000 m, much better than the coverage from the higher Debdou site to the south. A radar at Nador would also greatly improve surveillance of storms coming off of the Mediterranean; a region not covered by the current network, and improves DMN short term forecasts and warnings for these storm systems. This site would be within 26 km of the airport at Nador and potentially improve warnings related to aircraft safety.

A second coastal site has been considered to fill the current gap in radar coverage over the western portion of the Mediterranean, and the high flood risk area around Tetouan where the current Larache radar beam is blocked at the lowest antenna tilts (see **Figures 5.2** and **5.3**). The floor and beam occultation plots for a potential site near Fnideq for shown in **Figure 5.28** and **5.29**. Although the high terrain to the west through south-southeast of the site blocks beam tilts at and below 1.5°, this region to the west of the high terrain is effectively covered by the Larache radar. The improvement gained by a radar at Fnideq is the low altitude coverage of the Cotiers Mediterranees Basin, an area with high flood risk (**Figure 5.B3**) and multiple damage assessments, including loss of life, from past floods and extreme flood events (**Figures 5.B4** and **5.B5**). In combination with a new site at Nador, the coverage over the Mediterranean would be nearly complete to the coast of Spain, the southern tip of Spain, and a portion of the Atlantic Ocean including the Strait of Gibraltar. **Figure 5.31** shows a close-up view of the potential Fnideq site and indicates the Fnideq site is in a well-developed area with roads and other infrastructure that is needed to support a radar.

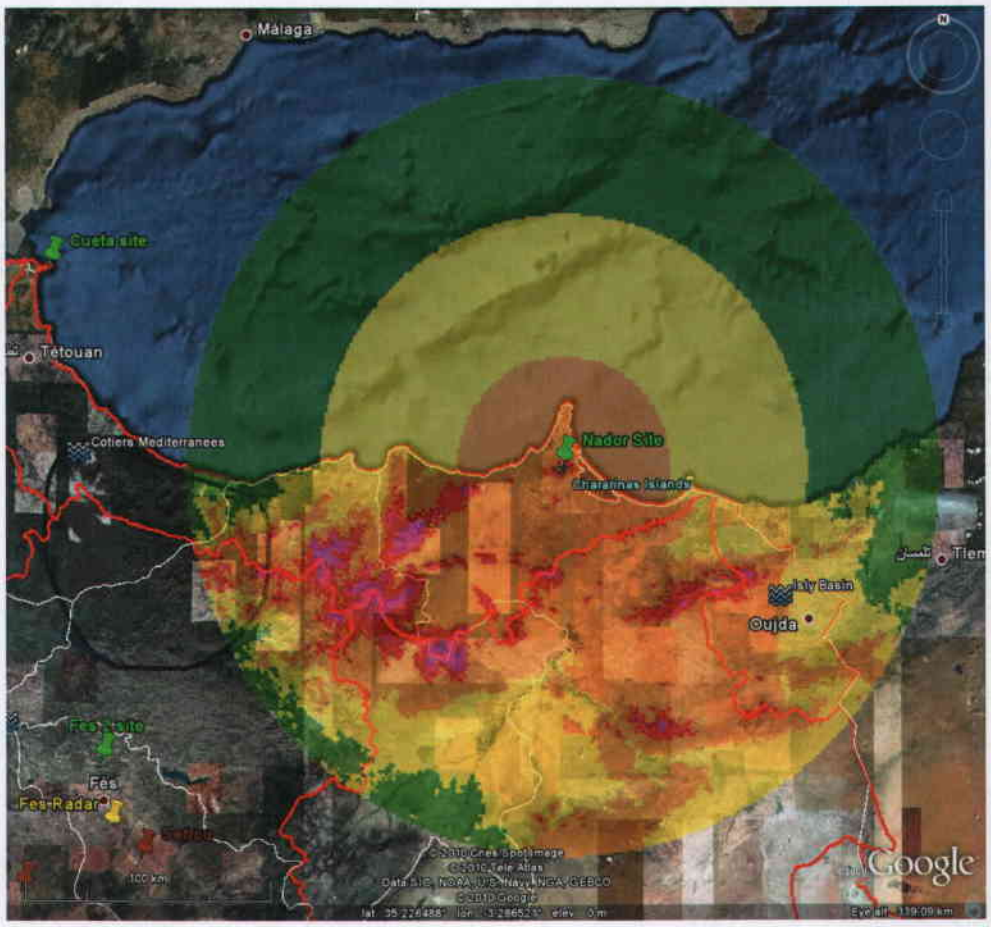


Figure 5.26 – Floor analysis plot for a potential radar site near Nador. The current Fes site is shown as is a potential site at Fnideq just north of Tetouan. The region having the highest annual precipitation in Morocco is outlined in black.

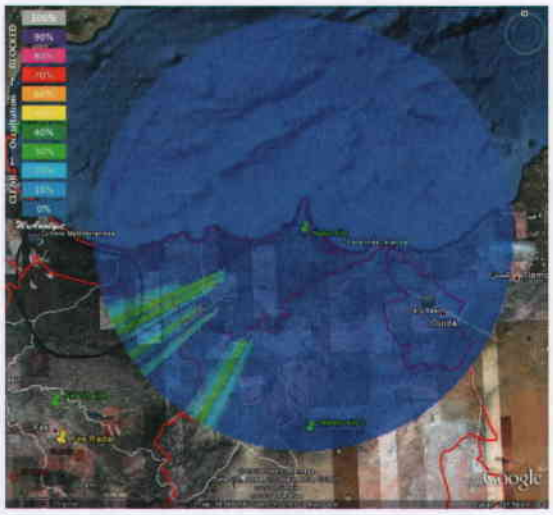


Figure 5.27 – Occultation analysis at 0.5E tilt for a potential new radar site at Nador. No blockage was noted above 0.5E.

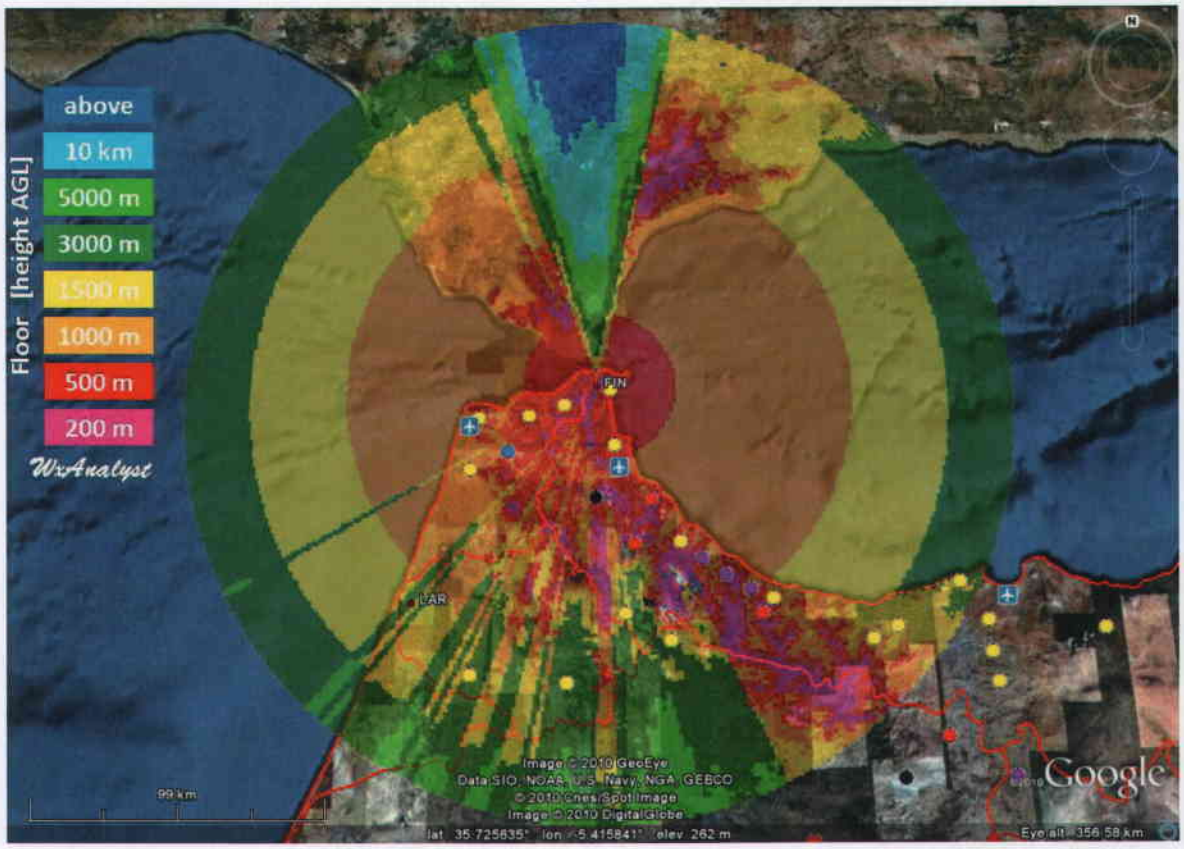
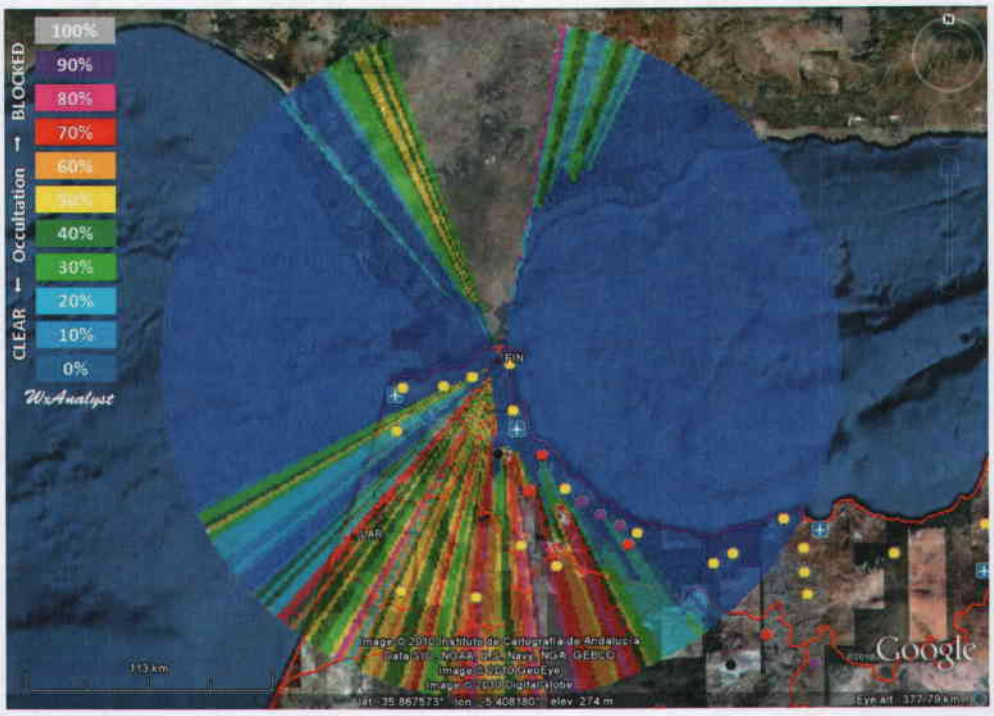


Figure 5.28 – Floor analysis plot for a potential radar site near Fnideq. The current Larache site is also shown.



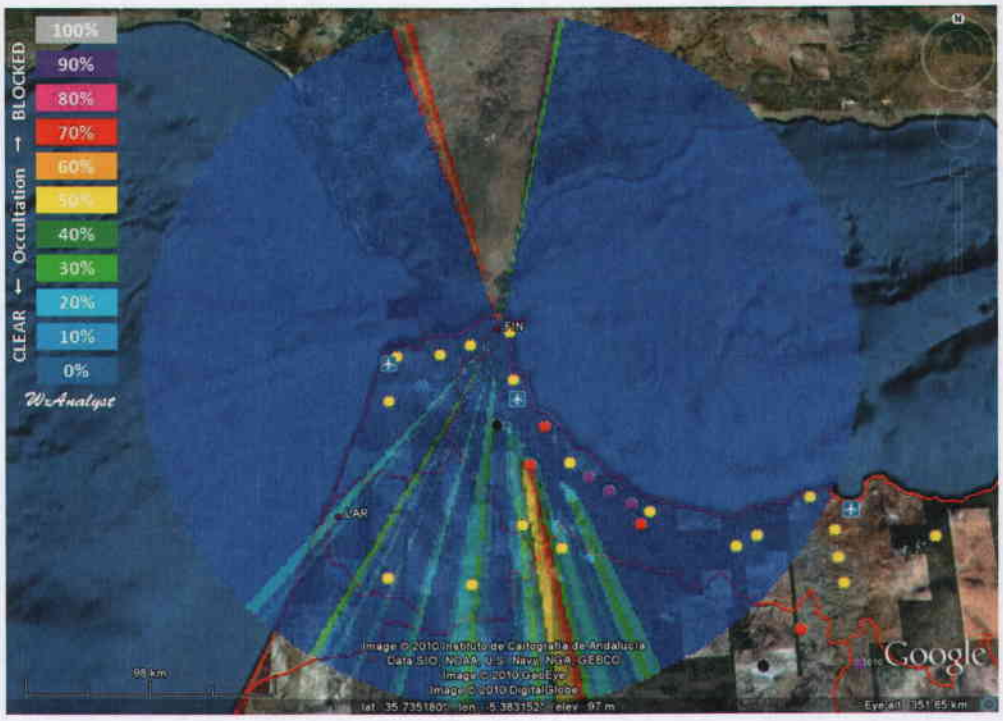


Figure 5.29 – Occultation analysis at 1.5E tilt (top) and 2.0E tilt (bottom) for a potential new radar site at Fnideq.

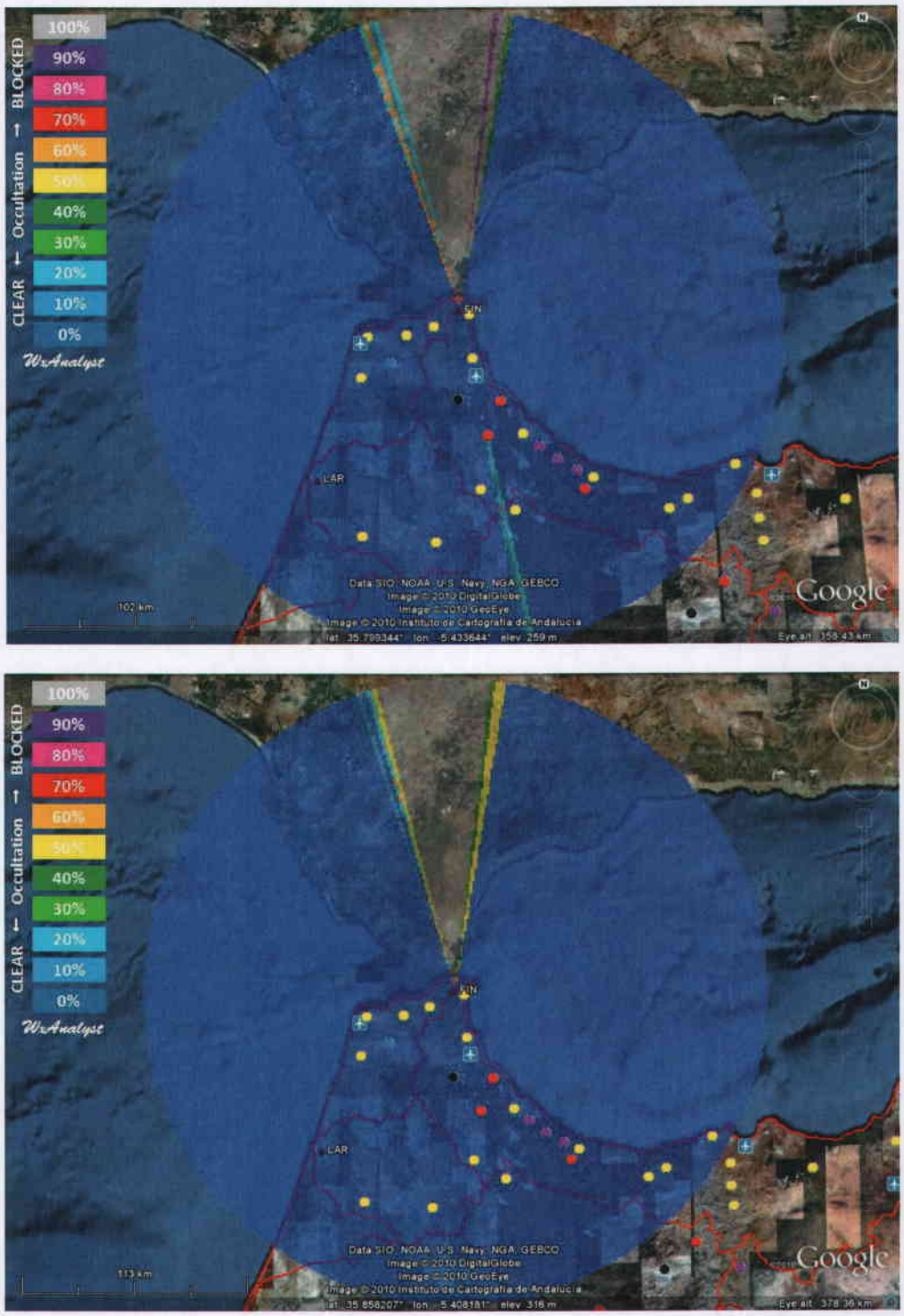


Figure 5.30 – Occultation analysis at 0.5E tilt (top), 1.0E tilt (bottom), 1.5E tilt (lower left) and 2.0E tilt (lower right) for a potential new radar

Figure 5.31 – Close-up views of a potential radar site near Fnideq.

5.5.2.3 Potential new sites for the southern portion of the Moulouya Basin, the Figuig, the Guir and the Ziz-Rheris Basins

As shown in **Figure 5.18**, to the east and south of the Moulouya Basin are the Figuig, Guir and Ziz-Rheris Basins. These basins have no coverage from the current radar network. In addition, the proposed Debdou site does not cover the southern portion of the Moulouya Basin. As with other basins on the east side of Morocco, these are relative dry regions which receive about 300 mm of annual precipitation at the eastern edge of the Atlas Mountains and less than 100 mm near the eastern border of Morocco (**Figure 5.B1**). Flood risk areas shown in **Figure 5.B3** are mostly in the southern part of the Moulouya Basin and in the southeast part of the Ziz-Rheris Basin. The damage assessment maps in **Figures 5B 4** and **5.B5** indicate a significant cluster of damage sites, including ones with loss of life, in the Ziz-Rheris Basin. The towns of Errachidia and Erfoud are within this cluster and Criteria 1 and 2 for prioritizing radar sites are applicable for this region.

Within the Figuig and Guir Basins no damage from flood or extreme flood events are noted **Figures 5.B4** and **5.B5**. So, the selection Criteria 1 and 2 do not apply. Extending radar coverage in this area will support and otherwise contribute to an improvement in forecasts by DMN, while also filling a gap in the current radar coverage.

To improve coverage over the southern portion of the Moulouya Basin, a relatively high altitude (1621 m) site at Midelt is proposed. The floor height and occultation plots are shown in **Figure 5.32**. The floor pattern indicates good low beam to terrain coverage along the southwest-northeast axis of the drainage containing Midelt. Relatively good coverage extends to the Atlas Mountain crest to the west where the coverage overlaps with coverage from Fes and Khouribga radars. The main advantage of the Midelt site is the extension of coverage over the southern portion of the Moulouya Basin, where the flood risk was highest and flood damage losses were the greatest. The site also provides low level (<1000 m AGL) coverage of a portion of the agricultural and hail suppression project area around Boulmane (assessment factor 5 in Section 1). Because higher tilts are needed to clear the terrain to the south of Midelt, the coverage of the Ziz-Rheris and Guir Basins is poor with the beam height being 1500 – 5000 m above the terrain. The Midelt site was initially proposed on a small mesa west of the town of Midelt (see top panel of **Figure 5.34**) a short distance from a main road. This proposed site was moved into the town of Midelt because of lack of access at the initial Midelt site. There did not appear to be a significant difference in the occultation and floor analysis to justify the extra expense to develop access at the initially proposed Midelt site.

Installing a radar at the Midelt site would eliminate the need to move Fes to Fes-2. This would allow the Fes Radar to remain near the airport providing excellent surveillance of the area around Fes, including approach and departure routes. Midelt would provide excellent coverage back towards Fes, filling in the area that is currently blocked by terrain. If the Fes-2 site is commissioned, then the need for Midelt is reduced, as the Fes-2 site would provide coverage back to Midelt.

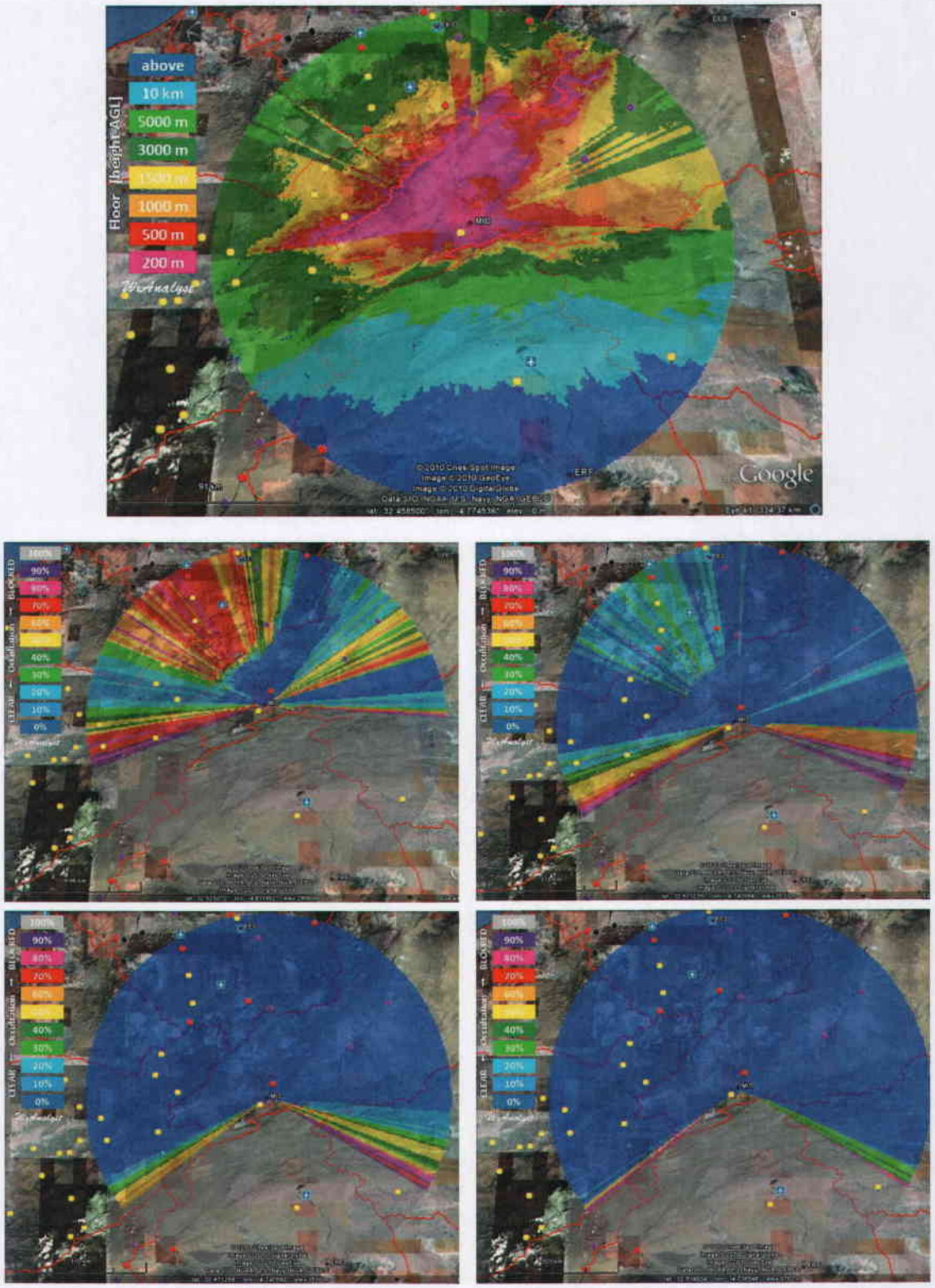


Figure 5.32 – Floor analysis plot (top) and occultation plots at 0.5E, 1.0E, 1.5E and 2.0E tilts for a radar site at Midelt in the southern Moulouya Basin. Tilts to 3.0° gave patterns similar to 2.0° (lower right).

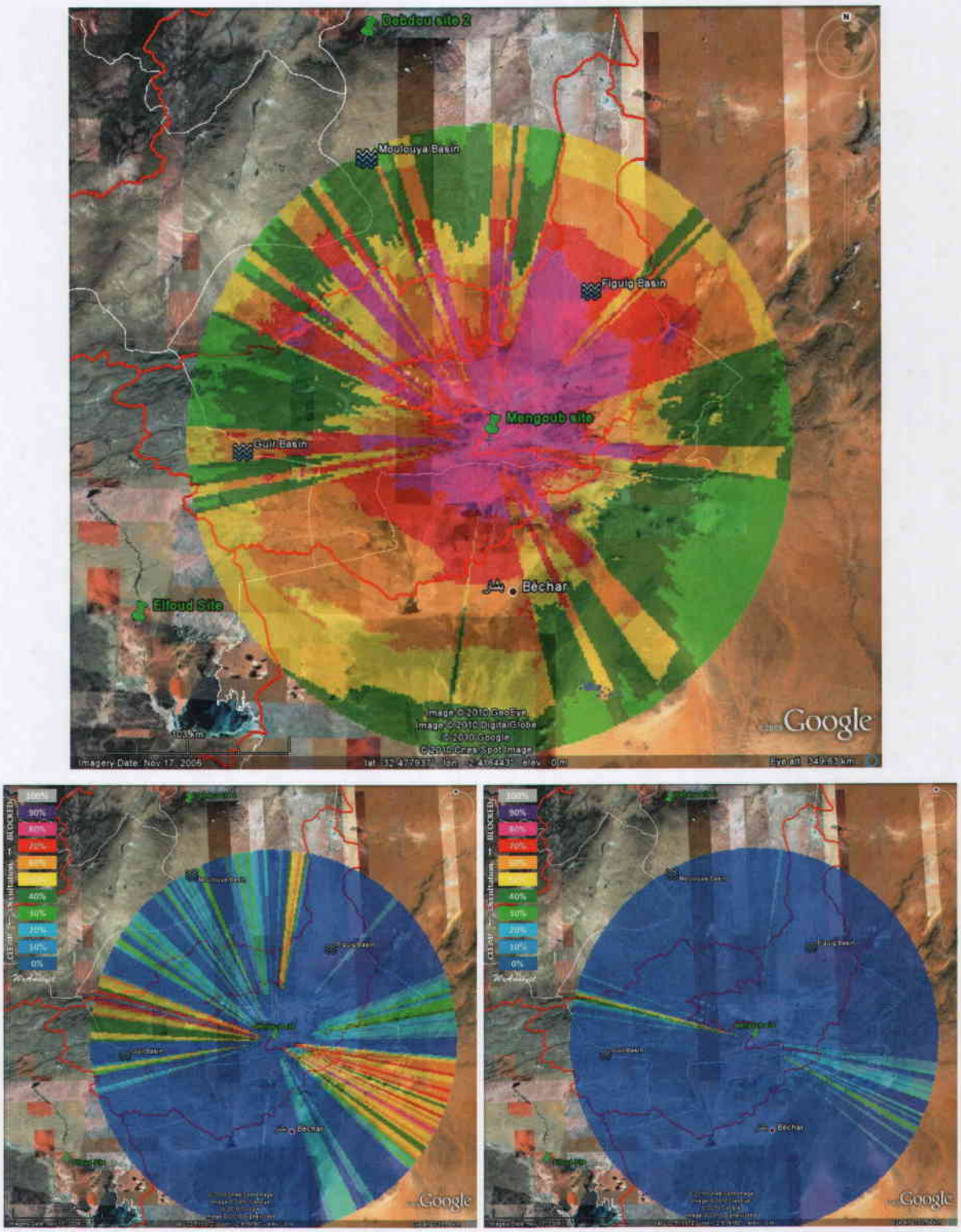


Figure 5.33 – Floor analysis plot for a radar site at Mengoub (top). Floor plot also shows potential new radar sites at Debdou and Elfoud. The occultation plots for 1.0° and 1.5° tilts are shown in the lower left and right panels. The 0.5° tilt is severely blocked in nearly every direction and is not shown.

Figure 5.34 – Close-up views of the Midelt site (top, looking northwest), the Mengoub site (center, looking north), and the Erfoud site (bottom,

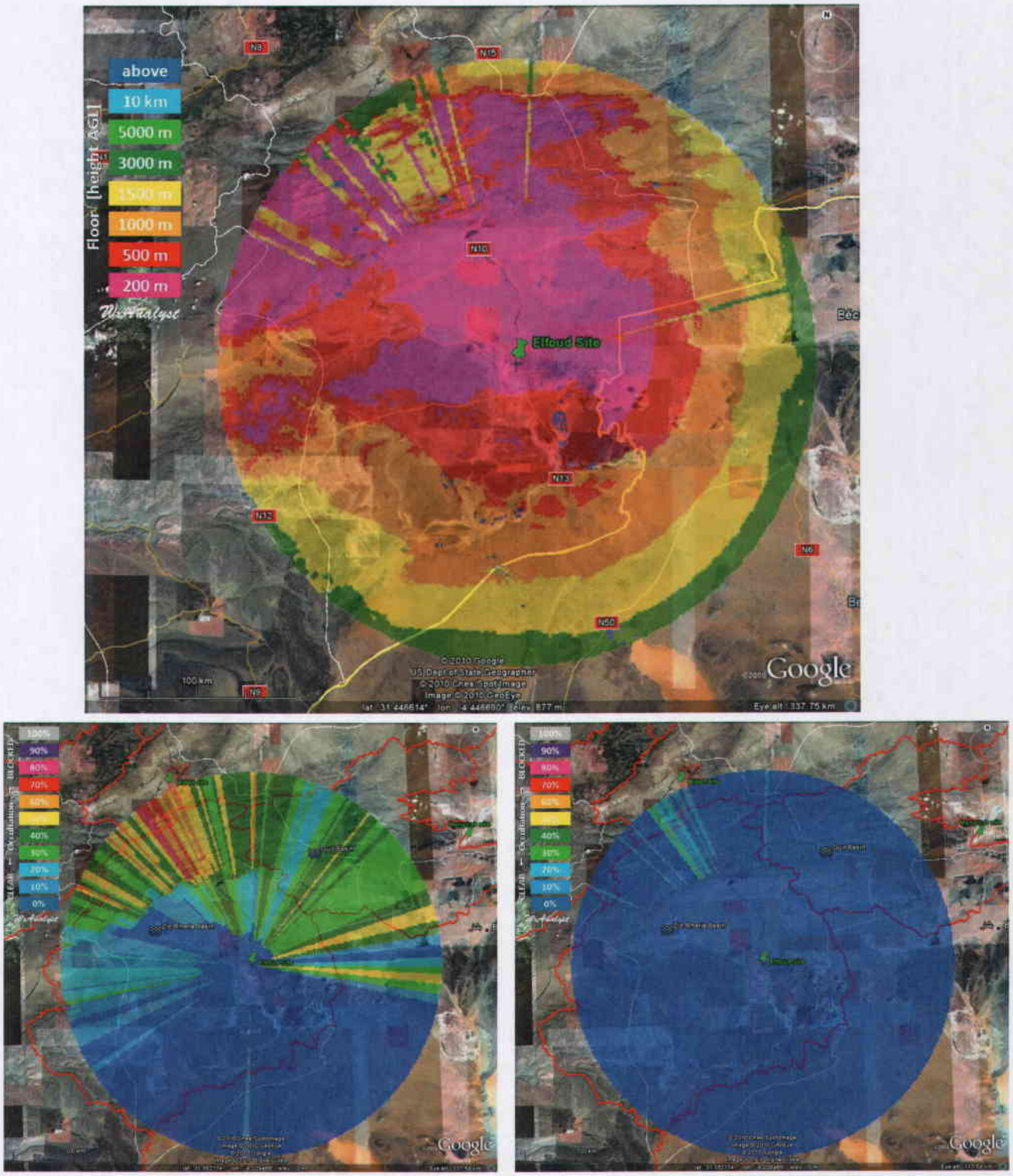


Figure 5.35 – Floor analysis plot for a radar site at Erfoud (top). Floor plot also shows potential new radar sites at Midelt and Mengoub. The occultation plots for 0.5° and 1.0° tilts are shown in the lower left and right panels. Tilts above 1° showed no evidence of blocking.

Radar coverage over the Figuig and Guir Basins can be accomplished with a radar sited at Mengoub. The floor height and occultation plots for Mengoub are shown in **Figure 5.33**. The floor analysis indicates that the Figuig Basin is covered relatively well with beam to terrain heights generally less than 1000 m. Coverage of Guir Basin is nearly complete with a radar at Mengoub, but several spokes of higher above-ground beam heights are present due to blocking by some nearby small scale terrain features. In the southeast quadrant, low altitude coverage extends only a short distance beyond the eastern border of Morocco. The site is in a rural area south of the small town of Mengoub (see middle panel of **Figure 5.34**). There is no existing infrastructure at the site, but a main road is a few hundred meters to the west. Of the three radars suggested in the section, this site would have lowest priority based on the lack of good socio-economic criteria.

Radar coverage of the Ziz-Rheris Basin and the western part of the Guir Basin can be accomplished with a radar sited at Erfoud. The floor height and occultation analyses are shown in **Figure 5.35**. Since terrain gradually rises from Erfoud to the west through north, beam to ground heights less than 500 m extend out to 150 km. The exceptions are some spokes of greater height values beyond about 80 km where the 0.5° tilt is partially blocked by a ridge. Note that at 1° tilt the Erfoud coverage fills in the relatively poor coverage in the southern part of the Midelt coverage (**Figure 5.32**). Coverage from Erfoud would encompass the cluster of assessed damage sites shown in **Figures 5.B4** and **5.B5**, which includes the populated region of Errachidia. These criteria and the fact that this site would fill a large gap in the current network would make the addition of this site a relatively high priority. The site is on a ridge south of the town of Erfoud with road access and a small existing facility in the cleared area on top of the ridge (see **Figure 5.34**).

5.5.2.4 Potential new sites for the Draa Basin

The Draa Basin is situated in the Ouarzazate region, south of the Ziz-Rheris Basin. Radar coverage is lacking in the Draa Basin of the Atlas Mountains. The current Bengrir radar covers part of the region up to the mountain crest from the west, but the beam height east of the mountains is too high to allow routine detection of storms over the Ouarzazate Basin (see **Figures 5.8** and **5.9**). Ouarzazate is the key city near the junction of the Oued Dades and the Oued Draa. The main airport for this region is also in the city of Ouarzazate. The Oued Draa originates in the High Atlas Mountains about 75 km west of Ouarzazate. As in the basins to the north, annual precipitation exceeds 600 mm in the mountains, while the east side of the basin receives less than 50 mm. The average over the entire Draa Basin is 120 mm.

Figure 5.B3 shows that several historic flood events have occurred in this region, although considerably fewer than in basins to the west and north. The damage maps (**Figures 5.B4** and **5.B5**) also show less than other regions, although this basin did not appear to have one of the key "representative" sites for the country-wide disaster assessment. This region also appears to have escaped the serious flooding events of September/October 2008. Part of the reason for fewer documented socio-economic losses could be the relatively small population (4% of Morocco's total) that is predominantly rural, and the relatively small agricultural and industrial production of this region.

The Ouarzazate region should be considered a priority site for a new radar because of the current lack of coverage, but with somewhat lower priority than the Moulouya and Ziz-Rheris regions, due to the lower incidence of disastrous flood events causing loss of life and property damage. Also the rural character of this region will limit the number of available sites that satisfy land, power and communication requirements. The city of Ouarzazate has the necessary infrastructure for a radar installation, so it is the first recommendation for a radar site. The proposed site is on a small hill with no existing infrastructure, but very close to the main road. **Figure 5.36** shows a view of the site from the east-southeast, looking toward the higher terrain.

Figure 5.36 – View of the Ouarzazate site from the east-southeast, looking toward the higher peaks of the Atlas Mountains.

On the negative side of site selection criteria, the Ouarzazate site has some relatively serious terrain blocking problems. **Figure 5.37** shows the potential coverage area in the floor eight and occultation plots. Over the high terrain to the west, coverage overlaps well with coverage from Ben Guerir (**Figure 5.8**), effectively filling in the gap over the upper Draa Basin. As shown in **Figure 5.37**, the 2° tilt clears almost all the blocking terrain at close range. This would be the best tilt for monitoring precipitation over the mountains since the beam center to terrain distance remains relatively constant, and generally less than 500 m, out to about 90 km. Coverage at tilts of 1.0° and higher from west-southwest clockwise through northeast is relatively free of terrain interference, but since the terrain slopes downward in these directions the beam height above terrain is above 1500 m beyond about 75 km.

If logistical support was not an issue, a site further to the east might be preferable since it would eliminate most of the blockage problem. However, on the road between Ouarzazate and Zagora, the small rural communities appear to be within a relatively narrow river valley whose sides would also block the lower beam tilts at close range. Attaining a site on higher ground would likely require a new road and the extension of power and communication to such a site.

The Draa Basin extends far south of the Ouarzazate region, eventually to the Atlantic Ocean near Tan Tan. The north-south length of the entire basin prevents the region from being covered by a single radar such as the one proposed at Ouarzazate. A second site southwest of Ouarzazate will be needed. The lower part of the basin is quite dry with annual precipitation being less than 50 mm in the east near the Moroccan border, and about 100 mm on the Atlantic Coast at Tan Tan (**Figure 5.B1**).

Figure 5.B4 presents historical flood events for the area that includes the towns of Guelmim, Ifni, Tadalt and Assa with habitat and structural damage. There is documentation of damage amounting to more than $21M at Guelmim from a 1995-96 flood event. Several of the 391 sites evaluated for extreme events are found in this region, but no specific damage is indicated by the map "spots" in **Figure 5.B3.**

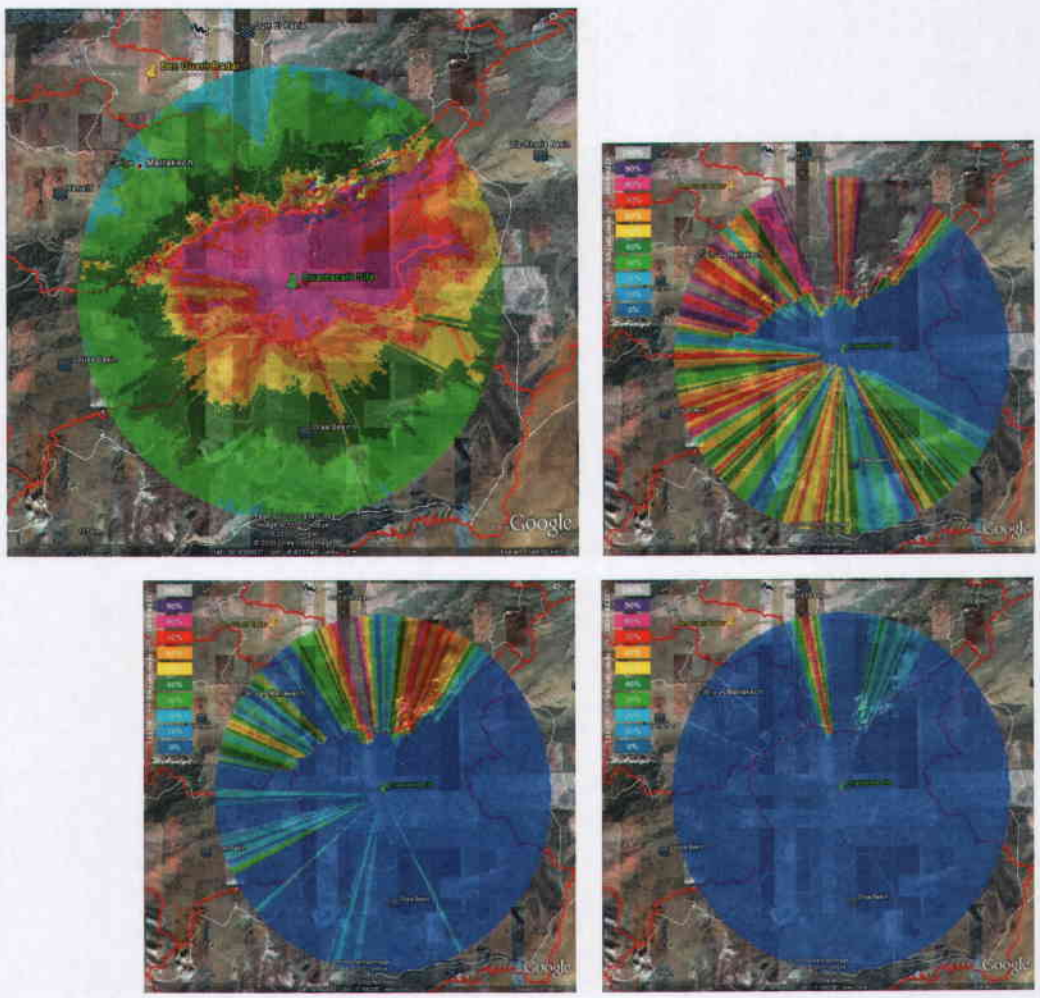


Figure 5.37 – Floor analysis plot (top) and occultation plots, clockwise from upper left, at 1.0E, 1.5E and 2.0E tilts for a radar site at Ouarzazate in the northern Draa Basin. The 0.5° tilt (not shown) was almost entirely blocked.

This region would benefit from expanded radar coverage, and two site possibilities were examined. The first is a coastal site at Tan Tan Airport. A view of the Tan Tan site from the southwest is shown in **Figure 5.38**. The floor and occultation analyses for Tan Tan are shown in **Figure 5.40**. Advantages of the site include overlapping coverage with the current Agadir radar, good offshore coverage, and potentially good logistical support (land, power and communications) at the small airport. Inland from the site the terrain slopes upward and **Figure 5.40** show some minor blockage at the 0.5° tilt by a ridge to the east, but no significant blockage above this lowest tilt. Over land the beam to terrain heights are generally less than 1000 m. A Tan Tan site will provide coverage of the southern portions of the Draa and the Cotiers Guelmim-Tiznit Basins, and the extreme northern part of the Southern Provinces.

Figure 5.38 – View of the Tan Tan Airport site from the southwest. The Oued Draa is visible to the north just east of where it enters the Atlantic Ocean.

The second site considered is near Guelmim about 129 km northeast of Tan Tan. Both Tan Tan and Guelmim, combined with the Agadir and Ouarzazate radars, would provide radar coverage over sites that have experienced extreme weather events (**Figure 5.B3**). **Figure 5.41** shows the floor and occultation plots out to a range of 150 km from Guelmim. There is considerably more coverage overlap with the Agadir radar than from Tan Tan, and coverage is also more complete over the southern portion of the Draa Basin. Guelmim would provide complete coverage of the Coltiers Guelmim-Tiznit.

Figure 5.39 – Close-up view of the Guelmim site from the south. Note the Atlantic Ocean in the upper left part of the image.

Figure 5.41 indicates that terrain to the northeast will partially block the 0.5° tilt, but the 1° tilt has generally 10% or less occultation in this direction. The more significant blockage to the north at 1° results in the greater than 1000 m beam heights, but this region is covered at much lower heights above ground from the Agadir site (see **Figure 5.16**). The specific site location is shown in **Figure 5.39**. In this view from the southwest it is obvious that the site is on a ridge (~586 m altitude) above the town of Guelmim (284 m altitude). There is a road to the location, existing facilities, and one or more communications towers at the site. The site appears to satisfy most logistical requirements, but the compatibility of the existing communications with microwave transmissions from a weather radar is not known and will need to be determined.

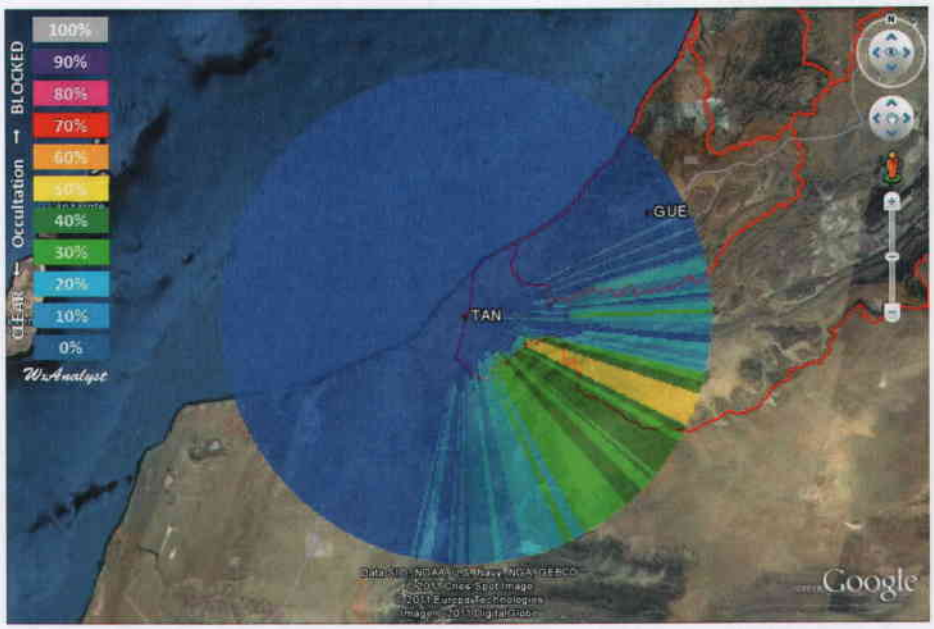
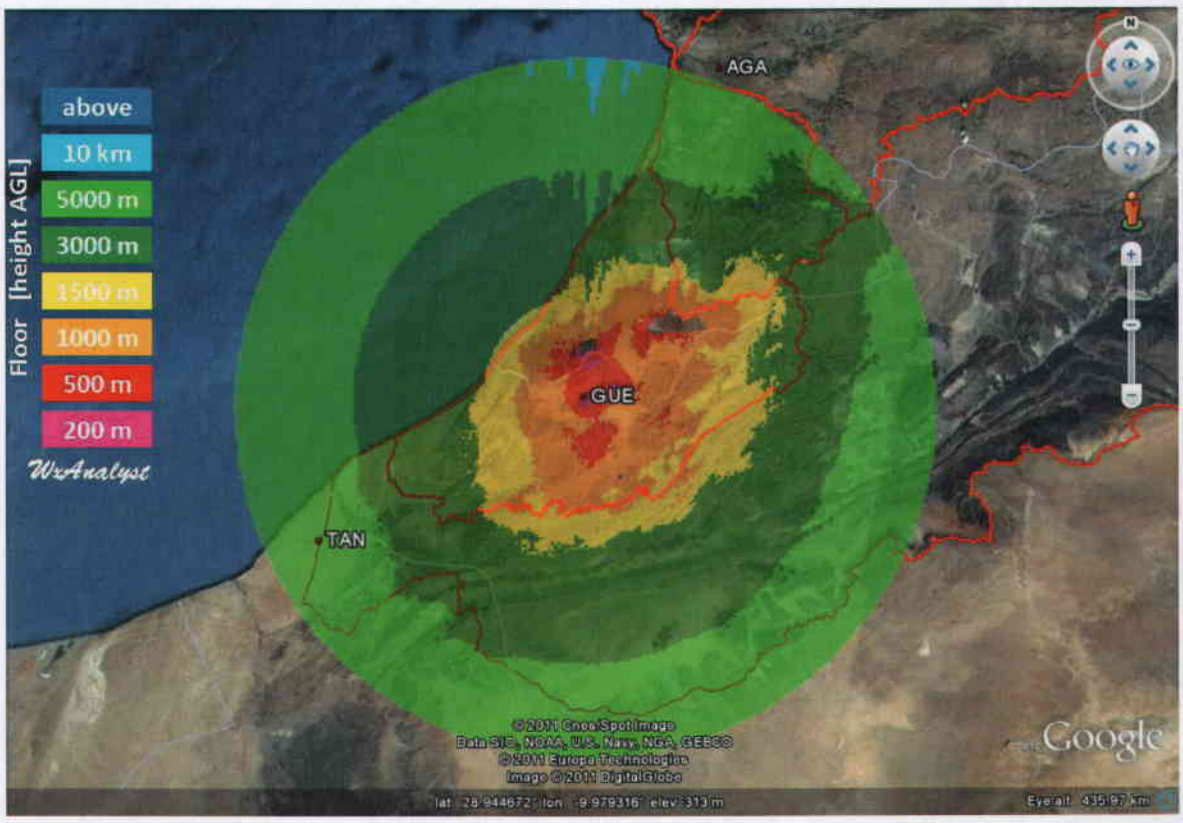


Figure 5.40 – Floor analysis plot for the potential radar site at Tan Tan. Also shown are two other potential sites at Guelmim and Laayoune. The occultation plot for the 0.5° tilt is shown in the bottom panel. Tilts above 0.5° showed no blockage from terrain.



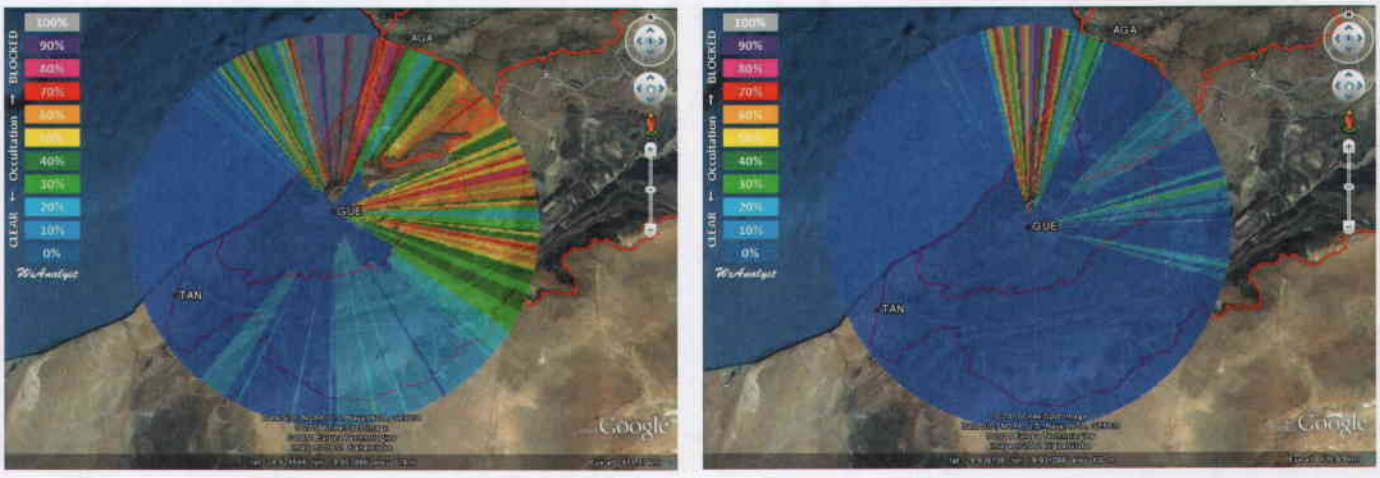


Figure 5.41 – Floor analysis plot (top) and occultation plots at 0.5E and 1.0E tilts for the proposed Guelmim radar site in the southern portion of the Draa Basin. Agadir and Tan Tan sites are indicated.

5.5.3. Proposed Radar Coverage in Relation to the Assessment of Flood Risk in the Study Area

The design of the expansion of the Moroccan weather radar network was based on a comprehensive study of weather events that contributed to socio-economic losses. These socio-economic losses consisted of not only losses of life, but also property, commercial productivity. **Figure 5.42** shows areas that have suffered losses from weather related events. The color coding relates to the frequency of weather threats at a given point. The black spots identify localities where the greatest threat from weather related events exist. The occurrence of weather related events are considered to be very high at black spots. Red spots represent localities that have weather related threats that are "high" rather than "very high" as in the case of the black spots.

The next less severe category is indicated by purple spots, which is considered to have average threats from weather related events. The purple spots are considered to be an indication of an average weather related threat. The blue spots identify moderate threats to weather events while the green spots indicate negligible weather related threats. The final category is indicated by yellow spots from which there is no detailed information about the weather threats, except that the locality is subject to threats from weather related events.

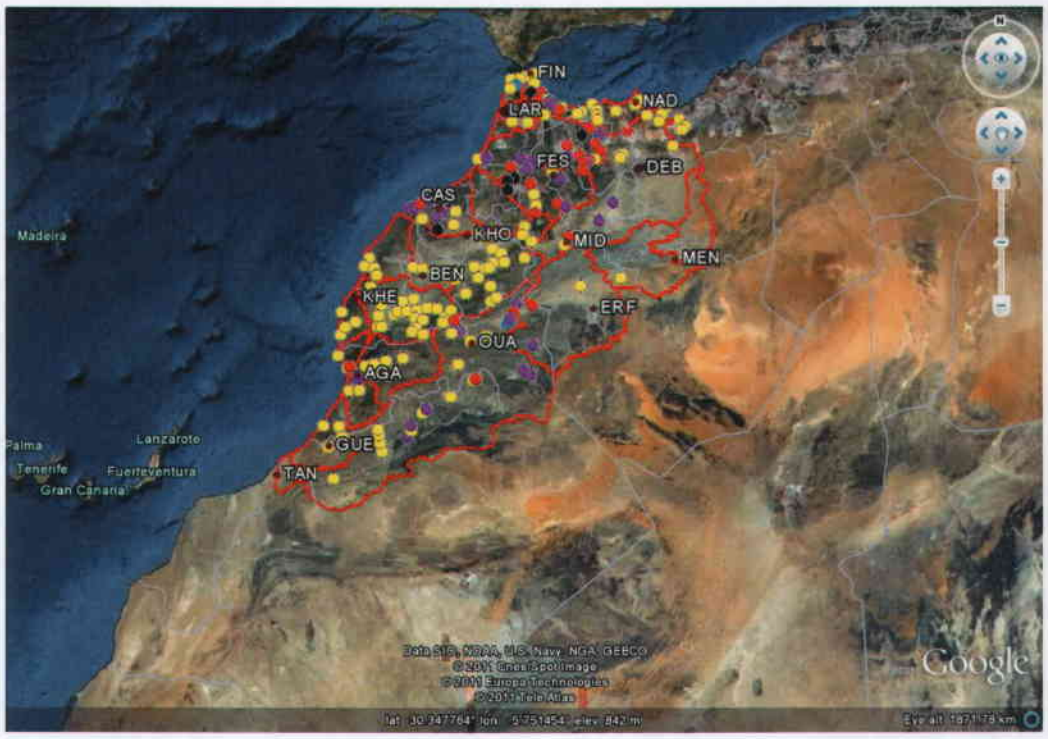


Figure 5.42 – Threat assessment analysis. These points identify areas where there has been socio-economic losses due to weather related events.

Figure 5.43 overlays the floor height analysis with the threat assessment analysis for the Study Area. The color bands on the floor analysis correspond to the height of the lowest altitude measured by the radar. The purple area is 200 m and below, the red area is 500 m and below, the orange area is 1000 m and below, with the yellow area is 1500 m and below, and the green area is 3000 m and below. It is very important that the areas of great threat are covered by radar with a relatively low floor height.

The proposed new radar locations, combined with the existing radar network provide a significant improvement to coverage in the northern part of Morocco. The threat areas and "black spots" in the Rif Mountains are covered better under radar surveillance with the proposed network. Other threat area in the vicinity of the Middle Atlas that produce destructive floods in the mountains and the river reaches downstream of the headwaters are also addressed with the proposed radar configuration. Moving the FES site helps provide much improved coverage in the mountains. The new FES site, named FES-2, floor analysis can be found in **Appendix 5A** with the rest of the floor analysis for the proposed radar network.

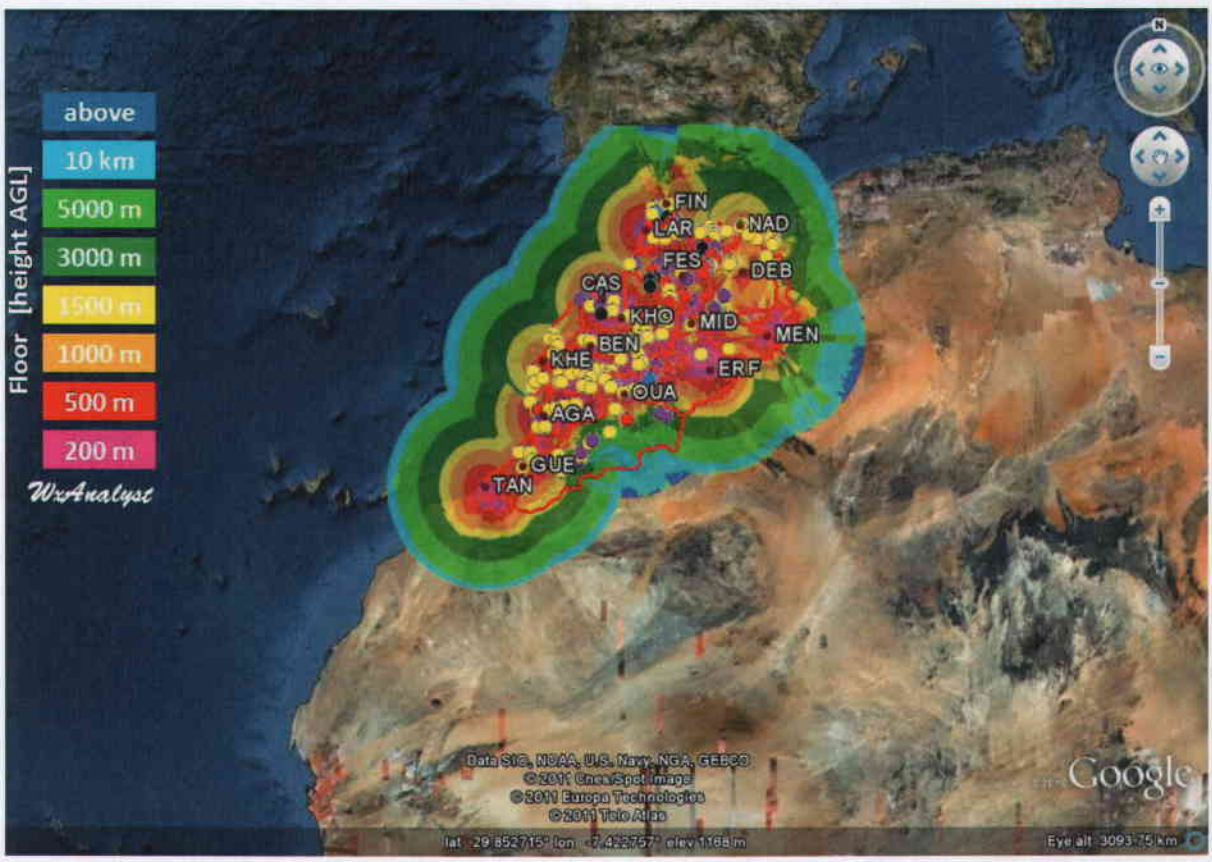


Figure 5.43 – Flood risk points with Floor Analysis from enhanced Radar network for the Study Area

Other "black spots" west of the Middle Atlas and in the vicinity of Casablanca are also well within the surveillance of the enhanced radar network. There could be an argument to improve the coverage in the area of Rabat, and the mountains to the east of Rabat, by placing a radar in Rabat. This would allow for radar coverage at lower altitudes and help monitor "black spots" area to the east.

5.5.4. Proposed Radar Coverage in Support of Civil Aviation

Another purpose of the radar network is to support the civil aviation sector. Several radars from the existing network were located within close proximity to major airports. **Figure 5.44** presents a map of northern Morocco with the location of the various airports shown along with the mosaic floor analysis. The major airports are all within the coverage area of the weather radars which will assure that weather events that may affect flight operations will be monitored by the proposed network.

In examining the climatological data there didn't seem to be just cause for a Terminal Doppler Weather Radar (TDWR), though our team is prepared to add the specification for TDWRs where wind shear and downbursts may be prevalent. In lieu of using radar to monitor these microscale and mesoscale conditions, an enhanced surface monitoring network (surface wind measurements and wind profilers) can be used to detect hazardous wind conditions in the vicinity of airports.

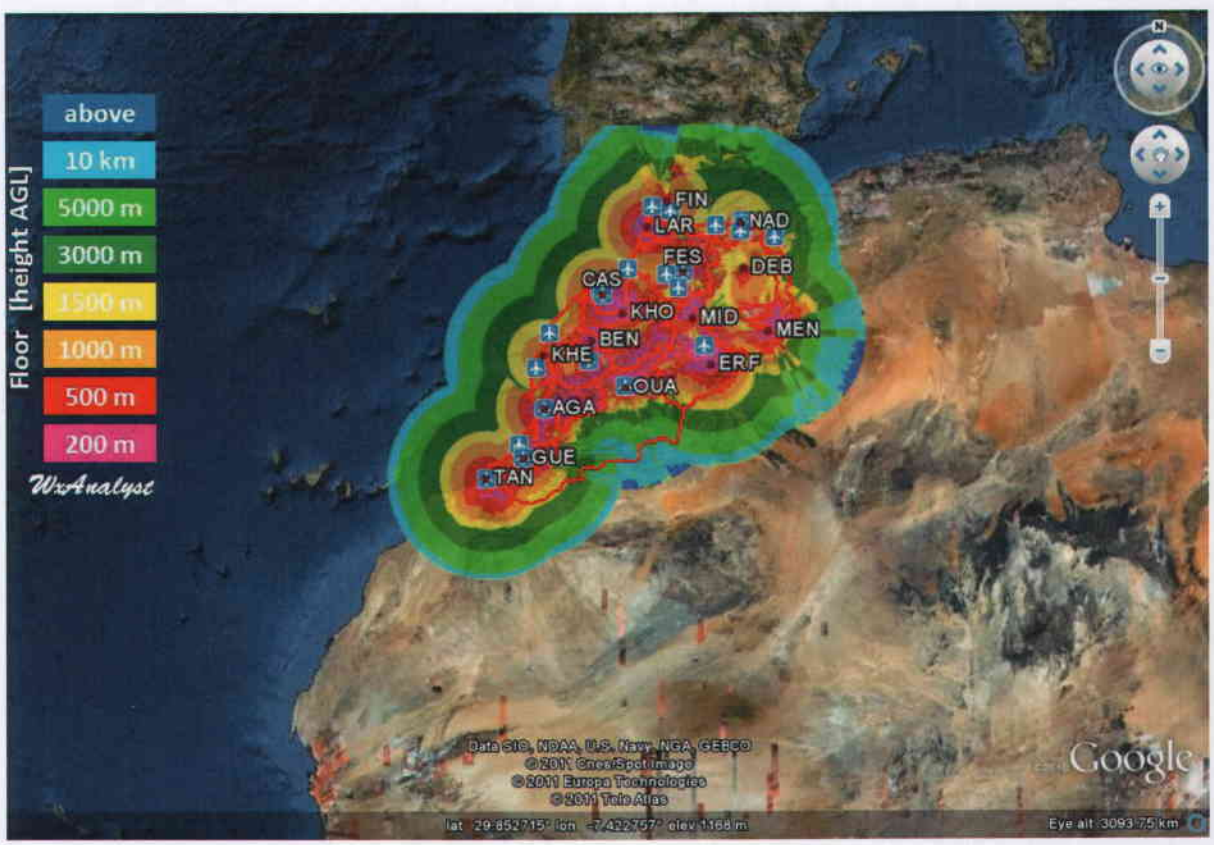


Figure 5.44 – Floor Analysis with location of civil aviation airports in the Study

5.5.5. Proposed Radar Coverage for an Enhanced Weather Radar Network in the Study Area

In summary, the Floor Analysis of the proposed radar network in Morocco is shown in **Figure 5.53**. It should be pointed out that the Floor Analysis for each radar extends to approximately 300 km in range. The radar coverage is complete except though there are a few regions where the minimum detectable elevation is fairly high. These areas are extremely small. These regions are in far basins to the East of Agadir. Coverage in this region is between 5,000 and 10,000 m.

Table 5.4 lists the location of the existing and proposed radars. The locations were taken from SRTM digital elevation data which has a 90 m resolution.

Table 5.4 – Existing and Proposed Radar Sites in the Study Area

	Latitude	Longitude	Elevation (m)
Agadir	30.32764	-9.39769	72.8
Ben Guerir	32.13897	-7.95198	467.5
Casablanca	33.36862	-7.57687	203.7
Fnideq	35.862704	-5.408187	431.0
Debdou	33.96992	-3.02058	1628.2
Erfoud	31.4336	-4.21836	911.7
Fes	33.93078	-4.97402	572.5
Fes-2	34.16651	-5.015275	724
Guelmim	29.00665	-10.02456	585.1
Khemis Takate	31.73219	-9.45339	702
Khourigba	32.85518	-6.9568	775.6
Larache	35.1635	-6.1167	72.9
Mengoub	32.25998	-2.34979	1000
Midelt	32.67147	-4.74102	1517.0
Nador	35.22153	-2.99788	862.3
Ouarzazete	30.87863	-6.89441	1281.8
Tan Tan AP	28.449	-11.17324	197

5.5.6. Summary of analysis of Study Area Coverage of existing and expanded Weather Radar Network Facilities

Analysis of total radar coverage in the Study Area shows a significant increase in coverage. The entire Study Area has coverage. Seventy-seven percent of the Study Area has radar coverage within the first 1000 m above the ground. This will greatly improve precipitation estimation and make the network a very useful tool for Flash Flood and Early Warning (FFEW). With good coverage close to the ground, Quantitative Precipitation Estimates (QPE), and

Quantitative Precipitation Forecast (QPF) through Nowcasting will provide a very useful tool to achieve useful information in the 0-3 hour time frame.

The addition of 10 new radars would serve Morocco very well. All areas that represent black spots would greatly benefit from the improved area of radar surveillance. If DMN decides to expand to the extent as proposed in thus Study, it would rank among the most well covered regions of the world. The level of non-divergence, which is so important to the development of synoptic and meso-synoptic events, would almost be completely monitored, with 98.5% of the Study Area receiving radar surveillance at 5000 m AGL and lower.

Table 5.5 – National coverage percentages and cumulative percentages for existing and expanded radar network.

Altitude m (AGL)	Percentage	Cumulative Percentage
≤ 200	29.8%	29.8%
200 to 500	21.9%	51.7%
500 to 1000	25.3%	77.0%
1000 to 1500	10.4%	87.4%
1500 to 3000	6.9%	94.4%
3000 to 5000	4.3%	98.6%
5000 to 10000	1.4%	~100.0%
> 10000	<0.1%	100.0%
no coverage	0.0%	

The five regions discussed herein would all benefit from the acquisition and siting of one or more new weather radars. The order in which the regions were assessed, from northern to southern Morocco, also represents a relatively logical progression of priority in siting from highest to lowest. This is due both to the socio-economic benefits gradually declining from north to south, and also to the logistical siting factors becoming more problematic in southern areas of the country where roads, power and other requirements are not as readily available. **Table 5.6** lists the potential new sites discussed herein and the relocated site for the Fes radar, including the socio-economic selection criteria from Section 5.1 (Column 5) and the logistics (site development issues). Since the specific sites have not yet been inspected, the logistics factors are estimated based on high resolution map views, the communications map in the **Figure 5.B2**, and the types of roads and facilities that are visible at or near the sites. **The last column lists the recommended installation priority.**

This analysis includes the information available to the study team. There could be a situation that (and should be the case), that DMN may adjust these priorities based on information that was not available to the B&N study team. In addition, constant changes in priority based on future weather events and losses may suggest a different order of new radar site installations.

Table 5.6 – New Radar Sites Considered for Regions of Morocco

Site	Latitude	Longitude	Hydrologic Basins	Socio-economic	Logistics	Priority
Agadir	30.32764	-9.39769				Current
Ben Guerir	32.13897	-7.95198				Current
Casablanca	33.36862	-7.57687				Current
Fes	33.93078	-4.97402				Current
Khourigba	32.85518	-6.9568				Current
Larache	35.1635	-6.1167				Current
Debdou	33.96992	-3.02058				Planned
Finideq	35.8627	-5.40819	West 50% of Cotiers Mediterannes	1,2,3,4	R,C,P,L	1
Nador	35.22153	-2.99788	Isly 100%, east 60% of Cotiers Mediterannes	1,2,3,4	R,C,P,L	2
Erford	31.4336	-4.21836	Ziz-Rheris 100%, south 50% of Guir	1,2,3	R,C,P,L	3
Tan Tan AP	28.449	-11.1732	North edge of Sequia El Hamra (5%), south 50% of Cortiers Guelmin-Tiznit, western part of Draa (20%)	3,4	R,C,P,L	4
Oaarzazete	30.87863	-6.89441	North 33% of Draa (mountainous region)	1,2,3,4	R,C,P,L	5
Midelt	32.67147	-4.74102	West 50% of Guir, south 40% of Moulouya	1,2,3,4	R,C,P,L	6
Khemis Takate	31.73219	-9.45339	Cotiers Essaouria, Cotiers Safi-Judida (67%), east 70% of Tensift, Temri (100%), north 20% of Souss	1,2,3	R,C,P,L	7
Mengoub	32.26998	-2.34979	Nearly all of Guir (95%)	2,3	R,L	8
Guelmin	29.00665	-10.0246	Cotiers Guelmin-Tiznit (100%), South 33% Draa	2,3	R,C,P,L	9

P=power C=communications R=Road L=land

The floor height mosaic maps in **Figures 5.45** summarize the potential new radar coverage in the study area. These maps, together with the mosaic of current coverage in **Figure 5.18**, indicate that all provinces and hydrologic basins will be covered with only very minor gaps if the DMN elects to eventually install all 10 new radars. The expanded network would satisfy the most important of the socio-economic factors, particularly the inclusion of all the flood assessment points found on the maps in the **Appendix 5B**. The new network potentially improves the sampling of storms over the hail suppression regions south of Fes with the relocation of Fes and the addition of Midelt. If this still proves to be inadequate for the specific project needs, the next solution might be the addition of a specific hail suppression project radar with dual-polarization capability (for differentiation between ice particles and water drops) positioned within the project area (such as at Ifrane). This is not considered a high priority for a national weather radar network.

The DMN legacy radar network was initially (and properly) designed to provide necessary monitoring on the west side of the country, where the major population centers are, along with

the capital. The Sebou Basin, which is one of the most important rivers in Morocco, handles runoff from the part of the Atlas Mountains. The Sebou Basin yields up to 28.5% of the total river water supply in Morocco and 40% of the Middle Atlas Basin. Naturally, the Sebou Basin was considered in the legacy radar network with no significant changes occurring in the proposed radar network upgrade.

The following is a basin by basin analysis of the respective benefits of the proposed radar network.

Côtiers Méditerranées

The Côtiers Méditerranées Basin, which runs along the Mediterranean coast of Morocco had very virtually no coverage in the northern part of the basin, and on into the oncoming weather which at times propagates from the north to the south, into the basin. The addition of Nador and Finideq proposed radars now cover the north part of the basin to the coast. Also radar surveillance is provided over the Mediterranean Sea and on to the south coast of Spain.

Loukkos Basin

The Loukkos Basin radar coverage remained relatively unchanged as the Larache Radar provides adequate coverage of the Loukkos Basin.

Sebou Basin

The Sebou Basin was already well covered by the Fes and Larache radars, especially in the western part of the basin. The eastern part of basin has improved coverage from the Midelt radar to the south and the Debdou radar to the east of the basin.

Drader Souier Basin

The Drader Souier Basin is a very small basin, which just lies south of the Loukkos Basin along the Atlantic coast. No proposed radars add coverage to this basin, as the basin is covered very will by the Larache radar.

Moulouya Basin

The Moulouya Basin had very sparse coverage from the legacy radar network. The Debdou radar now provides coverage of the basin, though being in mountainous terrain, the radar coverage is compromised by the difficulty of placing a radar in complex terrain. The Mengoub and Midelt radar provide coverage in the southern Moulouya Basin, and the Nador radar provides a bit of coverage into the northern Moulouya Basin. There were not a great number of "black spots" in this region. The Midelt radar was more important than the Mengoub radar in the Moulouya Basin.

Figuig Basin

The Figuig Basin had virtually no radar coverage from the legacy network. The Mengoub radar addresses the lack of radar surveillance in the basin. However, there were no indications of

"black spots" in the region which would lead to giving this site a lower priority based on flood threat.

Guir Basin

The Guir Basin had very little radar coverage, with indications from the floor analysis that the legacy coverage was at or above 10000m. This, of course, is far too high to get benefit from the legacy radar network. The proposed Mengoub radar provides adequate surveillance in the basin, though with flood threat was considered very small based on the occurrence of "black spots" in the Guir ever basin.

Ziz-Rheris Basin

The Ziz-Rheris Basin, being on the east side of the Atlas Mountains had very little radar coverage from the legacy radar network. The floor analysis indicated that the lowest radar coverage over the basin was 3000m. The proposed Erfoud radar provides coverage in this basin with the proposed radar at Ouarzazete helping monitor the southern area of the Ziz-Rheris. There are more "black spots" in this basin than both the Guir and Figuig Basin combined which would indicate that the Erfoud and especially the Ouarzazete radar are more necessary than the Mengoub radar.

Oum Er-Rabia Basin

The Oum Er-Rabia Basin lies just to the west of the Ziz-Rheris Basin, and is in an area of increased annual precipitation as well as threat hazards from flooding. There are a great number of black spots in this region. The basin is well covered by the legacy the Ben Guerir radar as well as the Khourigba radar. None of the proposed radars help coverage in this region, though Ouarzazete and Erfoud are generally located to the east of the basin.

Bouregreg Basin

The Bouregreg Basin is an Atlantic coast basin. Rabat lies in the northern part of the basin with Casablanca in the basin just to the south of the Bouregreg. The basin appears to be well covered by the legacy radar network. No proposed radars add coverage to this basin.

Côtiers Atlantiques Basin

The Côtiers Atlantiques Basin is the basin where Casablanca is located. The basin is well monitored by the Casablanca radar. No proposed radars add coverage to this basin.

Côtiers Safi El Jadida

The Côtiers Safi El Jadida is another Atlantic coast basin. The Ben Guerir radar is located in the eastern part of the basin. The Casablanca radar provides surveillance into the basin along the north coastal area of the basin. The proposed Kemis Takate helps with monitoring along the southern coastal border, and of course Ben Guerir offers very good coverage for most of this basin.

Tensift Basin

The Tensift Basin is another basin to the west of the Atlas Mountains which takes runoff from the Atlas into the Atlantic Ocean. The eastern part of the basin is covered by the Ben Guerir radar while the proposed Kemis Takate radar covers the southern coastal portion of the basin.

Côtier Essaouira Basin

Just to the south of the coastal portion of the Tensift Basin is the Côtier Essaouira Basin. The Côtier Essaouira Basin, though being a coastal station, has very poor coverage from the existing radar network. The Agadir radar, which is relatively close, is blocked by very southern extension of the Atlas Mountains. The proposed Khemis Takate radar was placed here to pick up coverage in this region which had several threats from flooding.

Tamri Basin

The Tamri Basin is a very small basin that sits along the coast taking runoff from the southern Atlas. This basin was essentially unmonitored by the existing radar network. The proposed Kemis Takate radar provides adequate coverage of this area, though the many mountains make the use of radar a great challenge.

Souss Basin

The Souss Basin handles runoff from the eastern side of the southern Atlas Mountains north of Agadir. The Agadir radar does a very good job providing coverage in this basin. No proposed radars add coverage to this basin.

Draa Basin

To the east of the Souss Basin is the Draa Basin which handles runoff from the eastern side of the southern Atlas chain. This basin had very poor coverage from the existing radar network while having numerous threats of flooding as evidenced by "black spots". The proposed Ouarzazete radar provided improved coverage in the northern Draa Basin, while the proposed Tan Tan radar and Guelmim radar add coverage to the southern portion of the Draa Basin. There remains a significant gap of radar coverage in the basin which is located in the central part of the Draa Basin. The B&N Team had a very difficult time finding a suitable radar location that would effectively cover this area. This is largely due to a lack of suitable roads and power in the area, and especially in regions where a radar would be optimally located.

Massa Basin

The Massa Basin touches the Atlantic Coast just south of the Souss Basin. The basin is effectively covered by the Agadir radar. No proposed radars add coverage to this basin.

Côtiers Guelmim Tiznt

The Côtiers Guelmim Tiznt Basin is poorly covered by the Agadir radar. The proposed Guelmim and Tan Tan radar systems provide effective coverage in this Basin. There are not many flood threats in this area, though the airports of Guelmim and Tan Tan would greatly benefit from these two proposed radars.

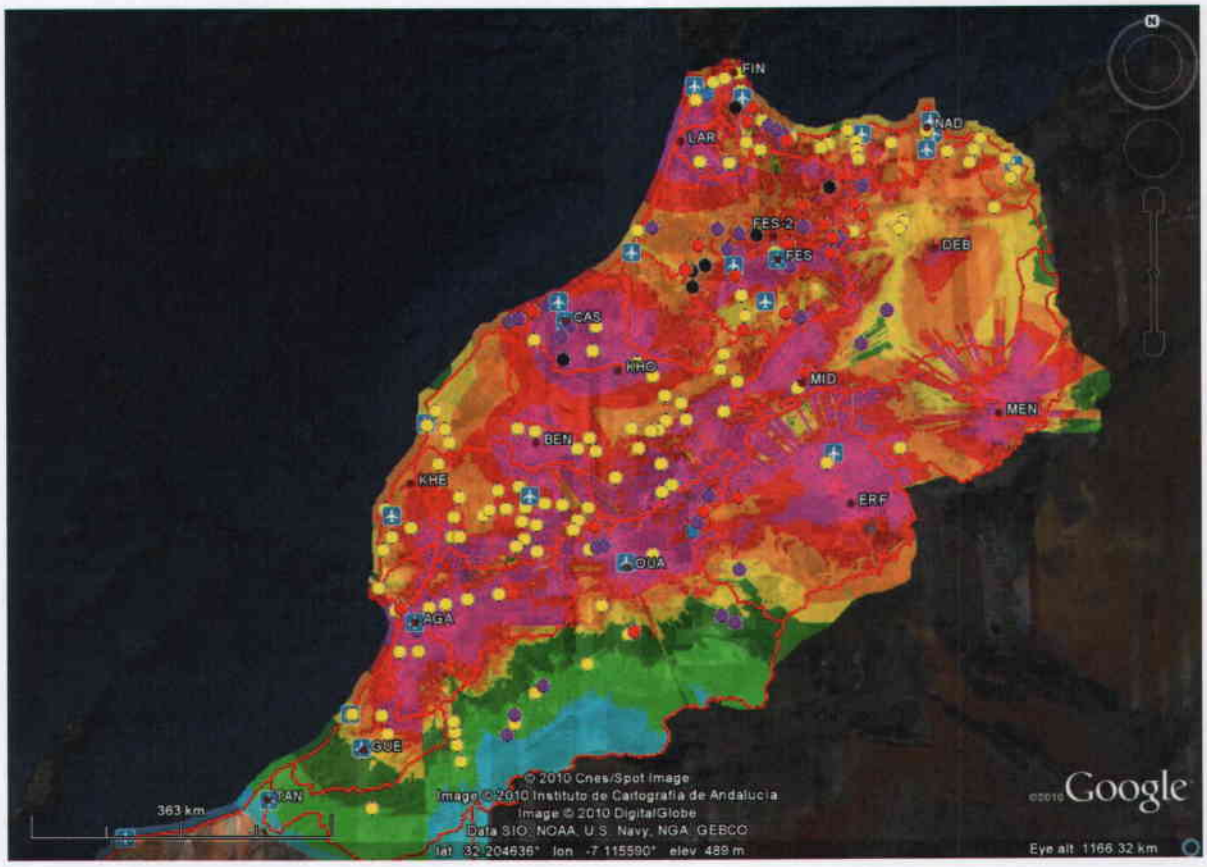


Figure 5.45 – Floor height mosaic analysis showing all potential new radar sites in northern Morocco. Hydrologic basins are outlined in red and labeled. Provinces are outlined in white. Calculations of the percent of coverage in the Study Area were based on the analysis of this product.

The expanded network would also marginally improve the capability of detecting hazardous wind conditions over airports, mainly because several of the new sites are proposed to be at airport locations for logistical reasons. Better sites for detection of wind shear over the airports would be 10-15 km away from the airports. However since no data currently exist to quantify the wind shear hazards, and since sites with good logistical support are likely to be scarce in the provinces east of the Atlas Mountains, the airport locations are preferred.

Finally, the complete expanded coverage would markedly improve DMN's capability to monitor storms and issue short-term forecasts and warnings throughout Morocco, including coastal

areas where offshore radar coverage is currently lacking for the Mediterranean and southern Morocco area.

5.5.7. Equipment Required to Construct Additional Radar Stations and U.S. Sources of Equipment

Based on the Field Assessments of the existing radar sites in the DMN radar network, and the site analysis for potential new radar sites, The B&N Team recommends that DMN should carefully consider the possibility that all new radar procurements/tenders should require Dual Polarity as either a technical requirement, or at the very least an upgradable option, as this technology is rapidly becoming the world standard state of the art in Doppler Weather Radars. The B&N Team feels this technology will greatly enhance the capabilities of DMN's weather radar network, going forward.

As DMN already has experience in procurement and installation of radar systems, this section of the Task 4 report will not presume to educate or instruct DMN on the mechanics of radar system procurement and installation. However, the team is required, per the TOR to describe the equipment required to construct additional radar stations. This will be done at a high level only, describing the major components, and will provide the most important technical specifications of these components.

It is B&N's understanding that all new radar stations should meet or exceed the existing radar specifications, and also that all new radar stations must be compatible with the existing radar network, and must be fully integrated, in terms of radar products produced, and the ability to display these products at Radar Central.

5.5.7.1 General Specification for C-Band Weather Radar

5.5.7.1.1 General

Weather Radar should be designed using the latest state of the art technology, built under ISO Standard. The technical details for the radar should be as below specification.

5.5.7.1.2 Overview of Weather Radar

- Doppler C-Band Weather Radar is designed to have a LINUX operational system.
- The weather radar can suppress clutters over 44 dB to achieve correct data under high clutter.
- The parabolic reflector antenna beam width should not be more than 1 degree.
- Tunable two-axis antenna covered by a hydro phobic coated radome
- The antenna can be operated in Volume scanning, PPI mode or scan vertically in RHI mode.
- Detection Capability: Better than – 10 dBz target at the range of 250 kilometers.
- Minimum radar sensor parameters:
  Operating Frequency: 5400-5800 MHz
  Transmit power: 350 kW
  Wavelength: 5 cm

Waveguide loss: 1.5 dB for approximately 30m one-way
Rotary joint loss: .1 dB one-way
Circulator loss: .5 dB one-way
Beam Width: 1.0 deg
Antenna gain: 44 dB
Radome loss: 0.3 dB one-way
Minimum detectable received signal at coupler: ≤ 114 dBm

- Pulse lengths: 0.4, 0.8, 1.0 or 2.0 µsec or better.
- Staggered PRF will be emitted from transmitter at ratio 3:2, 4:3 or 5:4 in 2 PRF values received from signal processor to correct the scanning at 16, 32 or 64 meters/second.

The DWR systems processing should provide at a minimum:

- Data Types, 0 to 250km range:
  - Z
  - V
  - W
- Volume scan [2.5min- 5min max.]
- Resolution (@50km up to 250km)
  - vertical <100m
  - horizontal <100m
  - radial ≤ 25m
- Measurement of wind components (3D, u,v,w)
  - 0 to 250 km
  - Resolution <100m

<u>Option, Dual Polarization:</u>

Microphysical discrimination of precipitation hydro-meteor classification (HMC).

5.5.7.1.3 External Components

- Parabolic Reflector Dish Antenna:
  - Diameter of dish antenna — not less than 3.7meters)
  - Beam width @3 dB — not over 1° or better
  - Antenna Gain — not less than 44 dB or better
  - Side lobes — -27 dB or better

- Antenna Control System
  - Elevation-over-Azimuth two axis directional antenna.
  - Elevation is adjustable from -2 to 90° or better
  - The angle of both axis must be accurate to 0.1° or better.
  - The antenna should controlled by computer.
  - Rotation (360°) at least 6 RPM or better, both clockwise and counterclockwise. Vertical sweep in automatic RHI, moving up and down speed in vertical line 5 times per minute or better,. In manual mode, adjustable from 0-15° per minute.

- Radome with the following parameters:
  - Spherical or geodesic design
  - Hydrophobic coating
  - Fiberglass with foam core
  - Wind loading capability of 240 km/sec (150mph)
  - Lightning arrestor system
  - Aircraft Warning Lights

- Tower with the following parameters (unless mounted on a building):
  - Should be constructed of galvanized steel
  - Should have stairs rather than a ladder for maintenance purposes
  - Top plate should have an access hatch to the inside and to the outside of the radome.
  - Earth grounding system for lightning protection.

5.5.7.1.4 Radar Operation Control System (RCP)

Radar should contain a sub-system that can detect common faults in the system, and provide security by password in local/remote mode. User and system administrator can control and the radar and determine the radar status precisely and quickly, through the radar network .

Radar control system consists of:

- Radar control kit with radar control processor software
- BITE system
- Local Control/Human Machine Interface

5.5.7.1.5 Receiver Front End

- Receiver front end is analog part that can set RF value for intermediate frequency digitizer.
- The transmission and reception uses same single antenna.
- Low noise amplifier (LNA) which amplies the RF signal, noise fugure < 2 dB.
- The RF signal is downconverted to IF= 60 MHz Intermediate Frequency (IF)

5.5.7.1.6 Doppler Signal Processor (DSP)

The Signal processor is the final step of digital receiver unit. It should convert the IF signal (Receiver and BURST) to meteorological moments, such as Z (dBZ) V(m/s), and W (m/s).

Receiver and signal processor should consist of:

- Intermediate frequency (IF) digitizer
- Signal processor host

IF Digitizer should have following features:

- Built-in test equipment
- 60 MHz IF
- Sampling rate > 70 MHz
- Level output of digitized I/Q data
- Remote configuration and control of all processing functions via host
- 3 (5 in the case of DPOL configuration) x 16 bit A/D converters
- Dynamic range > 100dB
- Multiple programmable trigger outputs

Digital Receiver should have the following features:

- Built in BITE
- Outputs of I and Q and processed moments
- Remote configuration and control of all processing functions via host
- Programmable trigger outputs
- Ray data acquisition, generation of physical moments
- 16-bit parallel antenna angle position interface
- Ray data pre-processing in real-time, in coherence with the antenna angles
- Processing of radar-meteorological algorithms for data correction and conversion into standard physical units: e.g. dBz, m/s etc.

Signal Processor should have the following features:

- Industry style 19" rack mountable
- Multi processor version
- Standard weather, clutter removal, signal and noise improvement and second trip removal algorithms.
- Enhanced clutter processing using DFT and FFT processing, PP processing also selectable
- Matched filter designer (Burst Tool) to adapt to the real transmitter pulse

5.5.7.1.7 Control and Display Units

The control of and display of the radar should support normal operation by using user friendly menus on the screens and should also display the real time radar data in an intuitive fashion.

Main Control Unit

A computer to control and analyze the data. It should have following features and components (or better):

Radar application software should have following specifications:

- Radar Transmitter/Receiver Control

- Radar antenna control
- Radar signal-processor control
- Radar control and product scheduling functions
- Radar data ingest function
- Radar product generation
- Raw data and product archiving and retrieval
- Flexible product generation and display
- Versatile network and data communication capability
- Diagnostic and maintenance function
- Calibration and monitoring of the BITE
- Current status report of radar
- Data ingest of raw data polar radar data

End User Display Unit

A workstation computer to display and analyze the radar products and data. This system should have following graphic features:

- Report weather conditions in PPI, RHI, split screen and CAPPI for Intensity and Velocity display
- Pan, scroll and zoom
- Archive and retrieve radar products
- Display the movement of storm forward and backward in time
- Transfer radar images remotely and print out in color
- Insert letters, maps and range/bearing cursor on the image display
- BITE control and fault monitoring submenus

Data Moments (Parameters)

Signal processor used with data analysis system should provide significant signal moments which are corrected intensity, uncorrected intensity, radial velocity and spectral width. Data analysis system should use these values to calculate the quantitative variables, such as, liquid water, accumulation, rain-rate, height and shear

- Uncorrected intensity/reflectivity
- Corrected intensity/reflectivity
- Radial velocity
- Spectral width - Derived moments

Data analysis system should process the data from the signal processor, and apply the standard technique to create additional data ,called derived moments, for weather analysis in detail.

Recommended Products and Specifications

- Standard products
  - Plan position indicator
  - Constant altitude plan position indicator
  - Range height indicator
  - Low altitude reflectivity product
  - Height of maximum Z product
  - Layer reflectivity average product
  - Column maximum product with horizontal max
  - Vertically integrated liquid product
  - Echo tops product
  - Accumulated rainfall product
  - Arbitrary vertical cross section product
  - Velocity azimuth display
  - Real time surveillance display – PPI and RHI
  - Sector and "A" Scope scan scheduling

- Forecast products
  - Storm tracking
  - Severe weather warning
  - Clutter map

- Meteorological products
  - Rain gauge
  - Subcatchment
  - Flash flood alert

- Wind Shear products
  - Shear processing includes:
  - Horizontal shear (Radial)
  - Combined shear (Radial & Azimuths)
  - Combined moments map
  - Gust front and micro-burst detection algorithm

- Dual Pol products (Optional)
- Z_{DR} (Differential Reflectivity)
- K_{DP} (Specific Differential Phase)
- PHI_{DP} (Differential Phase)
- RHO_{HV} (Co-Polar Correlation)

5.5.7.1.1 **Ancillary Components**

- Backup Generator with the following specifications:

  - Automatic transfer switch

  - KVA rating high enough to power all radar components, including the radar shelter and air conditioning units.
  - Fuel tank large enough to run generator for a minimum of two days

- Uninterruptable Power Supply with the following specifications:
  - Should contain Automatic Voltage and Frequency Regulation
  - System should be the in-line type
  - KVA rating should be high enough to power all radar components, internal and external for a minimum of 30 minutes.

The following is a list of radar manufacturers in the United States:

- Baron Weather Solutions
- EWR Weather Radar Systems
- Aero Express, Inc
- Ambient weather
- Eastern Avionics International
- Enterprise Electronic Corporation
- Radtec Engineering Inc.
- Advanced Designs Corporation

It should be stated here that the B&N team makes no guarantees as to the capabilities of any of these manufacturers, and makes no particular recommendation. Each manufacturer must stand on its own merits and capabilities. DMN should decide, as in the past, which radar supplier can meet all of the requirements for new radar procurement, bearing in mind the requirement to be integrated into the existing radar network.

5.6. References

Shipley, S. T., I. A. Graffman and R. E. Saffle, 2004: Weather Radar Terrain Occultation Modeling using GIS.

APPENDIX 5 A

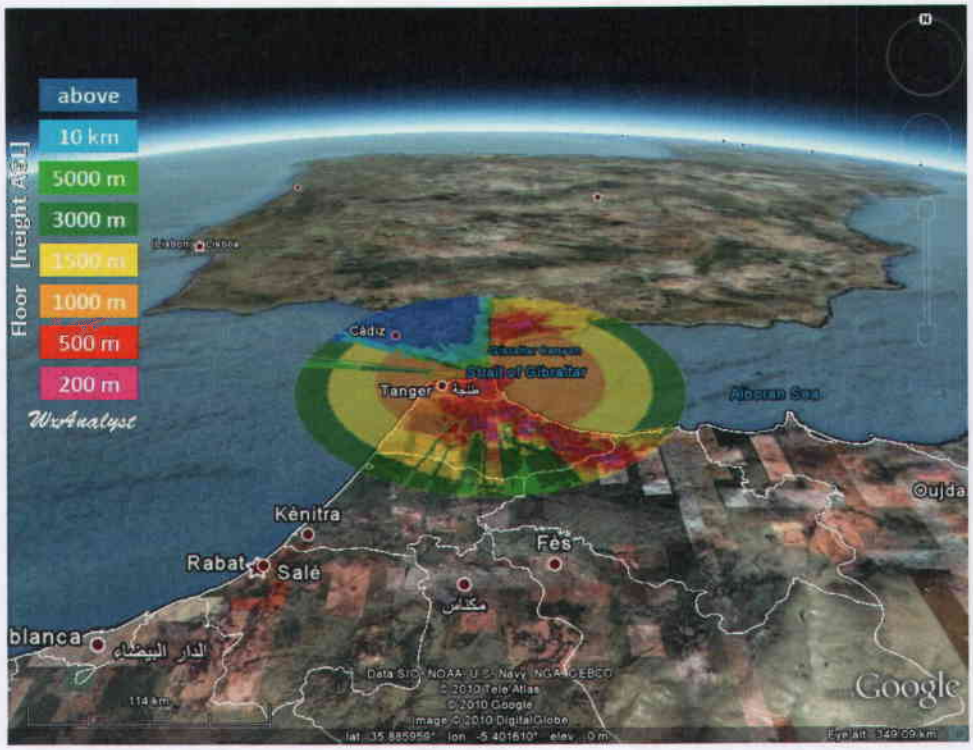


Figure 5.A1 Fnideq

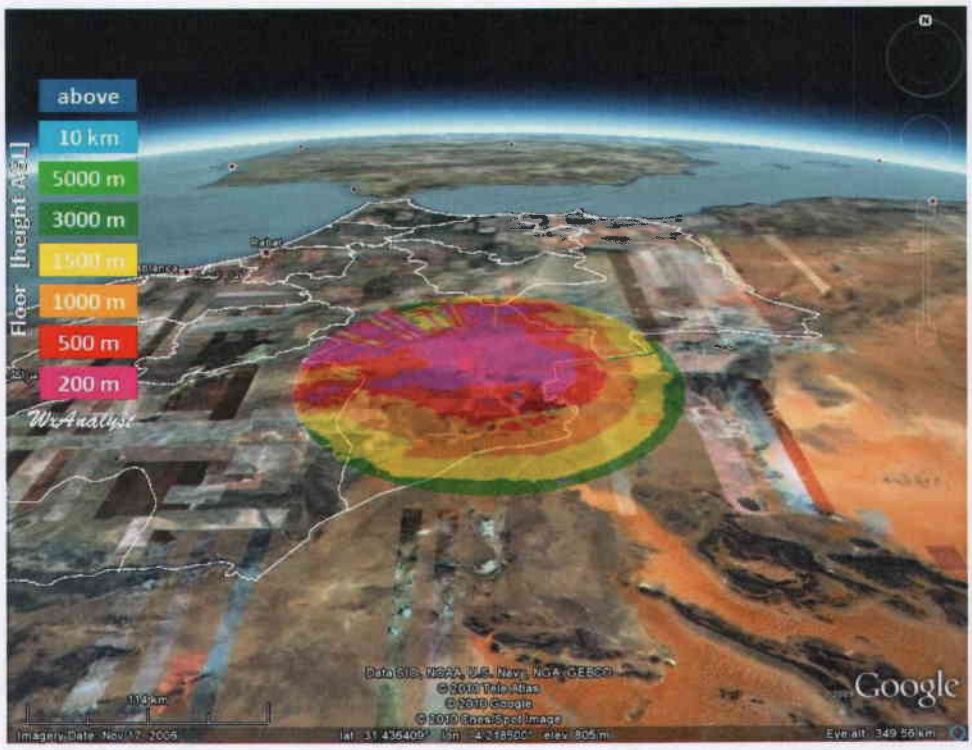


Figure 5.A2 ErFoud Radar

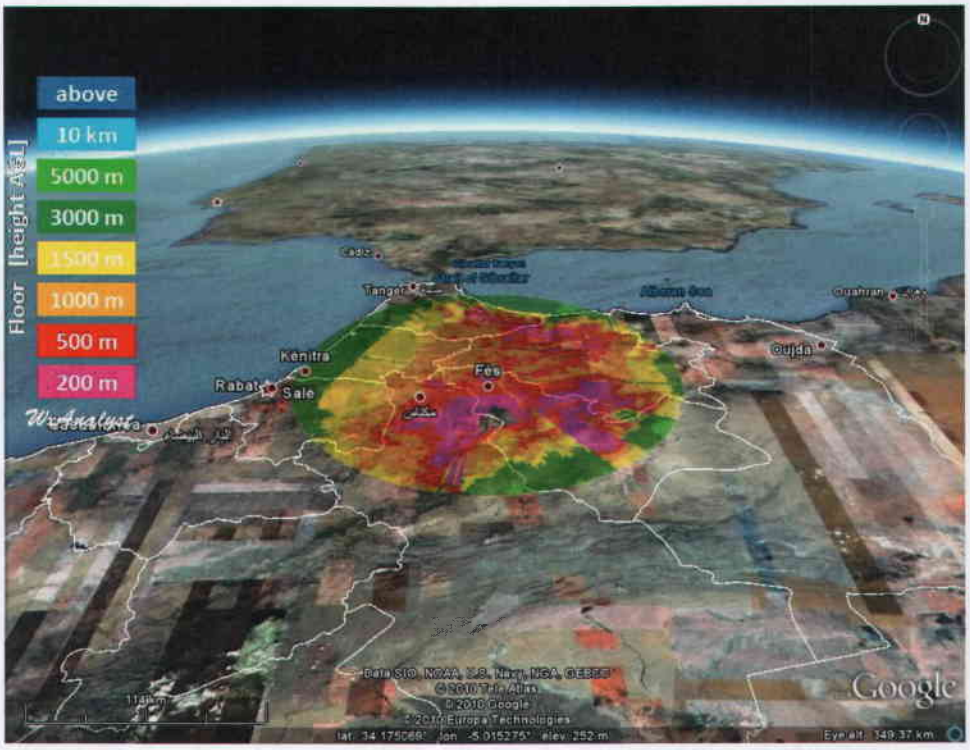


Figure 5.A3 Fes-2

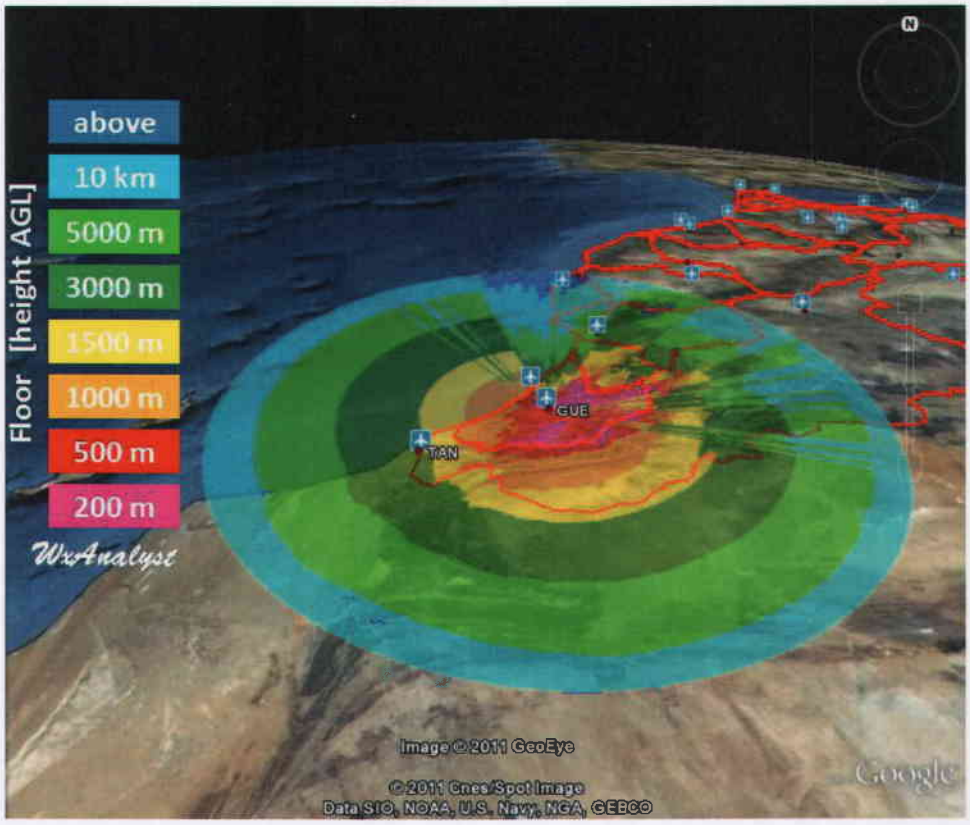


Figure 5.A4 Guelmim Radar

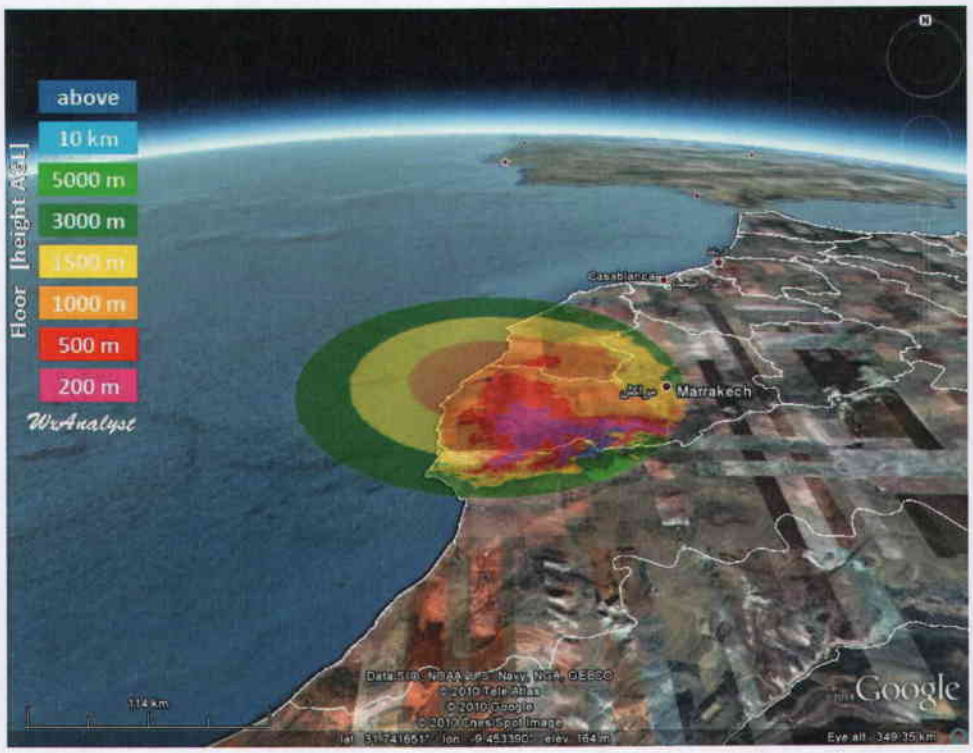


Figure 5.A5 Khemis Takate Radar

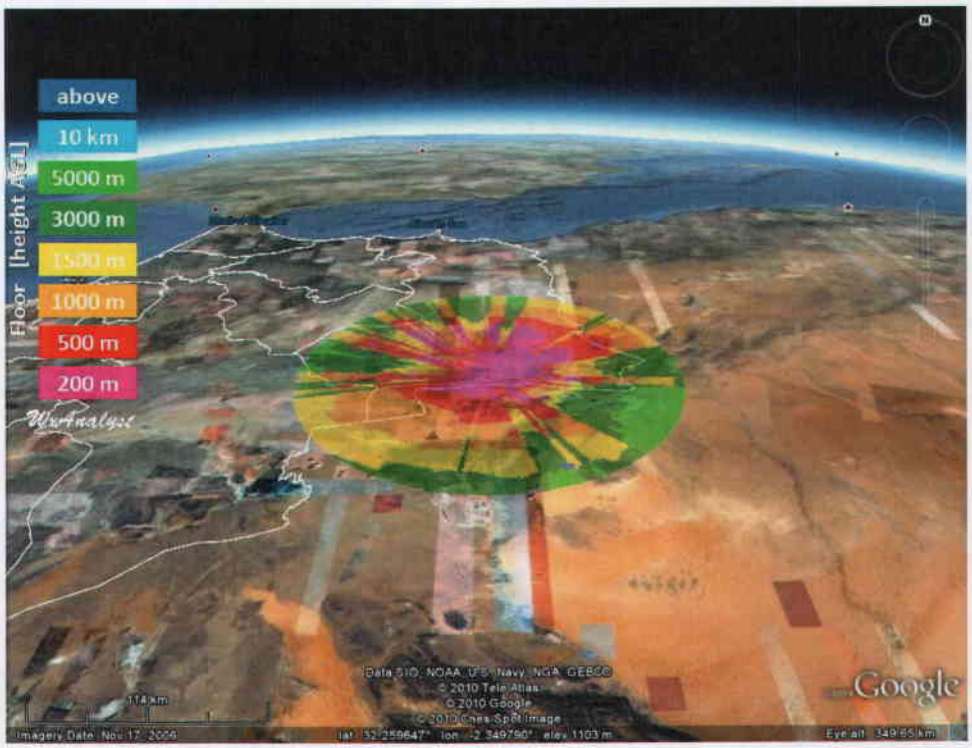


Figure 5.A6 Mengoub Radar

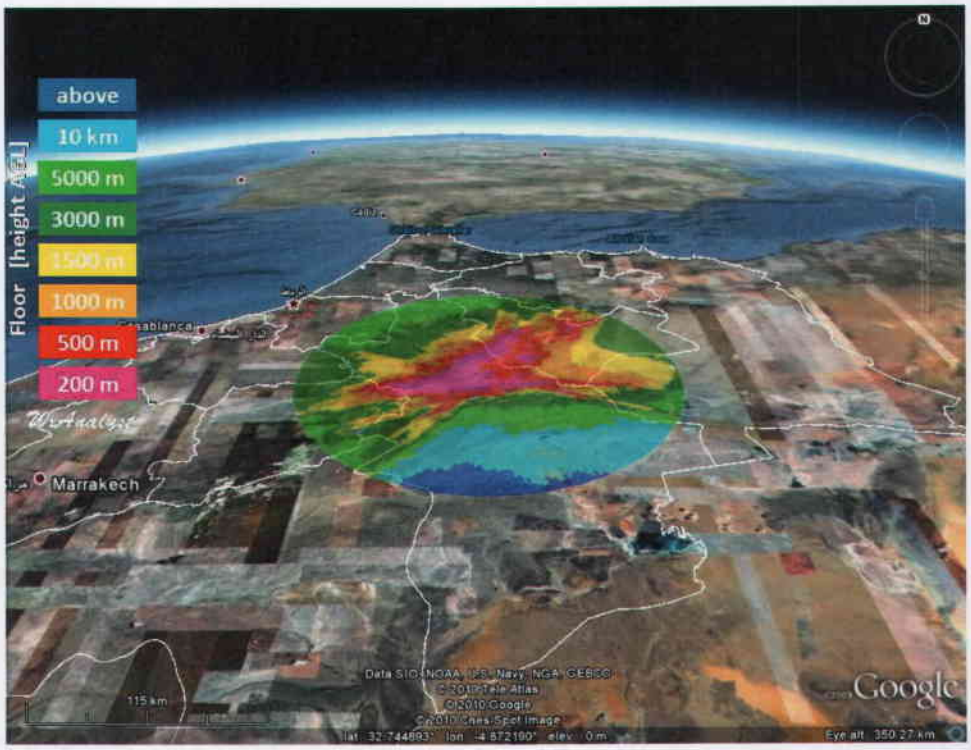


Figure 5.A7 Midelt Radar

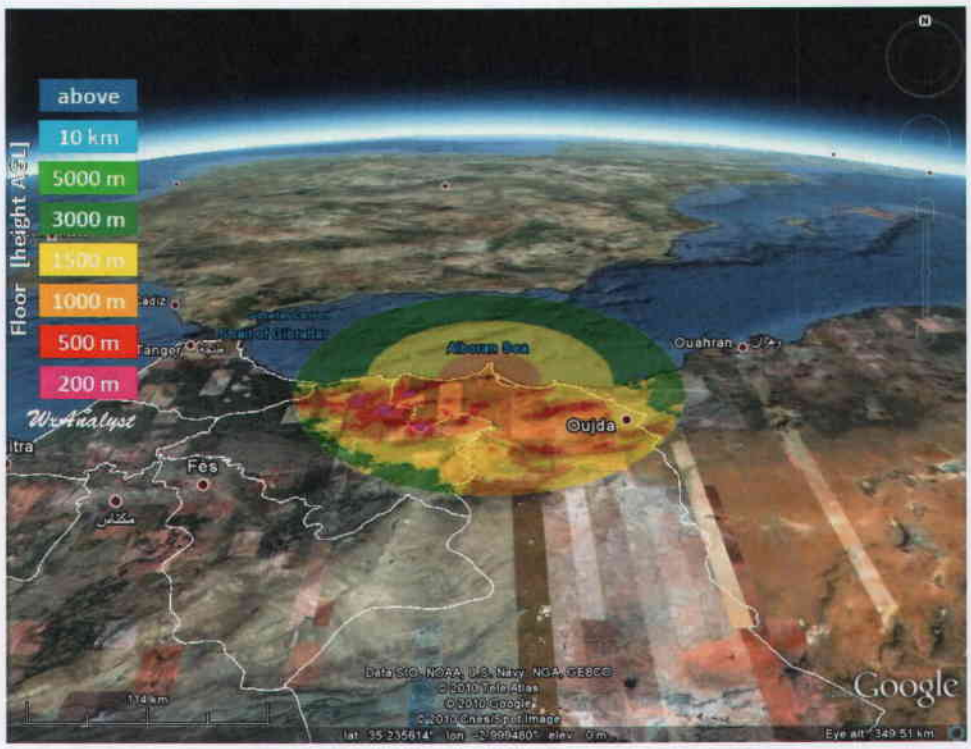


Figure 5.A8 Nador Radar

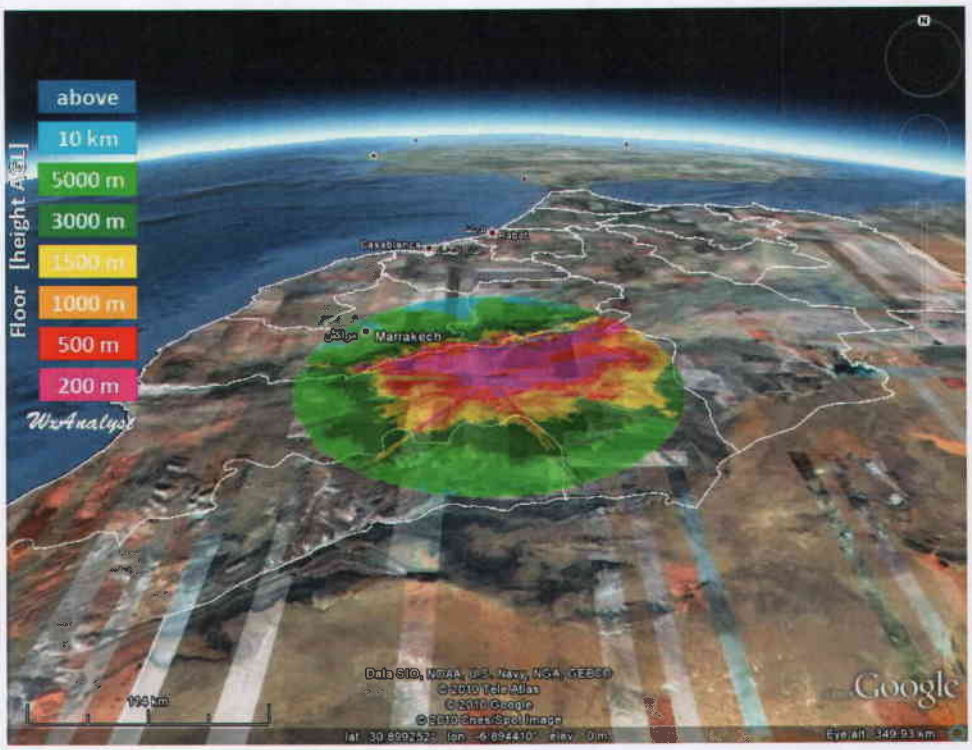


Figure 5.A9 Ouarzazete Radar

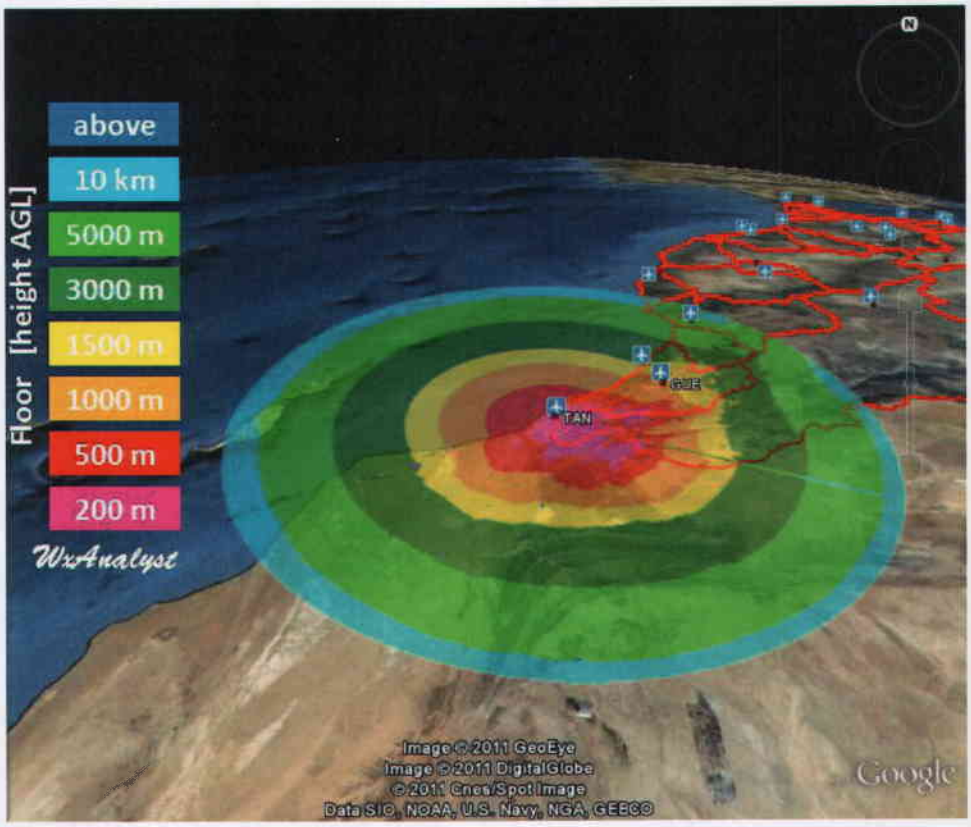


Figure 5.A10 Tan Tan AP Radar

APPENDIX 5 B

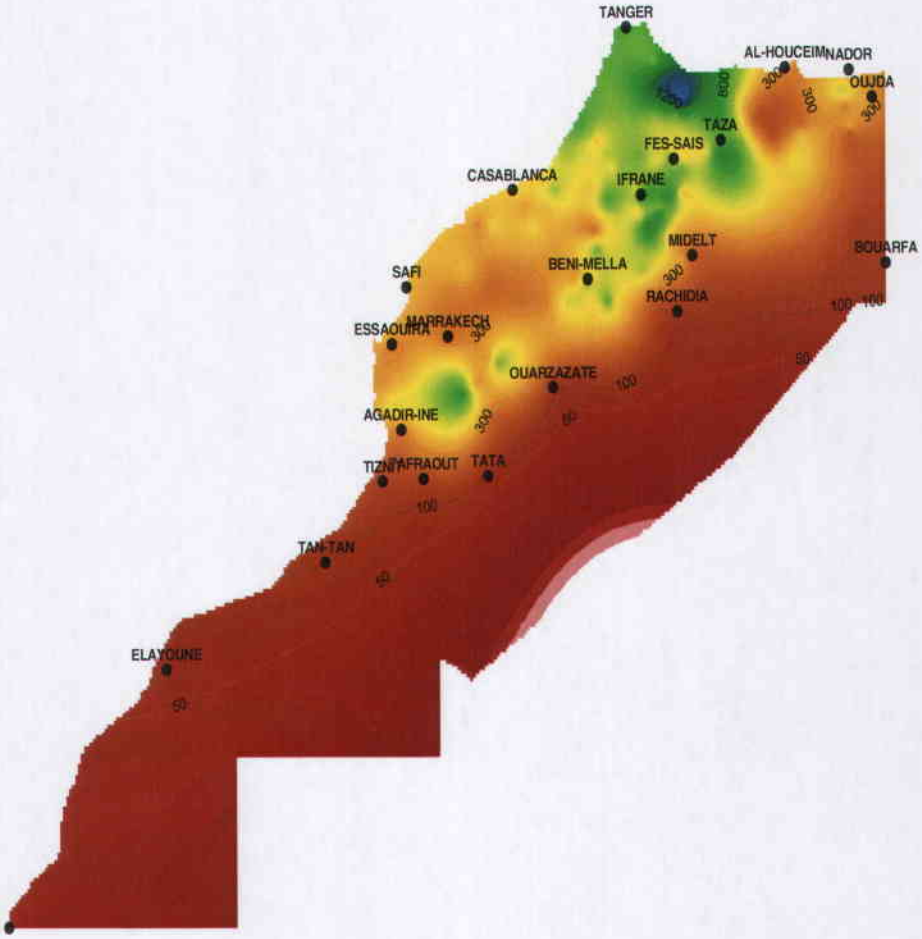


Figure 5.B1 – Map showing annual precipitateon in Morocco based on data from 1961 to 1990 (from El Krimi report p. 4).[1]

[1] This figure is property of the Kingdom of Morocco. The figure does not directly reflect or include work completed under the Terms of Reference for this project.

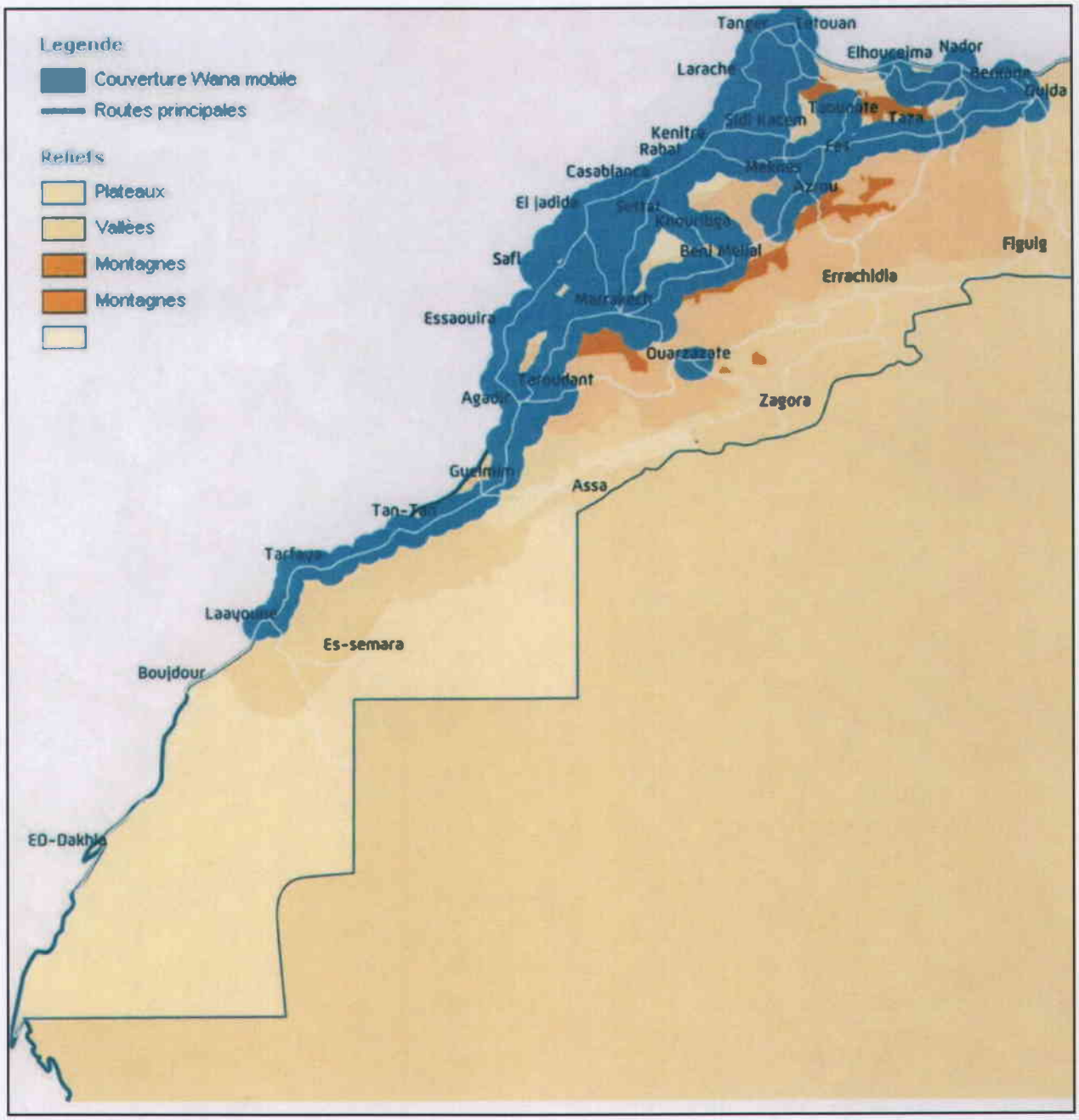


Figure 5.B2 – Map showing the wireless communication network for Morocco. Wireless coverage is indicated by regions shaded in blue.[2]

[2] This figure is property of the Kingdom of Morocco. The figure does not directly reflect or include work completed under the Terms of Reference for this project.

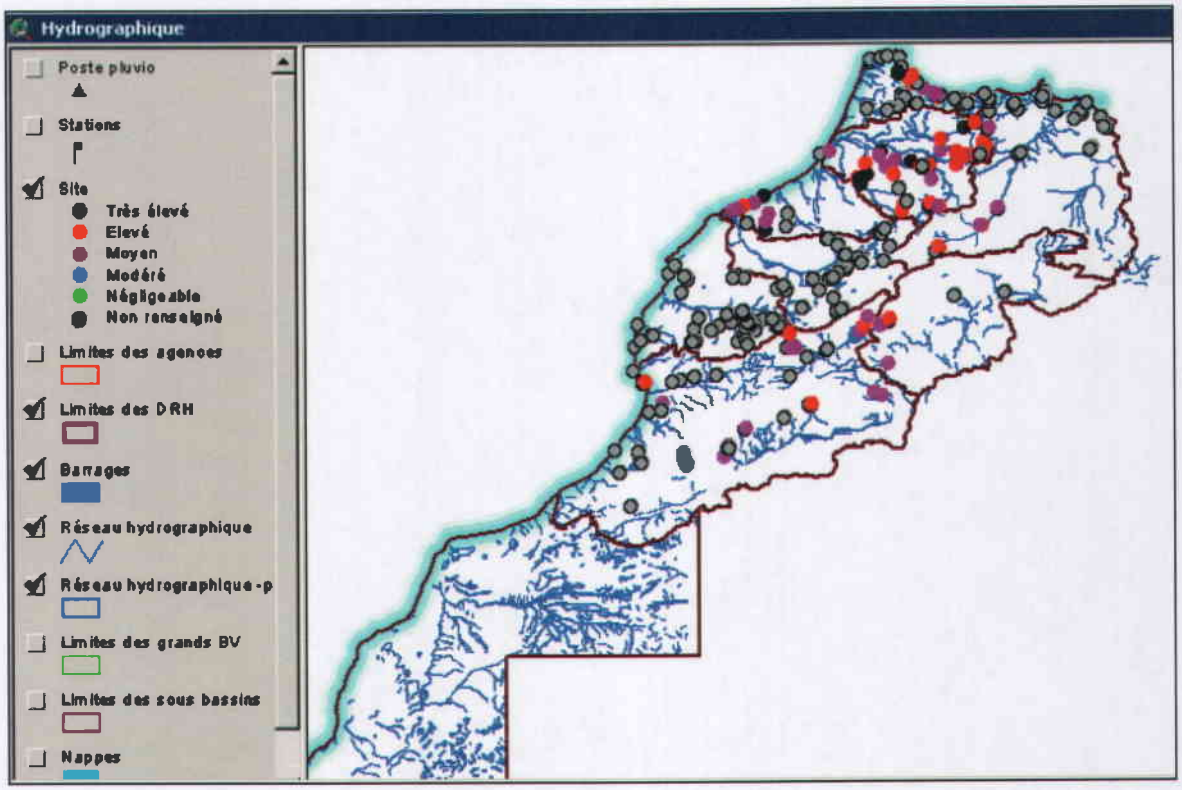


Figure 5.B3 – Map showing results of a national assessment of flood risk in Morocco at 391 specific sites. Colored circles are sites identified to be at some level of risk. The color scale on the left shows the level of risk, with black circles indicating the highest risk level (from El Krimi report p. 22).[3]

[3] This figure is property of the Kingdom of Morocco. The figure does not directly reflect or include work completed under the Terms of Reference for this project.

Figure 5.B4 – Map showing the distribution of damage assessment caused by some floods in Morocco. Color legend beneath the map indicates the type of damage that occurred (from El Krimi report p. 30).[4]

[4] This figure is property of the Kingdom of Morocco. The figure does not directly reflect or include work completed under the Terms of Reference for this project.

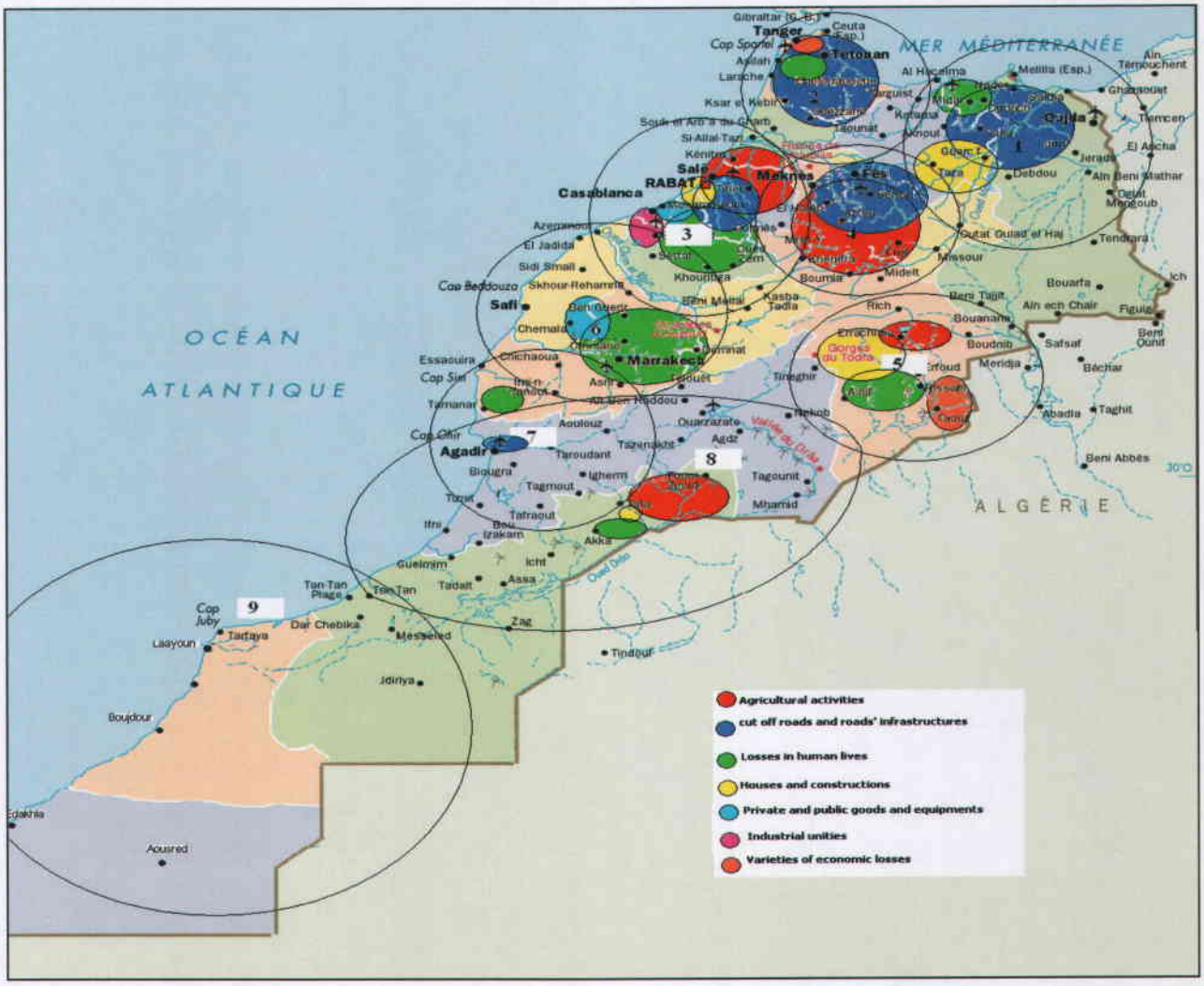


Figure 5.B5 – Map showing the distribution of damage assessment caused by some of the more extreme flood events in Morocco. Color legend beneath the map indicates the type of damage that occurred (from El Krimi report p. 43).[5]

[5] This figure is property of the Kingdom of Morocco. The figure does not directly reflect or include work completed under the Terms of Reference for this project.

APPENDIX 5 C (following 3 pages)

How to Use and Interpret COLLADA™ Radar Products

WxAnalyst White Paper

This paper describes a set of 3-Dimensional (3D) products for visualization and analysis of radar propagation and spatial coverage using Virtual Globes such as Google™ Earth. The 3D structures are created by the WxAzygy® Tools, a capability developed by WxAnalyst, which takes advantage of the Khronos Group's COLLADA™ Open Standard to achieve high visual quality and spatial accuracy. COLLADA™ (Arnaud & Barnes, 2006) brings the speed associated with game software and commercial animation to this geospatial application.

Radar beams operating in the S-, C- and X-Bands (nominally wavelengths 3 to 10 cm, or frequencies 10 to 3 GigaHertz) are impacted by atmospheric refraction, scattering and absorption. They are also blocked by obstacles which may intersect the radar beam such as the surface terrain, vegetation, and manmade objects such as towers and buildings. The WxAzygy® Tools for Radar currently use a standard atmosphere to model beam propagation through the atmosphere, and follow the methods outlined in Shipley et al. (2006).

Occultation

A concept for radar beam propagation through the standard atmosphere is shown in Figure 1. The lowest elevation radar beam is shown in color and oriented with its CENTROID at one half degree (0.5°) above the local horizon. The vertical beam spread is set to one degree (full width). Beam energy is not necessarily spread uniformly over the vertical beam, and is typically stronger near the beam CENTROID in most radar systems. Therefore, for engineering purposes we estimate beam blocking or OCCULTATION by finding the geometric fraction of the vertical beam that is intercepted by opaque objects. Radar engineers can use the geometric fraction with detailed knowledge of the radar beam pattern to calculate the actual fraction of beam power that is lost to occultation.

A color key for the occultation product is provided in Figure 2. A sample occultation pattern for the NOAA National Weather Service (NWS) NEXRAD KATX located in Seattle, WA is shown in Figure 3. Color is used to visually indicate degree of blocking. Blues and greens indicate that less than 50% of the beam is blocked by terrain. The NWS uses 50% occultation to indicate that a radar is receiving acceptable signal levels. Yellows and reds indicate that more than half of the radar beam is blocked, and the color grey is used for total occultation (100%).

WxAzygy® is a Registered Trademark of WxAnalyst, Ltd.

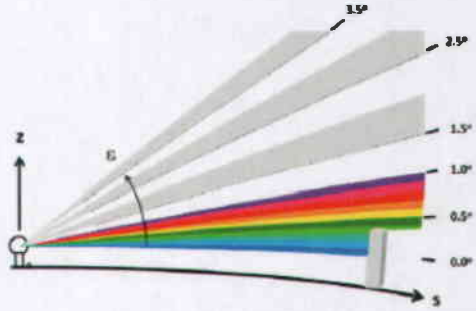


Figure 1 – Concept for radar beam propagation and occultation. The 0.5° elevation beam is shown in color, spread over a one degree vertical beam width. The color codes in Figure 2 indicate what geometric fraction of the beam is intercepted by objects. Also shown in this figure are higher beam elevations at 1.5, 2.5 and 3.5 degrees. A manmade object is shown blocking about 30% of the lowest beam.

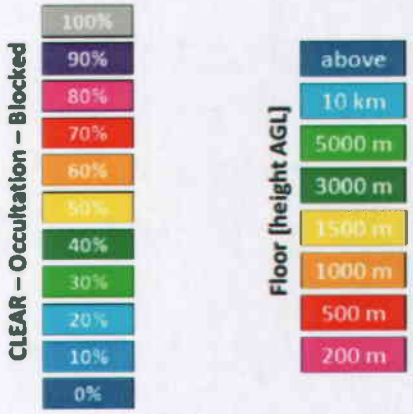


Figure 2 – Color keys for OCCULTATION and FLOOR. For occultation, the 50% blocked condition is located at the boundary of the dark green and yellow bands. Greens and blues indicate that the beam CENTROID has cleared known obstacles. Yellows and reds indicate that the beam CENTROID is intercepted by obstacles. The Floor value indicates that radar beam CENTROID is no higher that the indicated color. For example, a yellow Floor would indicate that beam centroids are in the range from 1000m to 1500m AGL (Above Ground Level).

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Note that Google™ Earth terrain intersects the radar beam centroid surface in all the right places.

Beam Centroid Floor

An example of the radar Floor is shown in Figure 4, corresponding to the occultation pattern displayed in Figure 3. The beam centroid Floor provides the lowest beam elevation ngle that can sample the atmosphere over each location {latitude, longitude}, starting with a lower limit of one half degree at the radar, and increased continuously as needed for the beam centroid (half power point) to clear obstacles in the radar beam path. This product must be combined with occultation scans at several beam elevation angles to determine which elevation will provide useful signals at locations subject to occultation. The Floor provides a quantitative measure of the performance of any radar in detection of precipitation as a function of height above the ground. Particular Floor levels are set to mirror precip climatology, as shown in Table 1.

Table 1 – Height range associations with mid Latitude precipitation events in the United States.

Height range	Pressure	Precip Type
≤ 10 km	< 500 hPa	Deep convection
≤ 5000 m	> 500 hPa	Mid Troposphere, Ns
≤ 3000 m	> 700 hPa	Lower Troposphere
≤ 1500 m	> 850 hPa	Boundary Layer

A Floor color of magenta is a special case where the beam centroid is within 200m AGL of the surface. This color was selected to be highly visible, and indicates those regions or locations where wind power generators may intercept the beam and become sources of radio interference.

Using WxAzygy® Products in Google™ Earth

For best results in Google™ Earth, make sure that Terrain Exaggeration is set to ONE and Terrain Quality is High (Tools/Options/3D View). The views provided in Figures 3 – 7 can be achieved following Figure 8 and using the sample KMZ located at:

http://wxanalyst.com/radar/sample.kmz

Occultation – Click radio button to show layer; double click layer zooms to View shown in Figure 3. Use Navigation Compass to do a quick tour of the horizon. Note that terrain intersects this layer at the first yellow boundary encountered with range from the radar, indicating intersection with the centroid.

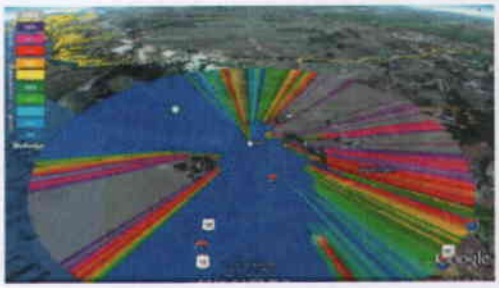

Figure 3 – Occultation pattern for NWS NEXRAD KATX, draped on the 0.5 degree CENTROID surface in 3D and displayed in Google™ Earth. Occultation patterns for the entire US NEXRAD system at http://wxanalyst.com.

Figure 4 – Radar beam Floor for NWS NEXRAD KATX. The Floor indicates the altitude of the radar beam centroid Above local Ground Level (AGL).

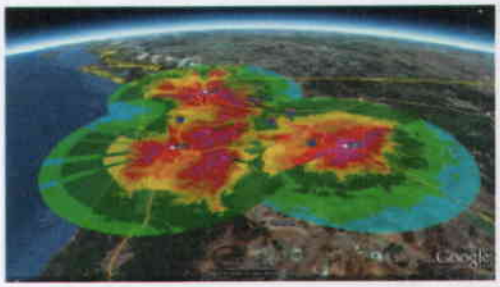

Figure 5 – Mosaic of Floors for adjacent radars, indicating coverage for regions located within the radar network.

Figure 6 – Scanning the horizon from the radar tower point of view.

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2 **0.5° Centroid Floor** – Click checkbox to show layer; double click layer zooms to View shown in Figure 4. This product is draped on the 0.5° centroid surface, so it has the same geometry as Figure 3. Note: Click checkbox by ***WxAnalyst's Floor Key*** to view the color key screen overlay.

3 **Floor Mosaic** – Click checkbox to show the integrated Floor Mosaic as a ground overlay; double click layer zooms to View shown in Figure 5.

4 **Virtual Reality** – Click checkbox to view a model of the radar; double click layer zooms to a View of the horizon similar to Figure 6. Use Navigation Compass to scan the horizon.

5 **Occultation Stack** – Click radio button to show the stack. Click the next level of radio buttons to select each elevation one at a time. This folder structure provides a "one click" animation of the intersection of the centroid surfaces by elevation angle with terrain. Use Navigation controls to Pan, Zoom and Tilt your point of view (POV) to the perspective shown in Figure 7.

References

Shipley, S.T., A. Peterlin and S. Cantrell (2009) Radar visualization and occultation in 4-dimensions using Google Earth, 25th IIPS, AMS, Phoenix, AZ. http://ams.confex.com/ams/89annual/techprogram/paper_150724.htm

Shipley, S.T., I. A. Graffman, R. E. Saffle, and J. Facundo (2006) GIS Tools for Radar Siting and Analysis, 22nd IIPS, AMS, Atlanta, GA. http://ams.confex.com/ams/Annual2006/techprogram/paper_104269.htm

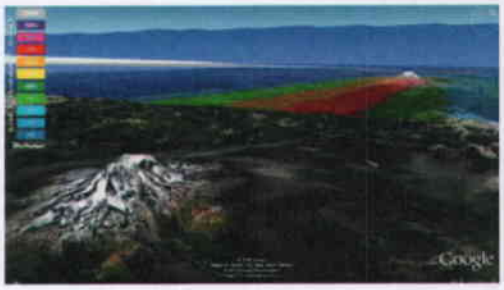

Figure 7 – Occultation Stack for the KATX NEXRAD at Seattle, WA, viewing intersection of the 0.5° centroid surface with Mt Rainier (to the right). The 1.5° surface is shown clearing Mt Rainier (top).

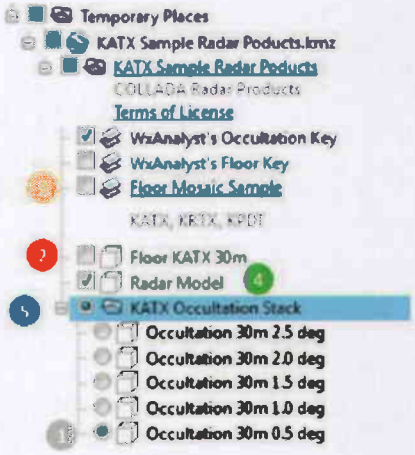

Figure 8 – Google™ Earth Sidebar content for the sample KMZ described in this paper. The sample KMZ is available online at:
http://wxanalyst.com/radar/sample.kmz

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APPENDIX 5 D

Radar Site Prospecting Mission, July – August 2010

Notes on Prospecting Trip 24 July – 7 August 2010

The last visit by the B&N team to Morocco was made during the diagnostic visit in June of 2009. During the last visit, the B&N team had come to an agreement with DMN with regard to the approach on prospecting. The B&N team would suggest sites and DMN would provide prospecting visits and provide feedback to the B&N team. This agreement was not only noted in the Diagnostic Mission Report last year, but also noted by Mr. Tahar Saouri, with DMN. The B&N team decided to help get 'prospecting' started despite the previous agreement and chose a group of the highest priority Radars based on results from the study of climatology as well as results from the socio-economic impact of past weather events. A more extensive prospecting visit will be required before the site should be considered to actually receive a Radar. We also believe that in context of a feasibility study, that the actual final prospecting should in fact be performed by DMN where property can be acquired and the final location of the Radar can be decided.

The sites visited included:

- Fes-2
- Nador
- Midelt
- Erfoud
- Ourazazate
- Khemis Takate
- Fnideq

DMN welcomed Mr. Mark Heggli, Project Manager and assisted in planning the visits, and provided a meteorologist from DMN to join Mr. Heggli. The first day, 26 July 2010, Mr. Heggli met with CNRM and discussed both project status and plans for the two week mission from the B&N expert. CNRM was represented by Mr. Saouri. Mr. Saouri has requested the following information/changed to our work effort. This included:

- DMN would like to have the occultation software. Mr. Heggli responded that the software was available from WxAnalyst, Inc, and that in fact this software was developed by B&N and WxAnalyst to provide the best analysis of Radar network evaluation.
- The ongoing issue about the geo-political borders was brought back up. Mr. Heggli requested that DMN provide these borders to our study group rather than to have us try to find them through other resources.
- Mr. Saouri asked for a complete priority list, itemized one-by-one rather than to be put in groups with other stations of similar priority. Mr. Heggli agreed to do this, but mentioned that the B&N list should be subject to modification (which is why stations were placed in groups)
- DMN would like alternative Radar wavelengths to be considered, and if they are not recommended, DMN would like to see an in depth discussion. The B&N team has already written this up in the latest siting report, and initially there has been a reluctance to use either C-band or X-band Radar because of the tradeoffs. We will reconsider this request and possibly propose a few X-Band Radars where the range is limited by the terrain, and the use of longer range Radar is not cost economical.

- DMN would like an analysis of the useful Radar coverage provided by the proposed (with existing) Radar network. This is not a problem as these statistics are part of our occultation and floor analysis.

After the discussion with CNRM, Mr. Heggli met with Mr. Mokssit, Director of DMN. Mr. Mokssit emphasized project goals as discussed with CNRM. Mr. Mokssit also committed DMN to provide the geo-political boundaries of Morocco thus solving an ongoing issue regarding the boundaries used by the B&N Team. Mr. Heggli reminded Mr. Mokssit about the prior commitment by Mr. Filali to have DMN provide the Radar prospecting, and that in fact our study was a feasibility study and not a complete design study.

After the meeting with Director Mokssit, a meeting was organized with CNEM, DTE and DSI. CNEM, DTE, and DSI were invited to comment on the proposed Radar network. CNEM provided comments about more completely covering regions generally east and south east of Ouarazazate, which appear as holes in the existing coverage. DSI suggested that Tan Tan AP was an important site, stating that weather systems enter Morocco in this area. Unfortunately, the B&N climate analysis was not able to substantiate this, and found that Tan Tan AP was in an arid location, though infrequent storms could still produce damaging weather events. Tan Tan AP was not higher in priority because other areas did in fact receive either more rainfall, or had documented areas damaging weather related events. DTE is the equipment maintenance team who also appears to build the tenders. Mr. Heggli requested the tender documents for Radars at Ben Guerir, Debdou and Tan Tan. The Debdou Radar procurement has not yet been released to the bidders.

DSI is the Information Systems Division, which was only started earlier this year. This concluded Mr. Heggli's work effort on Monday, 26 July.

On Tuesday, 27 July, the Radar prospecting began with a visit to the Fes-2 site. The Fes-2 site is approximately 10 km North of Fes (a bit longer to the Fes Radar, as the Fes Radar is to the south of Fes). The Fes-2 site is designed to improve Radar surveillance to the East. There could be an argument to simply downsize the FES Radar and use it as a scaled down Terminal Doppler Weather Radar (TDWR). Less expensive, smaller Radar wavelength can be used, though attenuation becomes a significant concern in high reflectivity cloud regions, such as convective complexes.

We were joined on the Fes-2 prospecting with DMN staff out of Fes. Mr Zaïdouni, with DMN in Casablanca, joined Mr. Heggli at both Fes-2 and Nador. The site at Fes-2 looked very good, with telecommunications and power available without great effort. The DMN Fes staff talked to a person residing on the property where Fes-2 may go. There appeared to be agreement that this site can be used for a DMN Radar. From the Fes-2 site, we spent the rest of the day and early evening driving to Nador.

On Wednesday, 28 July, we inspected the potential site at Nador. We were joined by two DMN Meteorologists from the airport near Nador. The DMN Nador staff provided great assistance in identifying the access to the Nador site as we drove there straight away. The proposed site is on one of the taller mountains along the coast. The mountain was selected so that the region south of the Rif could and toward Debdou could be observed. The Gourougou site will be able to observe weather events coming from the South and West, which is the predominant fetch of

weather systems. It was discovered that the Nador site identified by the B&N team was actually the site of an existing Radar, which looks to either military and/or civilian aviation. The precise site was identified as Gourougou, so effective immediately, the site we visited near Nador will be referred to as Gourougou. The B&N Team will leave it to DMN to negotiate for the use of this property and infrastructure for placement of the proposed DMN Radar. There are nearby ridges that should be investigated since there are certain problems trying to use two Radars from the same location unless the Radars could be stacked in such a way as to not interfere with each other. Further prospecting by the B&N Team will not be possible without further resources to perform the task. From Nador Mr. Zandouni and Mr. Heggli departed for Midelt for the next proposed site that will be prospected.

Mr. Heggli contracted a stomach ailment on the evening of 28 July, and spent 29 July recuperating after a hospital visit.

On 30 July we inspected the potential site at Midelt, which is actually about 8 km to the West of the town of Midelt. This site was unsuitable for a Radar because of the lack of access to the mountaintop. A road would need to be cut in. Instead, a new site will be identified which has better access. This will be performed over the coming week. We then drove to Erfoud and inspected the potential Radar site there. The Radar site had excellent access and telecommunications, though the antenna farm is problematic as it presents blockage. One concept would be to get the antenna dish on a tall enough mast to be higher than 30 m antenna which is common at these sites. The figure below shows the antenna farms that are common at the sites at Erfoud, Ouarzazate, and Khemis Takate. Another option is to find even a higher mountain and to take the radar to a negative elevation angle, though improved roads to mountaintop sites along with power seem unique with telecommunication sites with the 30 m (and taller) antenna.

This is the mountaintop site at Erfoud with telecommunication towers. This is also typical at Ouarzazate, and Khemis Takate.

On 31 July we inspected the potential site at Ouarzazate. The Ouarzazate site was much like Erfoud. The site was on a small mountaintop with numerous antennae. There were other mountaintops in close proximity to this one, which would be good for the Radar, though access and power would need to be brought to these mountain tops. There seemed to be an open area of considerable size adjacent to the antennae farm. The Radar could be placed in this area, and as far away from the antennae as possible so that the area of blockage is as small as possible. A major purpose of Quarzazate is to look towards the main ridgeline of the Atlas Mountains. The antenna farm is more to the North of the proposed Radar site, leaving the area to the West (towards the Atlas) unobstructed.

On 31 July we returned to Casablanca. 1 August, Sunday, we did not go into the field.

On Monday, 2 August, Mr. Saouri inspected the potential site at Khemis Takate. Mr. Heggli was not able to join Mr. Saouri on this trip because of a relapse of a stomach condition which was first experienced on 29 July while in Midelt. Mr. Saouri reported that there was access to the site over a 7km dirt road. The site had access, power and telecommunications available.

On Tuesday, 3 August, Mr. Heggli joined Mr. Saouri in inspecting the potential site at Fnideq. The drive to Fnideq was so long that it was not possible to get to the location identified by the B&N team, but rather a fire lookout station was identified along the roadway; with access most of the way to the lookout. Power would need to be run from the road which no greater than 1 km to the proposed Radar site. There is a very large meteorological tower to the south of the lookout, and looking back to the Rif. There are also very large wind turbines on the ridgeline within 30 km of the site. The meteorological tower may possible block a very small angle on the Radar, but considering the difficulty in finding access and power to potential Radar sites, this is not thought to be a major issue.

On Wednesday, 4 August, a meeting was held with DMN and the Divisions of CNRM, CNEM, DSI, and DTE. A review of the Radar siting process was discussed. This was the first time the B&N team was told that the Tan Tan Airport was being included in a tender process for a Radar. It was of great surprise to the B&N team member that DMN had not considered to mention this during their planning process, or provided the B&N team information as to why this Radar was important, being that the Socio-economic study did not indicate this site was as important.

Summary:

DMN requested that all potential Radar site is to have existing infrastructure such as access, power, and telecommunications already present. This greatly reduced the possible number of sites in remote regions. Remote Radar sites that met these criteria were usually telecommunications sites that have numerous 30m and higher antenna. These antennas provide significant challenges in achieving 360 degrees unobstructed viewing.

All potential Radar sites on the schedule were visited. Three of the Radar locations suffered from potential blockage of the Radar beam from existing telecommunication antenna farms.

The operational tradeoff at these sites is to either accept the blockage from the telecommunication antenna, or incur greater cost in providing access and power to nearby sites. It is our opinion that nearby sites should be examined and the cost of providing access and power should be strongly considered. The Midelt Radar site would need to have road access.

The B&N team will provide a replacement site for Midelt. At other sites that were visited, DMN should move away from the antenna farms as far as possible. This will likely require DMN to incur greater expenses in providing a road to the site as well as power. DMN will either incur higher installation expenses or need to accept the blockage presented by the antenna farm. There will need to be a great deal more 'prospecting' by DMN. The B&N team will continue to support this endeavor through the end of the contract using the occultation and floor analysis tools that were optimized for this Radar feasibility study. Mr. Heggli has loaned Mr. Tahar a GPS to help DMN in future prospecting.

In the coming days the B&N team will be requesting the tender documents for Ben Guerir, Debdou, as well as Tan Tan Radar purchases. A request to Mr. Tahar Saouri for the geo-political boundaries will also be made. The B&N team will now work at wrapping up the project.

APPENDIX 5 E

TECHNICAL PAPER

Digital Receiver Signal Processing
and
Dual-Polarization Data Processing

1. INTRODUCTION

This paper describes the hardware and software elements which provide a DUAL-POLARIZATION weather radar function

1.1 Dual Polarity Radar Systems

The benefit of dual polarity weather radar technology is the improvement in measurement accuracy of the actual water content of precipitation.

With dual polarity, single radar can provide reliable precipitation measurements over a large area. This data can be used to provide more accurate flood forecasting and to improve water management for flood mitigation, power generation, navigation and water supply.

Installing and maintaining a network of rain gauges to cover the radar's area, with comparable resolution, would be prohibitively expensive and would present a significant maintenance challenge and operating cost.

Dual polarity capability is available as an option on many radar sensors. The option includes all required features for the antenna, transmitter, receiver, signal processor and the required processing software. The radar is still capable of providing all normal reflectivity and velocity products in addition to the dual polarity products.

1.1.1 Significant Advantages of Modern Radar Technology STAR (Simultaneous Transmit And Receive) Mode

This implementation of dual polarity transmits and receives horizontally and vertically polarized pulses simultaneously through the use of a power splitter and two identical receivers. The power splitter divides a single pulse into horizontal and vertical components of equal amplitude and coherent phase. One receiver is dedicated to each polarity.

The STAR mode avoids the problems inherent in switched dual polarity systems. Switch based systems tend to have reliability issues, and PRF restrictions.

In addition, the inherent coherency between the horizontally and vertically polarized signals in a STAR type system makes it possible to build a magnetron radar that is capable of a full range of reliable dual polarity capability.

The end result is reliable dual polarity radar without resorting to the additional cost and complexity of a Klystron based system, or the problems inherent in a system based on switching technology.

1.1.2 Dual Polarization Signal flow

The received horizontal and vertical signals are converted to a common I/F frequency, and are digitized and multiplexed onto a fiber optic link for transmission to the Signal Processor.

The signal processor processes the two data streams simultaneously in real time.

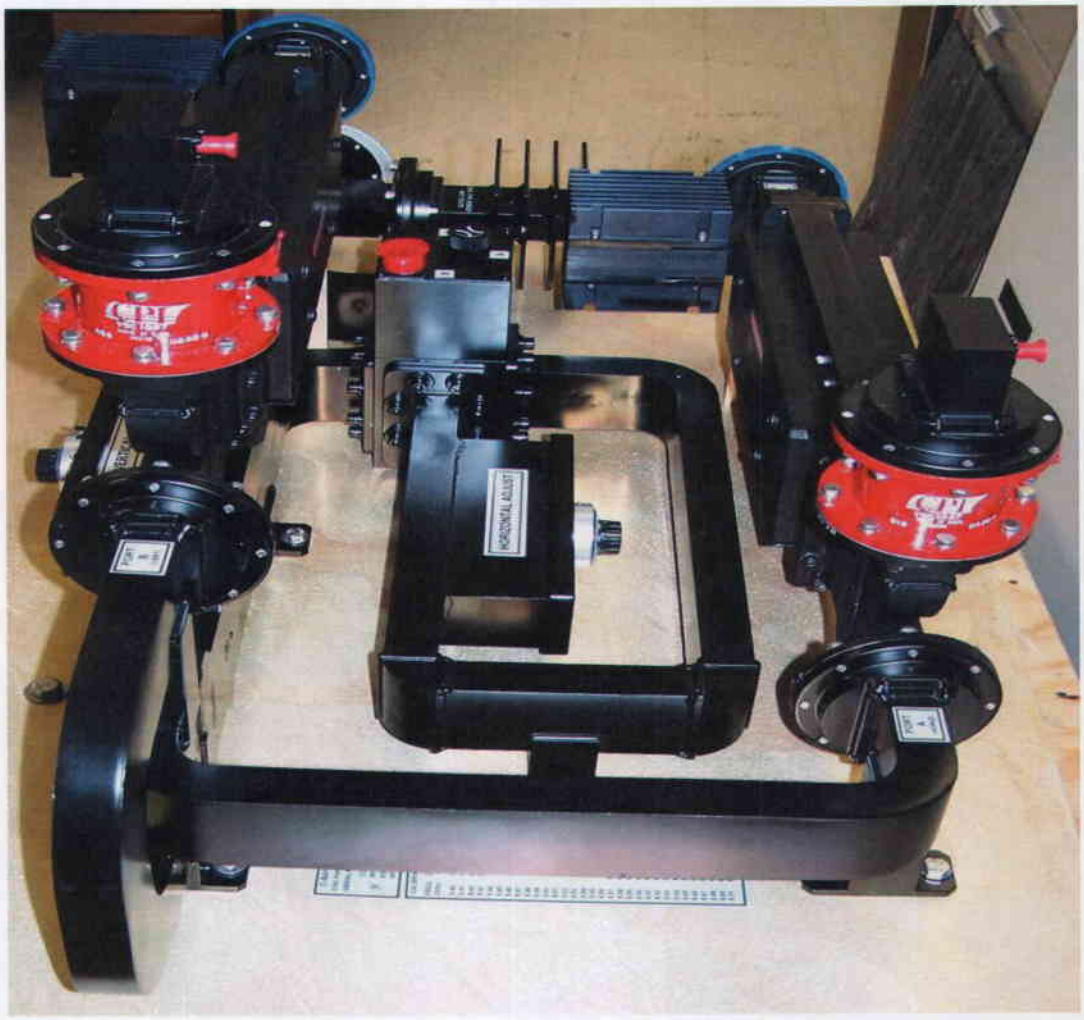
The output from the signal processor is a real-time data stream in radial format. Each radial of data includes an ID (radar ID, azimuth and elevation angles, time, etc.) followed by the data for each range bin in the radial. Each radial is a complete data set for that radial.

Note that when operating in dual polarity mode, the output data rate is significantly higher than in single polarity mode. In single polarity mode, the data includes reflectivity (Z), velocity (V) and spectrum width (W) data values for each range bin. In dual polarity mode, the data includes Z, V and W as well as data values for ZDR (differential reflectivity), KDP (specific differential phase), PHIDP (differential phase) and RHOHV (co-polar correlation). To preserve full real time operation, the data link between the radar and the central site must have sufficient bandwidth to handle the additional products. In most cases, this will require the full bandwidth of a T1 (1.544 Mbits/sec) circuit.

Doppler Weather Radars can be equipped with dual polarization capability feature thru a system reconfiguration of the hardware into a DPE. The DPE provides the hardware configuration additions for signal and data processing in a robust design includes the following features.

- Dual Polarimetric Scalar antenna

- Dual channel Microwave assembly with RF to IF analog receiver system with digitally controlled frequency synthesized C-band STALO and a high performance LNA. A Digital AFC unit is provided for STALO AFC control. The receiver also includes an integrated precision noise source for testing and calibration purposes.



- Doppler digital receiver and signal processor with a dual-channel IF Digitizer (IFD) packaged in a ruggedized rack mount chassis with redundant fans and power supply modules.

- Radar control processor (RCP) Interface PCA providing control and monitoring of the receiver environmental enclosure including the precision noise source.

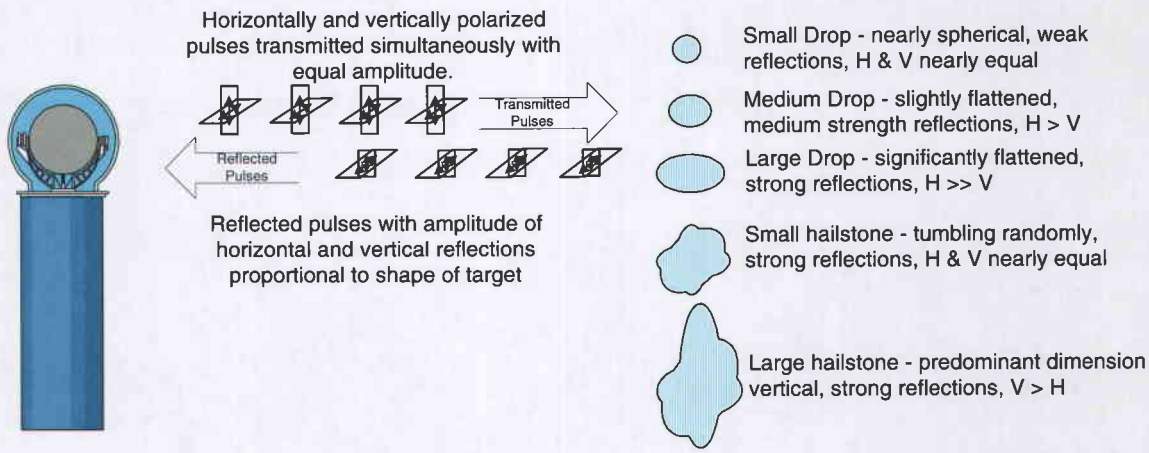
1.2 Dual Polarity Radar Theory

STAR type radars with the dual polarity software support the following dual polarity data products:

- ZDR - Differential Reflectivity
- PHIDP - Differential Phase Shift
- KDP - Specific Differential Phase Shift
- RhoHV - Co-polar Correlation Coherency Coefficient
- AZDR - Rain Correction Algorithm
- PPI/RHI/CAPPI - Products for both Polarizations
- HMC - Hydrometeor Classification
- HAIL - Hail Detection and Warning Product
- Many more

With traditional weather radar technology, the radar can only measure the total reflection. The total reflection is a function of the size, number and phase (rain, snow, hail, etc.) of precipitation particles (hydrometeors). Thus, determining the actual amount of liquid in the precipitation, or detecting a specific type of precipitation, such as hail, from only a radar image becomes at best an estimate which may be subject to large errors. Doppler adds the ability to measure velocity, which greatly enhances the radar's ability to detect certain types of severe weather.

There is a significant amount of research currently being done to determine how to get more precipitation information using a radar system. Much of that research is focused on radar systems that have the ability to control the polarization angle of the transmitted signal and to analyze reflectivity data at specified polarization angles. This is called a polarimetric (dual polarity) radar. Polarimetric techniques hold out the potential to greatly improve the accuracy of rainfall measurement, and to improve the accuracy of detecting specific types of precipitation within a storm cell. These advances are likely to make as big an improvement in radar based weather forecasting over Doppler radar as the addition of Doppler capability did over conventional weather radar.



ZDR (differential reflectivity) is one of the simplest polarimetric techniques. For ZDR, the radar transmits pulses with horizontal and vertical polarization, either simultaneously, or on alternating pulses. The differences in amplitude between the horizontally and vertically polarized reflections are analyzed to extract more information about the precipitation.

Small raindrops are nearly spherical and reflect horizontally and vertically polarized signals nearly equally. As raindrops become larger, they tend to flatten into oblate spheroids. This flattening is the result of air flow pressure on the bottom of the drop as it falls. Therefore, drops will tend to fall with the widest dimension of their shape aligned horizontally. The widest dimension (horizontal) will reflect horizontally polarized signals more strongly than the narrower dimension (vertical). Thus, the difference between the horizontally and vertically polarized reflections can provide an estimate of the size of the raindrops. This technique is referred to as differential reflectivity or ZDR.

ZDR has been demonstrated to provide ability to differentiate between hail and other types of precipitation. Small hail stones tend to be relatively symmetrical and tumble randomly as they fall. Therefore, there is little difference in amplitude between horizontally and vertically polarized reflections from hailstones. Large hail stones tend to be asymmetrical and fall with the longest dimension vertical (prolate), thus reflecting the vertically polarized signal more strongly. As a result, an area showing high dBZ reflectivity with a ZDR value of 3 or 4 dB is likely to be heavy rain. If the ZDR value is near zero, the reflection is very likely to be small hail. If the ZDR value is negative, it is likely to be large hail.

KDP is a parameter that research suggests may be useful in improving the accuracy of radar based rainfall estimates. Note that the "K" in KDP is different than the "K" in the Probert-Jones equation. In KDP, "K" is the specific differential phase shift per unit of distance, typically in degrees per km. In other words, KDP compares the phase shift of a horizontally polarized signal with the phase shift of a vertically polarized signal over the same distance. The research to date indicates that KDP has several significant advantages:

- Radar precipitation estimates that are independent of radar calibration.
- Measurement that is nearly linear with respect to rainfall intensity.
- Less dependence on drop size distribution than other parameters.

1.3 Dual Polarization Processing (Option)

For dual polarization systems, two channels (horizontal and vertical) are used to calculate additional physical moments. Depending on system configuration, the channel information can be acquired in parallel or by switching between the two channels from pulse to pulse.

For reflectivity processing, the two channels are calibrated separately. One is performed for the horizontal channel and one for the vertical channel. This compensates for any horizontal-vertical receiver chain signal offsets, which could bias the physical dual polarization moments like ZDR.

In dual polarization mode, the autocorrelation functions outlined in the figure above, are evaluated separately for each channel.

Additional parameters, which are estimated for dual polarization are :

- ZDR, H/V differential reflectivity
- PHIDP, H/V differential phase shift
- KDP, radial differential phase
- RHO-HV, coherence coefficient

Algorithms for rain retrieval require the use of dual polarization radar. This technique is based on „rain profiling". Instead of using the classical Z-R relationship, the rain rate estimation can be done by using the ZDR differential reflectivity and the differential phase shifts PHIDP and KDP.

From the horizontal channel, the following parameters are obtained:

- $T(0)_H$ - Unfiltered Autocorrelation zero lag
- $R(0)_H$ - Filtered Autocorrelation zero lag
- $R(1)_H$ - Filtered Autocorrelation first lag
- $R(2)_H$ - Filtered Autocorrelation second lag
- CZ_H - Corrected Calibrated Reflectivity
- UZ_H - Uncorrected Calibrated Reflectivity

From the vertical channel, the following parameters are obtained:

- $T(0)_V$ - Unfiltered Autocorrelation zero lag
- $R(0)_V$ - Filtered Autocorrelation zero lag

- $R(1)_V$ - Filtered Autocorrelation first lag
- $R(2)_V$ - Filtered Autocorrelation second lag
- CZ_V - Corrected Calibrated Reflectivity
- UZ_V - Uncorrected Calibrated Reflectivity

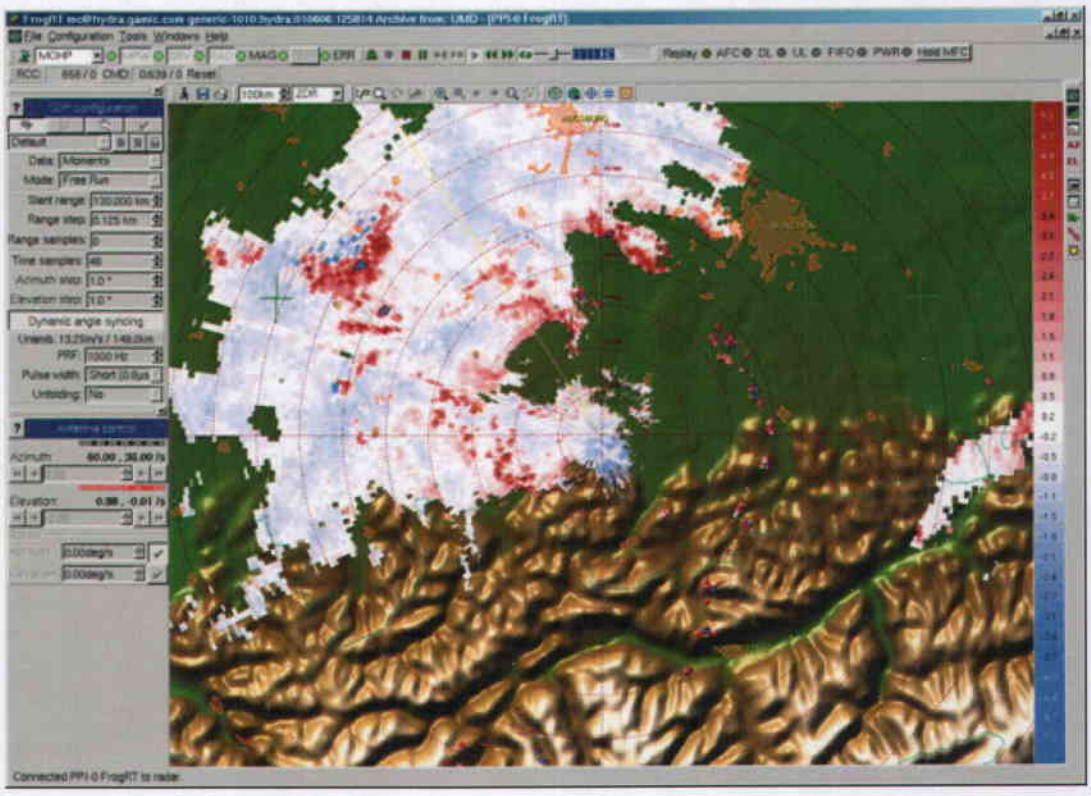
The estimations for radial velocity, spectral width, CCOR and SQI are estimated from the averaged AKF's as already outlined in the Doppler channel processing above.

Additional moments are calculated for dual polarization systems:

The **Differential reflectivity ZDR [dB]**, defines the ratio between the horizontal and vertical reflectivity as follows:

$$ZDR = \frac{CZ_H}{CZ_V}$$

ZDR (Differential Reflectivity) - Measures drop size distributions and the shape of the radar meteor.



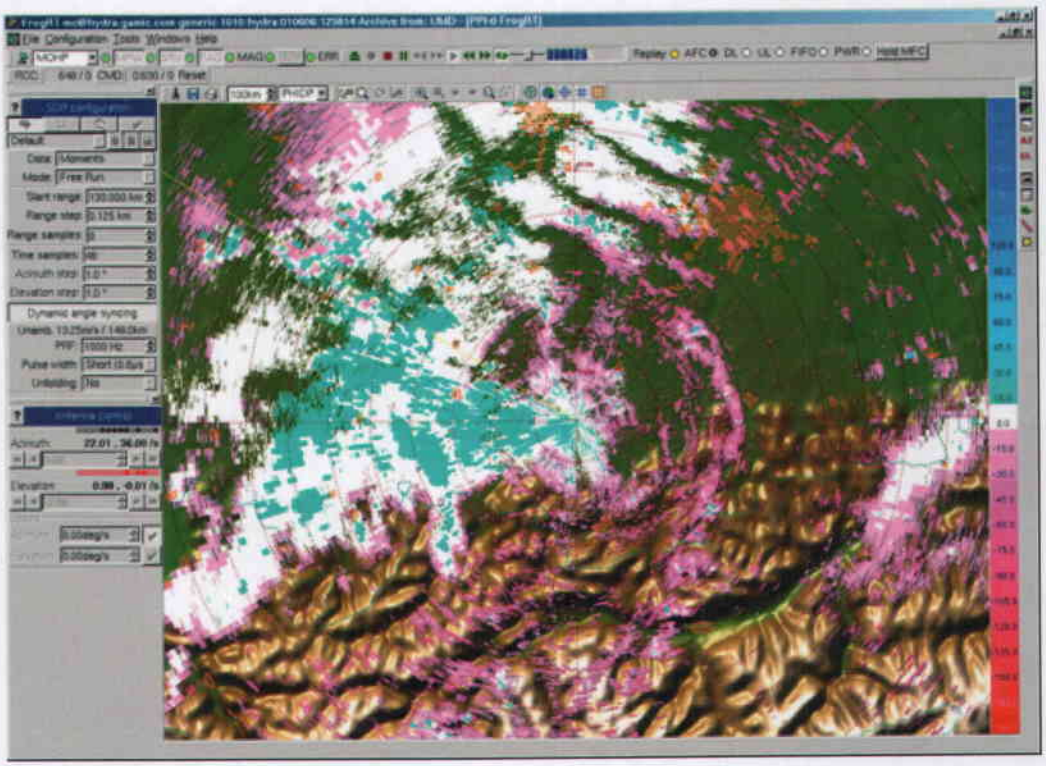
The **differential phase shift** is obtained from the cross-correlation of the two channels input data:

$$PHIDP = \arg\left(\frac{1}{M} \sum_{n=1}^{M} A_{nH}^{*} \cdot A_{nV} \right)$$

$\mathbf{A_H}$ - Horizontal channel complex time series value of I + jQ

$\mathbf{A_V}$ - Vertical channel complex time series value of I + jQ

PHIDP - Differential phase between H and V echoes of the same cell, can be effectively used for rainfall attenuation correction



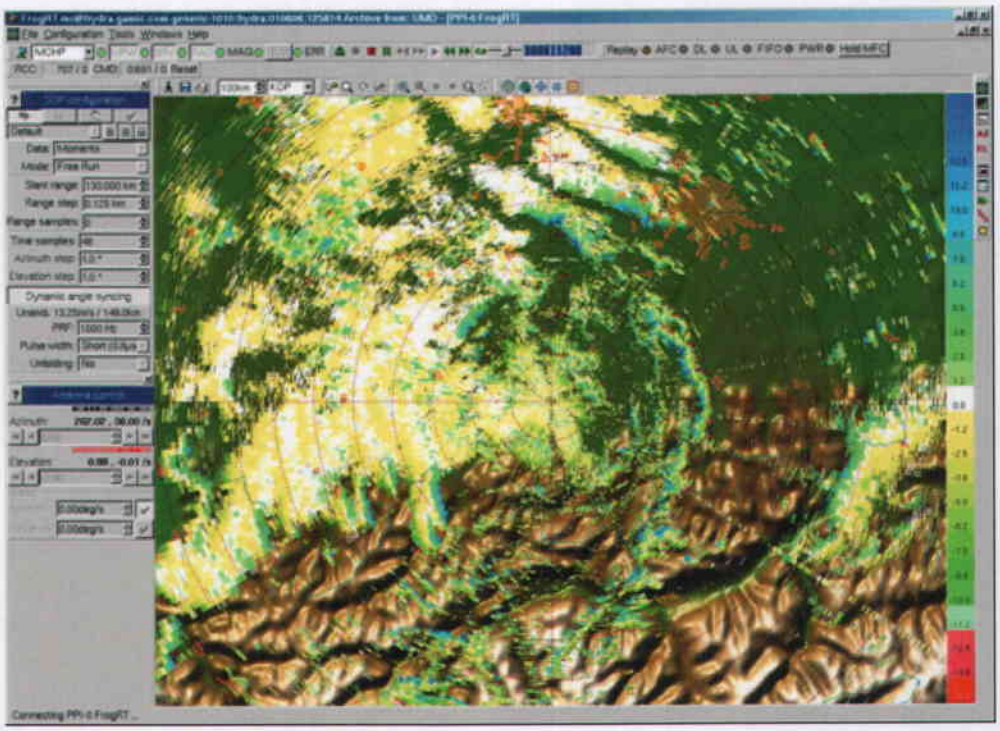
The **differential phase derivate** in the radial sense, KDP is defined as follows:

$$KDP = (PHIDP_i - PHIDP_{i-1}) / 2) r$$

KDP - The difference between the propagation constants (horizontal vs. vertical polarization) can be effectively used to estimate the rain rate R.

The following additional algorithms are applied to achieve an optimized result:

- Least square error interpolation (Savitzky-Golay method)
- Noise reduction
- Smoothing

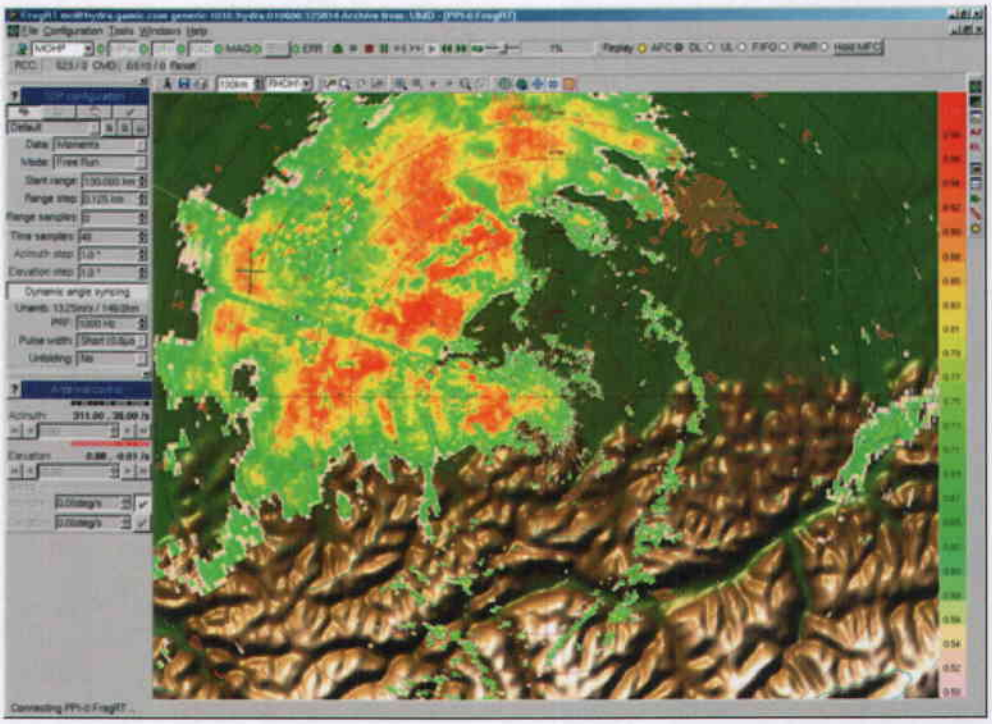


Coherency coefficient (RHOHV): Describes the similarities in the characteristics of H and V echoes, of shape and irregularities.

$|\rho_{HV}(0)|$

$$\rho_{HV}(0) = \frac{\left|\frac{1}{M}\sum_{i=1}^{M} H_i^* V_i\right|}{\sqrt{\hat{S}_H . \hat{S}_V}}$$

Hail = 0.90 – 0.95 (large hail is usually indicated by values <<0.90)
Rain => 0.95 – 0.99 (light rain is indicated by values < 0.90)



Additional post-processing algorithms are available on FROG – MURAN platforms.

1.4 Improved Dual-Polarization Algorithms for Rainfall Correction

When using a classical Z-R relation, there are three main sources of error:

1. Calibration error
2. DSD (Drop Size Distribution) uncertainty (a unique Z-R relation should not be applied to all rain type).
3. Attenuation (the measured Z is underestimated).

Dual polarization technique in weather radars is not new (the research effort started 20 years ago). Using the differential reflectivity ZDR or the specific differential phase shift KDP, people have been able in the past to demonstrate that they could improve the rain rate estimate:

- R(ZDR) estimator is independent of error calibration;
- R(Z,ZDR) estimator is independent of DSD uncertainty;
- R(KDP) estimator is independent of calibration error and of attenuation.

However, all the published algorithms require a very large number of independent samples, that is, a very long radar dwell time, not compatible with operational application. Moreover, these techniques only apply at S band, since at C or X band, attenuation or differential attenuation cause biasing of Z and ZDR and degrade severely the rain rate estimate.

1.4.1 Attenuation Correction Algorithm

For dual polarization radars ENIGMA III+ provides a attenuation correction based on the polarimetric measurement. The horizontal reflectivity is corrected for attenuation by the following formula:

$Z_h(r) = Z_h'(r) + \alpha[\Phi_{DP}(r) - \Phi_{DP}(0)]$Bringi et al 1990 (26)

with

$\Phi_{DP}(r)$	differential phase at range r
$\Phi_{DP}(0)$	differential phase at range 0
$Z_h(r)$	corrected reflectivity at range r
$Z_h'(r)$	uncorrected (measured) reflectivity at range r
α	reflectivity correction parameter in the range 0.04-0.15 (typically 0.08 for C-Band radars)

The differential reflectivity ZDR is corrected for attenuation by the following formula:

$Z_{DR}(r) = Z_{DR}'(r) + \beta[\Phi_{DP}(r) - \Phi_{DP}(0)]$Bringi et al 1990 (27)

With

$\Phi_{DP}(r)$	differential phase at range r
$\Phi_{DP}(0)$	differential phase at range 0
$Z_{DR}(r)$	corrected reflectivity at range r
$Z_{DR}'(r)$	uncorrected (measured) reflectivity at range r
β	reflectivity correction parameter in the range 0.01-0.03

The corresponding parameter are **RainfallAttenuation_alpha** and **RainfallAttenuation_beta** which can be adjusted through telnet or in the extended parameters of Frog/MURAN.

The parameter$\Phi_{DP}(r)$is unfolded and thresholded bins are interpolated prior to this algorithm (the same applies to the estimation of KDP).

The algorithm is applied to the (clutter) corrected reflectivity Z and the corrected differential reflectivity ZDR. The resulting moments are called AZh and AZDR.

In order to verify this algorithm, it is necessary to inject a dual polarization signal that contains a (for example constant) change in the differential phase over the range. The generation of such a signal in real-time is close to impossible (orrequires very expensive equipment). A synthetic signal (similar to the signal used for the KDP verification).

APPENDIX 5 F

List of Potential US Manufacturers

Baron Services, Inc.
4930 Research Dr.
Huntsville, AL 35805
Phone: 256.881.8811
Fax: 256.881.8283

EWR Weather Radar Systems
336 Leffingwell Avenue
Suite 112
Saint Louis, Missouri 63122
Phone: 314.821.1022
Fax: 314.821.5622
Aero Express, Inc.
1825-1 SW Market St.
Lee's Summit, MO 64082
TOLL FREE: 800-580-2376
Phone: 816-246-4500
Fax: 816-246-1452

Ambient Weather
6845 W. Frye Road
Chandler, AZ 85226
Phone: 480-346-3380
Fax: 480-346-3381

APG Eastern Avionics International, Inc.
Charlotte County Airport
28260 Airpark Drive, #114
Punta Gorda, FL 33982
Phone: 941-637-8585
Fax: 813-637-0388
Web site: www.apgavionics.com

Enterprise Electronics Corporation (EEC)
128 S. Industrial Blvd.
Enterprise, AL 36330
Phone : 334.347.3478
Fax: 334.393.4556

Radtec Engineering, Inc.
18330 Minnetonka Blvd.
Deephaven, MN 55391
Phone: 952-473-3483
Fax: 952-473-3966

Advanced Designs Corporation
1169 West 2nd Street
Bloomington, In 47403
Phone: (812) 333 1922
Fax: (812) 333 2030
Matt McGrath, President
mmcgrath@doprad.com

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6. ECONOMIC, FINANCIAL, AND SOCIO-ECONOMIC ANALYSIS (TASK 5)

Enhanced weather and climate data can have substantial economic value across a range of economic sectors and geographical settings. The economic value can range from tens of millions to hundreds of millions of dollars for individual economic sectors and events.

6.1. Background

The Kingdom of Morocco periodically experiences exceptional rainfall events which lead to flooding and landslides. These disasters often result in the loss of hundreds of human lives as well as considerable damage to property. The occurrence of weather-related disasters in the region and in the country in particular, underscores the importance of having an early warning system as a component in total disaster risk management system.

The Moroccan National Meteorology Department (DMN) is at the forefront of disaster mitigation activities as the government mandated agency responsible for issuing warnings and bulletins notifying of floods and other weather-related hazards. Given DMN's mandates, an effective weather radar surveillance system will provide benefit to a broad range of institutions and stakeholders. This includes flood forecasting, civil aviation, agrometeorology, and weather modification.

Specifically, DMN is in the process of upgrading its weather radar system to satisfy the current and future operational needs of DMN. This upgrade will enhance radar coverage will provide weather radar coverage in all areas of significant socio-economic concern, and will provide the most complete weather radar coverage compared to any other country. Given the benefits and developmental impacts of the Project on the civil aviation, agricultural and environmental sectors, there are strong incentives for lending institutions that are currently active those two sectors to support this project

6.2. Cost of Losses Associated with Existing Capabilities

The economic losses associated with the existing meteorological system of Morocco are difficult to assess quantitatively. DMN's system impacts many economic sectors. One significant area of DMN's responsibilities involves the impact of severe weather on the Country. Historical data is available from www.peventionweb.net quantifying the current level of losses from severe weather. This data suggests an average $39 million of damages result from severe weather events each year affecting approximately 400,000 people. However, individual events can be substantially higher; For instance, the 1999 drought had an economic impact of $900 million and impacted 275,000 people. Not only are there damages associated with these weather events **but** there is also significant loss of life; on average 68 people per year.

Research performed by B&N Team summarizes on **Table 6.3** suggests a total damage impact of $6.9 million per year is readily supportable as a minimum value.

Table 6.1 Damages from Severe Weather Events 1980 – 2010
(www.preventionweb.net)

	Affected per Year	Killed per Year	Damages per Year $US x 1000
Drought	91,667	0	30,000
Flood	12,257	60	9,000
Extreme Temperature	---		27
Storms	---	7.5	2
Total Direct Damages	**377,324**	**68**	**39,000**
Deaths valued at $525,750 per section 3.4 of this report			35,751
Total Damages			**74,751**

Table 6.2 Population Affected by Severe Weather Events 1980 – 2010
(www.preventionweb.net)

	Population Exposed in High Hazard Areas	Population Affected Per Year	% Affected	GDP Exposure $US x 10000
Drought	7,500,000	91,667	1.2%	
Flood	23,500	12,257	52%	70,000
Extreme Temperature				
Storms	16,000			30,000
Total				100,000

Table 6.3 Estimated Damage Summary

Category	Damages MAD	Damages $USD 1000
Human Lives	161,667,100	19,020
Direct Damage	5,059,915	595
Employment	11,855,520	1,395
Industrial Activity	534,880,400	62,927
Agricultural Activity	309,147,935	36,370
Construction	181,550,540	21,359
Property	125,382,100	14,750
Roads	13,735,130	1,616
Total	**1,343,278,640**	**158,032**
Number of Years	**23**	**23**
Average Per Year	**58,403,419**	**6,871**

Some percentage of these losses shown in Tables 6.1 through 6.3 could have been avoided with enhanced weather data leading toward better and timelier disaster planning and responses.

6.3. Potential for Reduced Losses Incurred with the Meteorological System Upgrade Program

Virtually every sector and individuals who base decisions about their everyday activities on the daily weather forecast benefit in some way from better weather and climate communication. Cost savings come in two forms: 1) people are more likely to invest in loss-reduction activities when better information is available; 2) better information can also reduce economic costs that arise when uncertainty about adverse weather causes government authorities, people, and business to "err on the side of caution" and undertake what later may turn out to be unnecessary loss-reduction activities.

These benefits derive from the fact that weather and climate information can help reduce uncertainty in:

- Improved Civil Government and Military Planning
- Responding to Natural Hazards
- Improved Industrial Planning
- Insurance and Hedging
- Tropical Cyclone Monitoring.
- Flood Management

Meteorological services support the day-to-day agricultural activities such as scheduling of farming operations including planning, irrigation, spraying and harvesting. Crop and livestock production are also affected by weather and climate. Timelier agro meteorological services will help minimize the adverse effects of extreme climate events while taking full advantage of favorable weather conditions at the different stages of production.

An important task of meteorological and hydrological services is the effective management of the country's water resources in cooperation with other agencies. Water resource development projects involving construction of dams, artesian wells, water and sewerage treatment plants designed on the basis of local climate data will benefit from this Project through improved maintenance and operation.

Weather is an important and contributing factor in the outbreak and spread of airborne diseases, and pollution, among others that can be mitigated by using improved and timelier forecasts arising from this Project. Reduced response times and improved effectiveness and coordination of response to weather induced environmental disturbances and floods

In each of these instances, new enhanced systems have value only to the extent that more timely information reduces uncertainty in ways that are economically valuable. In the case of planning for and responding to natural hazards, information about weather and climate will be valuable to the extent that: (1) having more information provides a measurable or significant reduction in uncertainty; and (2) reducing uncertainty "matters" in the sense that having more, or more reliable information has the potential to affect choices made by individuals, businesses, and government.

The value of weather and climate information itself is relatively small as a percentage of the economy. However, when dealing with weather and climate where each year millions of dollars and tens of lives are lost as a result of severe weather events, even a small improvement in predictive capability can add up to major savings in emergency planning for floods and hurricanes, as well as its application for industry, particularly the energy and utility sectors.

For the purposes of this analysis, it is assumed that reduced losses will be a small percentage (<5%) of the average annual damages calculated by www.preventionweb.net (Table 6.1) of $75 million from severe weather losses or $3.75 million per year.

6.4. Project Description

It is against this backdrop that DMN is embarking on a project to upgrade its weather radar network (Project) to ensure that weather observations are made in a manner that is timely, complete, and accurate and that warnings are formulated and disseminated to communities at risk. This Feasibility Study proposes the installation of nine (9) weather radars at a cost of $28,200,000. In addition, capacity building in maintenance and operation training is proposed at a cost of $360,000. Annual maintenance of $2.8 million is estimated. The specific equipment and services to be procured include:

Table 6.4 Project Cost

Item	Quantity	Total Cost
Weather Radar	9	$28,200,000
Training	1	$360,000
1st Year Maintenance	1	$2,800,000
Total		$31,360,000

6.5. Economic Justification

The cost of direct damages caused by natural hazards in Morocco exceeded $1.5 billion over the last thirty years. There is a strong economic incentive to reduce this impact. In addition, shipping and transportation will benefit from improved forecasting. Specific sectors of society have varying needs for meteorological, hydrological and allied services which will continue to grow to meet the demands of environmental changes and development. This Project will assist DMN to respond adequately to meet these changing requirements.

The value of weather and climate information itself is relatively small as a percentage of the economy. However, when dealing with weather and climate where each year millions of dollars and tens of lives are lost as a result of severe weather events, even a small improvement in predictive capability can add up to major savings in emergency planning for severe weather events, as well as its application for industry, particularly the energy and utility sectors.

6.6. Morocco Credit Rating

Credit agencies rate the banking sector of the Kingdom of Morocco as BBB-/Stable. According to Standard and Poor's Although Morocco has made significant progress toward diversification, its economy is skewed toward some cyclical sectors, especially agriculture and tourism, which leaves the country's economic performance vulnerable to external factors. In addition, Morocco's political situation has been tense since the unrest in many Arab countries. This has dampened credit demand and investment.

6.7. Lender Evaluations

World Bank

The World Bank (including IBRD) is not a likely candidate as the project does not align well with the current World Bank Strategy. The current 4-year period (2010-2013) strategy focuses on three thematic pillars aligned with the development priorities of the country:

1. Enhance growth, competitiveness and employment;
2. Improve service delivery to citizens; and
3. Ensure environmental sustainability in the context of a changing climate.

Morocco's future economic development is vulnerable to energy supply disruption and price volatility, water scarcity and natural resource depletion. Climate change impacts are already felt today. Activities under the third CPS Pillar aim to support government's renewed attention to long standing environmental sustainability issues and future challenges brought about by climate change and may present an opportunity in a broader program involving this pillar.

Islamic Development Bank (IDB)

IDB is a potential source of funding should this Project demonstrate that it can foster economic development and social progress in Morocco. The IDB provides loans and grants to finance development activities in member countries as well as in Muslim communities in non-member countries. It also provides technical assistance for capacity building and scholarships for human capital development. The IDB Group is engaged in a wide range of relevant activities including:

1. Project financing in the public and private sectors;
2. Development assistance for poverty alleviation;
3. Technical assistance for capacity-building; and
4. Emergency relief.

USAID

USAID is not a candidate for funding this project as it focuses on studies not equipment purchase and its goals do not align with this project. USAID's country goal for the period 2009-2013 is a well-governed, democratic, and prosperous Morocco meeting the needs of its people, especially youth. USAID/Morocco's three Assistance Objectives directly reflect the USAID response to the four established goals of the Morocco CAS and are as follows:

1. Increased Participation of Citizens, Especially Youth, in Governance
2. More Relevant Education and Opportunities for Youth ; and
3. Reduced Barriers to Trade and Investment.

The African Development Bank (ADB)

ADB pillars of investment are based on the following four criteria: (i) alignment on the main priorities of the country's National Development Agenda; (ii) increased Bank intervention in activities in which it has a proven comparative advantage and which a have a huge developmental impact and major structuring effects on the whole economy; (iii) increased harmonization of donor interventions and national ownership of reforms; and (iv) support to efforts aimed at reducing poverty and facilitating attainment of certain Millennium Development Goals. ADB has spent less than 4% of funds in the environmental area. Therefore, ADB is not a strong candidate for funding this project unless the project could be tied into improved water and energy supply.

Kuwait Fund

The Kuwait fund is not a likely source as it focuses on pre-investment activities. The Kuwait Fund assists Arab and other developing countries in developing their economies particularly by providing them with loans required for the implementation of their development programs. Eligible projects have direct development impact and high priority rating in the development programs of the countries. Technical assistance grants are provided to finance pre-investment feasibility studies aiming at exploring the opportunities for the build-up of productive capacities and for technical and economic advisory services.

Most Likely Lender: United States Export Import Bank (Exlm Bank)

Based on a discussion with the Exlm Bank, the Bank is open for lending in all sectors of the Morocco and would consider providing export financing or insurance for this project. The Exlm Bank has already provided export support for two projects involving similar products in 2007. Due to the Sovereign nature of this project, the United States Export Import Bank (Ex-Im Bank) is the most likely lender for this project. Ex-Im Bank assists exporters by guaranteeing term financing to creditworthy international buyers, both private and public sector, for purchases of U.S. goods and services. With Ex-Im Bank's loan guarantee, international buyers are able to obtain competitive term financing from lenders when financing is otherwise not available or there are no economically viable interest rates on terms over one-to-two years.

6.8. Financing Requirements

Eligibility

Ex-Im Bank's guarantee of a lender's loan to an international buyer is generally used for financing purchases of U.S. capital equipment and services. Goods eligible for Ex-Im Bank financing must meet Ex-Im Bank's foreign content requirements. Goods eligible for Ex-Im Bank financing must be shipped from the United States to an international buyer. U.S. flag vessel requirements must be complied with in connection with any guarantee transaction that is over $20 million (excluding Ex-Im Bank Exposure Fee). Prior to approving certain transactions, Ex-Im Bank will take into account the economic impact of a particular transaction (see Ex-Im Bank policies – Economic Impact[1]) and the environmental effects (see Ex-Im Bank policies – Environment[2]). Ex-Im Bank's Charter requires Ex-Im Bank to assess whether the extension of its financing support is likely to yield a net adverse economic impact on U.S. production and employment or would result in the production of substantially the same product that is the subject of specified trade measures. If a transaction is deemed by Ex-Im Bank to meet the legislatively specified standards, then economic impact can be the basis for denial of Ex-Im Bank support.

[1] Economic Impact Policies: www.exim.gov/products/policies/econ_impact_proc.cfm)
[2] Environmental Policies: www.exim.gov/products/policies/environment/envproc.cfm)

Coverage

Ex-Im Bank's loan guarantee covers 100% of principal and accrued interest on any amount. The total level of Ex-Im Bank support will be the lesser of 85% of the value of all eligible goods and services in the U.S. supply contract or 100% of the U.S. content in all eligible goods and services in the U.S. supply contract.

Cash Payment

Ex-Im Bank requires the buyer to make cash payment to the exporter equal to at least 15% of the U.S. supply contract. The 15% cash payment can either be borrowed from a lender or the exporter at market terms, or be from the buyer's own funds.

Repayment Terms

Repayment terms up to five years are generally available for exports of capital equipment and services.

Medium-Term Credit Standards

To qualify for Ex-Im Bank's medium-term financing, borrowers must meet certain credit standards, depending on the size of the transaction, the nature of the buyer, and the goods and services being financed. If a buyer does not meet these standards, the use of guarantors and other credit enhancements may be used to qualify.

Final Commitment (AP)

If the contract has been awarded, either the lender or the international borrower may submit the loan guarantee application. If the contract has been awarded and there is a lender ready to finance the transaction with Ex-Im Bank's support, a final commitment (AP) application may be submitted.

Letter of Interest (LI)

If the contract has not been awarded, then a lender, an exporter or an international borrower may request a nonbinding letter of interest (LI) containing Ex-Im Bank terms for the specific transaction. The LI is processed within seven working days, is valid for six months, and can be renewed.

Financing Costs, Interest Rates, Equity Requirements, Repayment Terms

The loan terms shown below assume United States Export Import Bank financing.

- Letter of Interest Application Processing Fee: $100
- Preliminary Commitment Application Processing Fee: 0.1 of 1% of the financed amount
- Commitment Fee: 0.125% per annum on the undisbursed balance of the loan
- Ex-Im Bank Exposure Fee: 5.68% up front
- Interest Rate: 1.38%

6.9. Financial Evaluation

Assumptions

Table 6.5 Assumptions

Category	Assumption	Comments
Equity	15%	See section 6.8
Debt	85%	See section 6.8
Term	5 years	See section 6.8
Interest Rate	1.38%	See section 6.8
Fees Upfront	5.68%	See section 6.8
Fees on Balance	0.125%	See section 6.8
Project Cost	$31,360,000	See section 6.4
Operations & Maintenance	$2,800,000	See section 6.4
Depreciation	20 Years	Typical value for such hardware
Escalation	1.8%/year	See discussion below
Damage Avoidance	$3,750,000/year	See Section 6.3

Inflation and Exchange Rate

Inflation in Morocco for the last five years has averaged 1.8% per year with the last three years having been at a 1% per year rate although December 2011 was 1.7%. The Moroccan dirham exchange rate to the US dollar has remained fairly steady over the last five years at 8.5 ±0.3. For this analysis a 1.8% inflation (escalation) and a steady exchange rate was assumed.

Table 6.6 Inflation and Exchange Rates

Year	Inflation,%	$US Dollar/ MAD Exchange Rate
2007	2.036	8.590
2008	3.891	8.115
2009	0.972	8.474
2010	0.994	8.829
2011	0.9 est.	8.478
Average	1.759	8.497

6.10. Financial Projections

The 20-year proforma for the project is included in Appendix 6.1. Summaries of the financial data are presented in Tables 6.7 (Project Profile), 6.8 (Summary Proforma), and 6.9 (Summary Balance Sheet).

Table 6.7 Project Financial Profile

Overnight Construction Capital	$31,360,000
Land	$0
Overnight Project Cost	**$31,360,000**
Interest During Construction	$108,070
Financing Costs	$1,514,061
Project Total Cost Including IDC & All Financing Costs	**$32,982,131**
Initial Loan Value	$26,656,000
Loan Value to Overnight Construction	85%
Loan Value At Startup	$26,764,070
Loan at Startup to Total Project Cost	81%
Exlm Loan Term, years	5
Bank Loan Term, years	5
Exlm Loan Interest Rate	1.51%
Bank Loan Interest Rate	1.51%
Financing Costs	$1,514,061
Construction Period, months	12
Project Length, years	20
Total Equity	
Land Cost	$0
Utilities Cost	$0
Development Costs	$0
Equity from DMN	$3,622,000

Table 6.8 Summary Proforma

Total Equity	$3,622,000			
Total Capital Cost	$31,360,000			
Total Cost	$32,982,131			
Project Level IRR after local tax	13.0%			
Net Present Value	$1,394,655			
Discount Rate	10%			
Years to Recover Equity	9			
	2011	**2012**	**2013**	**2020**
		$0	$0	$0
		$0	$0	$0
Savings		$0	$3,817,500	$4,248,794
Total Damage Avoidance		**$0**	**$3,817,500**	**$4,248,794**
Total Cost of Operation		$0	$2,856,000	$3,216,320
Interest		$402,388	$201,703	
Depreciation		$1,319,285	$1,319,285	$1,319,285
Amortization		$0	$0	$0
Income Before Taxes		**($1,721,674)**	**($559,488)**	**($286,811)**
Taxes	0%	$0	$0	$0
Economic Payback		($1,721,674)	($559,488)	($286,811)
Economic Payback without Depreciation	**($3,622,000)**	**$0**	**$0**	**$1,026,464**

Table 6.9 Summary Balance Sheet

Cash			
Accounts Receivable			
Prepaid Expenses			
Total Current Assets			
Fixed Assets	$32,982,131	$32,982,131	$32,982,13
Accumulated Depreciation	$0	$16,491,065	$32,982,13
Net Fixed Assets	$32,982,131	$16,491,065	$0
TOTAL ASSETS	$32,982,131	$16,491,065	$0
Accrued Taxes			
Short Term Loans			
Accounts Payable			
Total Current Liabilities			
Long Term Debt	$26,736,773	$0	$0
Equity Additions			
Retained Earnings			
Total Shareholders' Equity	$6,245,358	$16,491,065	$0
TOTAL LIABILITIES	**$32,982,131**	**$16,491,065**	**$0**

6.11. Sensitivity Analysis

Summary

A sensitivity analysis was performed for the Project considering the factors that are expected to have the greatest impact on the project as measured by payback period. Disaster economic cost savings and operating costs dominate the project sensitivity. Following behind those factors with a lesser impact are interest and construction.

Interest Rates

Given the nature of the current credit market, interest rates are a variable of considerable concern. The base proforma adopted a 1.38% Libor interest. Changes in interest rate had little impact on the payback period.

Construction Cost

Construction costs are an area where change can be expected. The potential impact of construction cost inflation was assessed and:

A 10% reduction in construction cost from the base proforma has no impact on the payback; while

- A 10% increase in construction cost from the base proforma increases the payback by one half of a year; and
- A 20% increase in construction cost from the base proforma increases the payback by a full year.

The impact of changes in construction cost has a moderate but manageable impact on the project.

Table 6.10 Impact of Construction Cost

Change in Construction Cost	Payback, Years
-10%	9.0
0%	9.0
+10%	9.5
+20%	10.0

Disaster Economic Damage Prevention

The base proforma assumes economic savings of $3.75 million/year in disaster prevention. This value varies by year and can be subjective. The evaluation of the impact of changes in disaster cost prevention on the project indicated that:

- A two percentage point increase in economic savings reduced the payback by two years and
- A two percentage point reduction in economic saving increased the payback to 25 years.

Without question, disaster economic savings is the most dominant sensitivity factor affecting the project.

Table 6.11 Impact of Disaster Savings

% of Disaster Economic Cost Prevented	Payback, Years
7%	7
5%	9
3%	25

Operating Costs

- The base proforma assumed an operating cost of $2.8 million a year.
- A 10% increase in operating cost extends payback by two years; while

- A 10% decrease in operating cost shortens payback by one year.

The impact of changes in operating cost has a moderate but manageable impact on the project.

Table 6.12 Impact of Operating Costs

Operating Costs, % Increase	Payback, Years
-10	8
0	9
10	11

6.12. Risk Analysis

A risk analysis was performed to identify the predominate risk factors that may affect the project. These involved both controllable and uncontrollable risks. The identified risk factors are identified in Table 6.16 along with potential risk mitigation approaches.

Table 6.13 Risk Analysis

Risk Factor	Mitigation
War	Beyond project control, Insure as possible
Political Instability	Beyond project control, Insure as possible
Terrorism	Beyond project control, Insure as possible
Natural Hazards	Beyond project control, Insure as possible Implement construction standards consistent with hazard potential.
Economic	Complete project in increments to optimize timing of economic impacts
Material Shortages	Lock in supply contracts at project start
Construction Management	Hire and maintain a highly professional experienced construction management staff. Insure project completion.
Project Management Continuation	Key Man Insurance
Convertibility of funds	Laws and investment agreements address convertibility issues. There are minimal restrictions on transferring funds, supported by laws and bi-lateral treaties. Risk mitigation insurance will further reduce financial risk.

Cash Flow Projections Summary

Based on the above loan terms and conditions the cash flow of the project is projected along with the savings estimated to result from the project implementation.

Table 6.14 Cash Flow Analysis

Moroccan Weather Radar Network Feasibility Study
10-Year Cash Flow $US in thousands

			2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Annual payback			($1,722)	($559)	($5[illegible])	($447)	($390)	($333)	($299)	($287)	($275)	($262)
Depreciation			$1,319	$1,319	[illegible]319	$1,319	[illegible]319	$1,319	$1,319	$1,319	$1,319	$1,319
Debt												
Cash In Flow	$2,674	$23,982										
Principal Repayments			($2,386)	[illegible]974	($5,419)	[illegible],464)	($5,513)	($2,590)	($2)	$0	$0	$0
Capital Spending	($2,674)	($30,308)										
Sub Total	$0	($6,326)	[illegible]	($4,615)	[illegible]	[illegible]591)	($4,584)	($1,604)	$1,019	$1,032	$1,045	$1,057
Equity Additions		$6,326										
Change in Working Capital			$0	($305)	($5)	($6)	($6)	($6)	($6)	($6)	($6)	($6)
Sub Total	$0	$0	($2,788)	($4,920)	($4,608)	($4,597)	($4,590)	($1,609)	$1,013	$1,026	$1,039	$1,051
Cash Flow	$0	($6,[illegible])	$0	$0	$0	$0	$0	$0	$1,013	$1,026	$1,039	$1,051
Undistributed Payback			$0	$0	$0	$0	$0	$0	$1,013	$2,039	$3,078	$4,129
Debt Coverage			1.00	1.00	1.00	1.00	1.00	1.00				

DRAFT

PROFORMA OUTPUT

DMN Weather Radar Proect		2/19/2012
Total Equity	$ 3,622,000	
Total Capital Cost	$ 31,360,000	
Total Cost	$ 32,982,131	
Project Level IRR after Malian Tax	13.0%	
Net Present Value	$ 1,394,655	
Discount Rate	10%	
Yrs to Recover Equity	9	

	0	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Damage Savings	$ -		$ 3,818	$ 3,886	$ 3,956	$ 4,027	$ 4,100	$ 4,174	$ 4,249	$ 4,325	$ 4,403	$ 4,482	$ 4,563	$ 4,645	$ 4,729	$ 4,814	$ 4,901	$ 4,989	$ 5,079	$ 5,170	$ 5,263	$ 5,358
Total Revenues	**$ -**	**$ -**	**$ 3,818**	**$ 3,886**	**$ 3,956**	**$ 4,027**	**$ 4,100**	**$ 4,174**	**$ 4,249**	**$ 4,325**	**$ 4,403**	**$ 4,482**	**$ 4,563**	**$ 4,645**	**$ 4,729**	**$ 4,814**	**$ 4,901**	**$ 4,989**	**$ 5,079**	**$ 5,170**	**$ 5,263**	**$ 5,358**
Total Cost of Operation	$ -	$ -	$ 2,856	$ 2,913	$ 2,971	$ 3,031	$ 3,091	$ 3,153	$ 3,216	$ 3,281	$ 3,346	$ 3,413	$ 3,481	$ 3,551	$ 3,622	$ 3,695	$ 3,768	$ 3,844	$ 3,921	$ 3,999	$ 4,079	$ 4,161
Interest	$ -	$ 402	$ 202	$ 157	$ 113	$ 67	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Depreciation		$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319	$ 1,319
Amortization	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Income Before Taxes	**$ -**	**$ (1,722)**	**$ (559)**	**$ (503)**	**$ (447)**	**$ (390)**	**$ (333)**	**$ (299)**	**$ (287)**	**$ (275)**	**$ (262)**	**$ (250)**	**$ (238)**	**$ (225)**	**$ (213)**	**$ (200)**	**$ (187)**	**$ (174)**	**$ (161)**	**$ (148)**	**$ (135)**	**$ (122)**
Taxes		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Net Income	**$ -**	**$ (1,722)**	**$ (559)**	**$ (503)**	**$ (447)**	**$ (390)**	**$ (333)**	**$ (299)**	**$ (287)**	**$ (275)**	**$ (262)**	**$ (250)**	**$ (238)**	**$ (225)**	**$ (213)**	**$ (200)**	**$ (187)**	**$ (174)**	**$ (161)**	**$ (148)**	**$ (135)**	**$ (122)**
Income To Investors	**$ (3,622)**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 1,013**	**$ 1,026**	**$ 1,039**	**$ 1,051**	**$ 1,063**	**$ 1,075**	**$ 1,088**	**$ 1,100**	**$ 1,113**	**$ 1,125**	**$ 1,138**	**$ 1,151**	**$ 1,164**	**$ 1,177**	**$ 1,190**
Debt Coverage		1.00	1.00	1.00	1.00	1.00	1.00	630.39	#DIV/0!	#DIV/0!	#DIV/0!	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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7. PRELIMINARY ENVIRONMENTAL IMPACT STATEMENT (TASK 6)

Enhanced weather and climate data can have substantial economic value across a range of economic sectors and geographical settings. The economic value can range from tens of millions to hundreds of millions of dollars for individual economic sectors and events.

7.1. Introduction

Nine new radars are recommended to improve weather forecasting and assist in preserving and protecting the environmental resources and socio-economic conditions in Morocco. The new radars will have a positive impact on the tourism and agriculture sectors, unemployment, transportation and goods movements, and private industries. Section 9.0 - Development Impact Assessment (Task 8) will summarize these impacts in more detail.

This section identifies potential environmental impacts (temporary and long-term) of each of the recommended Radar locations and presents measures that can be implemented to mitigate these impacts. Section 6 – Economic, Financial and Social Economic Analysis of the Project (Task 5) presented several opportunities that may be used to fund the radar installations. These funding opportunities will likely require documentation of the potential environmental impacts of the radar installations and the measures that can be taken to mitigate these impacts. A full environmental impact assessment is not anticipated.

7.2. Recommended Radars

Table 7.1 summarizes information on each of the proposed radar sites. Figure 7.1 is a location map depicting all of the proposed sites.

Table 7.1 –Proposed Radar Site Locations and Siting Comments

Radar Name	Latitude	Longitude	Elevation (Meters)	Comments
Erfoud	31.4336	-4.21836	912	Located on the east side of the Atlas Mountains and just east of Erford. The climate is arid with little or no vegetation. Site is located on a hillside near some existing structures and access roadway.

Radar Name	Latitude	Longitude	Elevation (Meters)	Comments
Fnideq	35.862704	-5.408187	430	Located in the mountainous north near existing development and northwest of Fnideq. Proposed site is already cleared of vegetation but surrounded by dense forest in all directions. Access is readily available due to existing roads in the area.
Guelmim	29.00665	-10.02456	585	Located northeast Guelmim in an arid climate with little to no vegetation. Existing structures are present in the area with access readily available via existing roads.
Khemis Takate	31.73219	-9.45339	702	Located in a mountainous area with sparse trees and vegetation. Existing structures and an access road are located to the north. Site development may require road extension and clearing of minimal vegetation.
Mengoub	32.25998	-2.34979	1000	Located south of Mengoub in the Atlas Mountains. The climate is arid and small patches of development are located in areas around the site. Although some roads are located in the immediate area, new road construction may be required for access.
Midelt-a	32.67147	-4.74102	1524	Located in a developed area of Midelt in the Atlas Mountains. The site itself is barren, but surrounded by development, including roads. New road construction may be required for access.
Nador	35.22153	-2.99788	862	Located in the north, this site is mountainous and heavily forested. An access road is located to the north which leads to a developed area approximately 100 meters west of the site. Development of this site may require clearing of existing trees to construct an access road.
Ouarzazete	30.87863	-6.89441	1282	Located south of Ouarzazete in an arid area with sparse development to the east/northeast and west. Some access roads exist in association with these developments, but additional road construction would be required.
Tan Tan AP	28.449	-11.17324	197	Located west of Tan-Tan in a barren area with little to no development. The Tan-Tan airport is located approximately 1,100 meters east of the site. Construction of an access road would be required.

Figure 7.1 – Location of Recommended Radars

Construction of each radar installation will consist of a building (approximately 3 by 6 meters) that will house the computer hardware, software, I/O racks, communication equipment, and radar support equipment; stand-by power generator; and a tower that supports the radome and radar. Other construction activities that may be necessary (depending on site conditions) include the construction of an access roadway and support facilities and the extension of electrical power.

7.3. Environmental Issues and Mitigation Measures

The Moroccan Ministry of Energy, Mines, Water and Environment is responsible for environmental protection within Morocco and faces its most serious challenge in dealing with water quality. However, other environmental issues often arise in relation to erosion/land degradation, deforestation, desertification, destruction of natural resources, air and water pollution in urban centers, and oil pollution of coastal waters. As of 2010, an environmental charter was being drafted to target preservation of the environment and encourage sustainable development within Morocco. Morocco is also party to international agreements on biodiversity, climate change, desertification, endangered species, hazardous wastes, ozone layer protection, and wetlands and has received contributions from the World Bank to assist with preservation of natural resources and the environment in Morocco. Through the World Fund for Environment,

the World Bank is financing a project to improve ecosystem preservation and species protection.

Most of the environmental issues identified above will not be associated with construction of the proposed radar stations. However, several of these issues including soil and erosion control and mitigating the effects of deforestation will arise during development of the proposed facilities. These topics, along with other potential issues related to agricultural lands and wildlife species protection are addressed below.

7.3.1 Construction Impacts & Mitigation Measures

Construction of towers, equipment buildings, access roads, and extension of electrical power are considered non-environmental critical projects and should not require completion of an Environmental Impact Assessment (EIA). Environmental impacts fall into two different categories – temporary impacts and long-term impacts. Temporary impacts will result from construction of access roads, proposed radar facilities, and operation of construction vehicles and equipment. These impacts will include:

- Desertification/erosion and loss of soil during construction activities;
- Increases in air emissions/dust and noise during construction work;
- Disturbances to wildlife in rural areas and people in urban centers during construction.

Long-term impacts associated with the project will primarily include the following:

- Conversion of undeveloped land (agricultural/forested) to a developed area;
- Deforestation, tree clearing, and removal of other vegetation;
- Potential loss of wildlife habitat in natural areas;
- Creation of barriers to wildlife (primarily birds) movement.

To help mitigate the temporary and permanent impacts occurring as a result of construction, erosion control techniques can be used during construction and permanent post-construction controls can also be implemented. In general, conversion or clearing of sustainable agricultural land, forested areas, or other natural habitat for native wildlife should be minimized to the fullest extent possible while developing only the areas necessary for project completion. This helps protect sustainable resources and natural habitat. For arid locations, sand fences can be used to help control erosion and direct wind-blown material to certain areas. During construction of the radar sites, contractors should keep oil, fuel and other waste materials associated with vehicle and equipment operation from discharging to the ground surface.

In areas where tree clearing will be required for project construction, efforts should be made to implement reforestation work at the project site or in close proximity. As of 2007, Morocco currently plants nearly 37,000 hectares of new forest per year and is attempting to increase the

number of hectares planted each year. Tree planting efforts will help re-establish vegetation cleared due to project construction and increase vegetative cover in the immediate area which will also help control soil erosion. As allowed, developers should take into account vegetation existing in the area and design projects in accordance with the position of existing trees to preserve larger native vegetation.

7.3.2 Construction Sites and Storm Water Control

Protecting water resources is important to Morocco, but no specific requirements related to construction and storm water pollution prevention were found. Soil or sediment-laden (i.e., muddy) storm water that reaches sewers, streams, rivers, or other surface waters can result in a variety of problems. Among them, impacts to fish (and other aquatic life) can occur. In addition, storm water runoff from construction sites can destabilize ground surfaces and stream banks, pollute water supplies, and affect streams, rivers, or coastal areas making them less suitable for recreation such as fishing and swimming. Storm sewers in urban areas can be impacted by increased sediment loads causing flooding on streets and in homes, and requiring expensive maintenance.

Construction site runoff is typically 10 to 20 times greater in volume than the amount of runoff from undisturbed sites. For the proposed construction sites in arid or barren locations, this issue is not expected to result in any significant impacts to surrounding areas. However, for locations in the north that are more heavily forested, contractors should implement appropriate erosion and sediment controls in an attempt to reduce runoff during construction. These could include sediment basins, construction phasing, silt fence, diversions, and temporary stabilization. Some typical best management practices often used during construction include the following:

- Only disturb, clear, or grade areas necessary for construction. Flag or otherwise delineate areas not to be disturbed. Exclude vehicles and construction equipment from these areas to preserve natural vegetation.

- All graded or disturbed areas including slopes shall be protected during clearing and construction until they are permanently stabilized. This practice would be more applicable to sites located in the northern areas of Morocco or other forested sites along the coast.

- If topsoil is required for the establishment of vegetation, it shall be stockpiled in the amount necessary to complete finished grading and protected from erosion during the interim.

- Areas to receive topsoil shall be scarified to a minimum depth of 76 mm prior to placement of topsoil.

- The outer face of a fill slope should be allowed to stay loose, not rolled, compacted, or bladed smooth. A bulldozer may run up and down the fill slope so the dozer treads (cleat tracks) create grooves perpendicular to the slope. If the soil is not too moist, excessive compaction will not occur.

- Use slope breaks, such as diversions, benches, or contour furrows as appropriate, to reduce the length of cut-and-fill slopes to limit sheet and rill erosion and prevent gully erosion.

- The finished cut-and-fill slopes, which are to be vegetated with native grasses, shrubs, or trees, should not be steeper than 2:1.

- Slopes to be maintained by tractor or other equipment should not be steeper than 3:1.

- Slopes in excess of 2:1 may require hydroseeding, hydromulching, tactifying, and/or "punching-in" straw, bioengineering techniques, or retaining walls.

- Roughen the surface of all slopes during the construction operation to retain water, increase infiltration, and facilitate vegetation establishment.

- Stabilize all graded areas with vegetation, crushed stone, riprap, or other ground cover as soon as grading is completed or if work is interrupted for 21 working days or more.

- Use mulch for temporary stabilization where final grading must be delayed.

- Stockpiles, borrow areas and spoil areas shall be covered or stabilized to prevent erosion and sedimentation.

7.3.3 Agricultural Lands

Historically, it appears that Moroccan law has provided some form of protection for properties zoned for agricultural use outside urban areas. These laws ensured that agricultural properties could only be acquired by certain Moroccan individuals or legal entities. Little could be located on the current status of these historic laws which would appear to still be applicable for the acquisition of agricultural properties. Desertification associated with overgrazing of agricultural lands and lack of water is a major issue faced by farmers in Morocco. Agricultural lands did not appear to be present at any of the proposed radar sites and no environmental impacts are anticipated in this area.

7.3.4 Threatened & Endangered Species, Wildlife Habitat, and Migratory Birds

As discussed above, Morocco is party to several international agreements concerning threatened and endangered species and the protection of biodiversity. In addition, Morocco is an important staging point on the flight path of many migratory birds that winter in Africa and spend the summer in parts of Europe. Construction of the proposed radar facilities will convert a small amount of natural wildlife habitat to a developed land use, primarily for the forested locations. In addition, erection of the radar facilities will create new features that must be navigated by the bird population and any migratory birds traveling through the area.

Given the location of the proposed facilities and the small scale nature of the construction footprint, impacts to wildlife in the area are expected to be minimal due to the availability of nearby habitat similar to what will be removed at several of the forested locations. In addition, several of these facilities have already been constructed in Morocco. The construction of these additional facilities is not expected to create any significant barriers to local birds or the migratory bird population.

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8. PROCUREMENT PLAN AND BID PACKAGE PREPARATION (Task 7)

Based on the findings of Tasks 1-6 that have been provided earlier in this document and in conjunction with DMN to the extent information was shared with the B&N Team, a Procurement Plan and bid specification for the upgrade and expansion of the current weather radar network in Morocco are provided in the following subsection.

Tender documents such as the document that are routinely prepared by DMN to acquire equipment have two main components. The first component is the commercial conditions and the second component is the technical specifications. Within both the commercial conditions and technical specifications there are standard clauses and special clauses that are used to point out various conditions of the contract. This could include qualification clauses that don't necessarily relate to the equipment or services being offered, but possibly to the strength of the bidder in performing and similar contracts in both subject and size performed in the past.

This section employs both elements of specifications developed by DMN in recent weather radar tenders as well as additional specifications that will improve the product that is to be delivered by the winning bidder. There is an emphasis in the added clauses to assure operational sustainability of the network, not only in the lifespan of the radar network but also in the efficient operation and use of the products from the radar network. An example of this is found in the training element. The weather forecast office of DMN should be one of the prime users of the numerous weather radar network products, but instead the B&N Team found the weather forecasters in need of more training as they were only using a very small fraction of the products. The multi-media training proposed in Section 8.16 is the key element of the proposed program. This will allow for the basic training on the operation and maintenance of equipment. On-site training at the beginning of equipment startup along with periodic refresher training is essential to maximize the critical knowledge of the operation and maintenance staff. The regular multi-media training will test the understanding and knowledge of personnel and ensures they remain current on equipment operation and maintenance. On-line multi-media training that is provided by independent firms, such as 360 Water, may be a step up in the multi-media training process. Bottom line, annual refresher training must be performed. Both operational and maintenance staff should have a minimum of 24 contact training hours per year along with the satisfactory passing of all tests. Section 8.16 includes two components: (1) onsite training by the manufacturer; and (2) training modules specifically developed for the supplied equipment; including quizzes and tests that will be prepared with the full cooperation of the manufacturers. Training modules can be developed used by both current operational staff (as a refresher module) and new operational staff. B&N has been using the services of a specialty firm for the production and hosting of online hosting materials. The website of the firm (360 Water, Inc.) that we have been using is: http://www.360water.com/. We recommend reviewing the website for your information.

A copy of the Radar Training Manual used by Baron's Services is provided as an Attachment to this Feasibility Study.

The preparation of the commercial clauses and building the final tender documents are not addressed in this section, and will be the responsibility of DMN.

8.1. Procurement Plan

The Feasibility Study for the modernization of the national weather radar network in Morocco studied the five existing radars at Casablanca, Fes, Khourigba, Larache, and Agadir. In addition, there is a new radar established at Ben Guerir, and another two radars being planned at Debdou and Tan Tan. This is based on the latest discussion with DMN. The table below is reproduced from the Needs Assessment in prioritizing all the radars that were recommended to give DMN complete weather radar coverage of high risk areas as determined from socio-economic losses from storm related events, such as flooding and damaging hail.

The radar priorities have been discussed with DMN and priorities adjusted only slightly based on more recent concerns and needs for weather radar coverage as shown in **Table 8-1**.

Table 8-1 – List of Existing, Planned, and Prioritized Proposed Weather Radars to Comprise of the National Moroccan Weather Radar Network

Site	Latitude	Longitude	Hydrologic Basins	Socio-economic	Logistics	Priority
Agadir	30.32764	-9.39769				Current
Ben Guerir	32.13897	-7.95198				Current
Casablanca	33.36862	-7.57687				Current
Fes	33.93078	-4.97402				Current
Khourigba	32.85518	-6.9568				Current
Larache	35.1635	-6.1167				Current
Debdou	33.96992	-3.02058				Planned
Finideq	35.8627	-5.40819	West 50% of Cotiers Mediterannes	1,2,3,4	R,C,P,L	1
Nador	35.22153	-2.99788	Isly 100%, east 60% of Cotiers Mediterannes	1,2,3,4	R,C,P,L	2
Erford	31.4336	-4.21836	Ziz-Rheris 100%, south 50% of Guir	1,2,3	R,C,P,L	3
Tan Tan AP	28.449	-11.1732	North edge of Sequia El Hamra (5%), south 50% of Cortiers Guelmin-Tiznit, western part of Draa (20%)	3,4	R,C,P,L	4
Oaarzazete	30.87863	-6.89441	North 33% of Draa (mountainous region)	1,2,3,4	R,C,P,L	5
Midelt	32.67147	-4.74102	West 50% of Guir, south 40% of Moulouya	1,2,3,4	R,C,P,L	6
Khemis Takate	31.73219	-9.45339	Cotiers Essaouria, Cotiers Safi-Judida (67%), east 70% of Tensift, Temri (100%), north 20% of Souss	1,2,3	R,C,P,L	7
Mengoub	32.26998	-2.34979	Nearly all of Guir (95%)	2,3	R,L	8
Guelmin	29.00665	-10.0246	Cotiers Guelmin-Tiznit (100%), South 33% Draa	2,3	R,C,P,L	9

Table 8-2 provides details of radar coverage as a percentage of national coverage at various altitudes above the ground. The importance of radar beam height above the ground relates directly to the performance or a reflectivity – rainfall relationship. The closer the beam to the ground, the better the correlation between reflectivity and rainfall rate.

Table 8-2. National Coverage Percentages and Cumulative Percentages for the Existing and Expanded Moroccan National Weather Radar Network.

Altitude m (AGL)	Percentage	Cumulative Percentage
≤ 200	29.8%	29.8%
200 to 500	21.9%	51.7%
500 to 1000	25.3%	77.0%
1000 to 1500	10.4%	87.4%
1500 to 3000	6.9%	94.4%
3000 to 5000	4.3%	98.6%
5000 to 10000	1.4%	~100.0%
> 10000	<0.1%	100.0%
no coverage	0.0%	

Not counting the radars currently planned and being tendered, there are eight new weather radar sites proposed for Morocco. The Feasibility Study indicates an order of priority as follows:

- Finideq
- Nador
- Erfoud
- Ouarzazete
- Midelt
- Khemis Takate
- Mengoub
- Guelmim

It is advised that the procurement of these radars occurs in a single tender. If funds are not available, then on the basis of the socio-economic study, the order should be followed as preascribed above and in Table 8-1. DMN may choose to alter the prioritization of the proposed radar based on more recent information gathered during the preparation of this Study.

The procurement cycle from tender preparation to a fully commissioned Doppler weather radar should be on the order of 18 – 24 months. The procurement, installation and commissioning of numerous radars will take longer, likely extending the process by one year. The phases of the procurement cycle of a tender typical for this type of purchase are outlined in **Table 8-3.**

Table 8-3 – Procurement Cycle for a Single Radar Tender, Multiple Radars Generally Require Longer Installation Time

	MONTH																						
ACTIVITY																							
Tender Preparation																							
Notice of Interest																							
Publish Tender																							
Pre-Meeting																							
Bid Award																							
Radar Installation																							
Radar Commissioning																							

8.2. Tender Language for the Acquisition of New Weather Radars

8.2.1. General

- The specifications described herein refer to C-band Dual Polarization Doppler Weather Radar, hereafter referred to as "The System." The System is capable of detecting and estimating parameters of severe weather related phenomena that cause widespread damage to life and property. The radar not only measures accurately the radar reflectivity factor, but also the radial velocity component of the echoes from rainfall particle group movement. It also provides dynamic parameters about storms for weather forecasts and identifies thunderstorm hazards by the distribution of velocity field and thus improves now- casting capability.
- The System will have dual polarimetric measurement in both linear horizontal and vertical polarizations.
- The user can select Single polarization and Dual polarization mode of operation at any time via key board operation from the Operator workstation.
- The entire operation of the System shall be computer based with operator interaction through standard man machine interface such as keyboard, display screen, GUI, etc.
- Latest state of art computer system shall be used for the generation of data and it's processing, e.g. Linux PC.
- All equipment shall be industry standard so as to enable easy up gradation and

maintenance. The manufacturer shall submit the full details of the hardware, including model numbers and the software proposed to be employed for meeting the requirements given therein.

8.3. Control of the Radar Network

Control of the existing network is performed at the regional level with FROG-RT, a product from GAMIC which is part of the meteorological data processing systems for Weather Radar Products. The FROG-RT solution is an acceptable solution. However, other solutions may be bid but must abide to general principles of control. The control software must allow for numerous levels of operation set forth through permissions.

- SUPERVISION PERMISSION: This level has unlimited access to the operating system and radar control
- NATIONAL PERMISSION: This level allows for the configuration of radar procedures and operation of radars within the national network. This includes the configuration of products and presentation products.
- REGIONAL PERMISSION: This level allows for the configuration and operation of radars belonging to the region. This includes the configuration of products and presentation products of radars that are in the region.
- MAINTENANCE PERMISSION: This level allows for maintenance and calibration of the radar including quality control procedures. Maintenance mode will be able to be executed from any workstation on the network.
- ADMINISTRATION PERMISSION: This level allows for the administration of the operating system and software systems, including upgrades, as well as installation of new software.

The operating software of the control of network radars must have the following capabilities:

- All systems will be able to go into STANDBY mode, minimizing consumption of electricity
- The control of the operation of the radar must be able to control all aspects of the radar, including but not limited to turning on the transmitter, control of radar scanning
- The priority and control of the operation radar must be given to a user with NATIONAL Level permissions.
- The control and operation of a radar within a given area must be possible from a control system with REGIONAL permissions. SUPERVISION LEVEL will allow defining radars that belong to a region.

8.3.1. Levels of Operation of the Radar Network

The control and operation software must allow DMN to ensure operation of any radar in the network at all levels (national, regional, and local) according to the rules that follow. Priorities of access mustgrant rights of access for each user who will be identified by user name and password. The bidder will thoroughly describe the function of the process that grants access to the users.

The operation of the radar network will be controlaccording to the following three levels.

8.3.1.1. Central (National) Level

The operation of this level will have the following characteristics:

- All radars will be capable of control from the Central Level. This includes the startup and shutdown of the radar, performing scans, and controlling parameters that are involved in acquiring and/or processing the signal.
- Defining and/or controlling scan sequences or scan strategies, along with the products to be generated and distributed.
- Collection of all radar data in mosaic form as selected from the Central Level system.
- Operation from this level will permit pre-programmed scan sequences which will not be interrupted. Certain products and scans may be allowed to override the Central Level Control.
- Immediate transfer of raw data and/or generated products from the raw data to the Central Level Server. This must be explained in detail by the bidder on how this will be accomplished.
- Allow for the collection of pertinent products for dissemination to the weather forecast office and hydrological forecasters.
- High resolution graphical product reception and/or generation.
- Integration of the radar data with other radar products, such as that required for nowcasting, and relay of products to consumers that are defined by the Administrator.
- Storage of all data and generated products.
- Monitoring the operation of the entire radar network.

Two workstations will be dedicated for maintenance function under this level. The maintenance function will have the following characteristics:

- Control parameters and constants used to process the radar signal
- Review of the results of recent calibrations
- Test and analysis results
- Collection of information that indicates the operational readiness of the radar. All BITE parameters will be accessible, though the information will have the capability to protected from change at this level
- Recovery of all other radar maintenance procedures through the capability of viewing reports
- Centralized maintenance management for all radars and associated assets in the network

8.3.1.2. Regional Level

The following functions will be supported at the Regional Level:

- Control all radar functions assigned to the respective region. This would include radar startup, shutdown, and scan strategy development and implementation.
- Operation of radars as related to the type of operation as well as products to be generated and transferred.
- Collection of data and products from radars assigned to the respective Regional Level. This will be defined by the Administrator and will allow for data to be built into Mosaics of all radars in the Region.
- Capability to view national mosaic products.
- Operation from this level will permit pre-programmed scan sequences which will not be interrupted. Certain products and scans may be allowed to override the Regional Level Control.
- Immediate transfer of raw data and/or generated products from the raw data to the Regional Level Server. This must be explained in detail by the bidder on how this will be accomplished.
- Allow for the collection of pertinent products for dissemination to the weather forecast office and hydrological forecasters.
- High resolution graphical product reception and/or generation.
- Integration of the radar data with other radar products, such as that required for nowcasting, and relay of products to consumers that are defined by the Administrator.
- Storage of all data and generated products.
- Monitoring the operation of radars assigned to the respective region.

8.3.1.3. Local Level

The following functions will be required at the local level.

- Control and operation of the radar will not be possible if the radar is operating in MAINTENANCE mode which may be implemented at either the Regional or National level
- Monitor the operation of the radar
- Under SUPERVISOR mode, the visualization of the products generated on-site.
- All functions necessary for preventative maintenance, including the startup, shutdown, and calibration of the radar.

There will be the following capability to control the following functions related to maintenance:

- Constants and parameters related to processing the radar signal
- View most recent calibration tests at the local site

- View products generated at the local site
- View BITE data from the local site
- Collect and view maintenance reports generated at the local site

8.4. Integration of other Weather Data Sets

The radar processing software will be able to integrate other meteorological data in real-time. Examples of this include precipitation and wind data. This data will be used to adjust the Z-R relationship for the continuous improvement of quantitative precipitation estimations.

Radar generated products will allow for the integration of products such as:

- Satellite data (any product)
- Rainfall records
- Lightning data
- Surface model plots
- Numerical weather forecast products

8.5. Technical Environment

8.5.1. Site Evaluation

The bidder will be required to make a site evaluation and adjust the location as needed to optimize quality radar data collection.

8.5.2. Access

The bidder will be required to develop the necessary access to the proposed radar site. The bidder must take into account and accommodate local laws and regulation on such works.

8.5.3. Telecommunications

The bidder will arrange for telecommunications using one of the existing providers of telecommunications being used by DMN. These provisions may include the addition of back-haul links that may not already be in place.

Telecommunication used by DMN is characterized by use of rented lease line connections. DMN requires the use of a VPN (Virtual Private Network) regardless of topology.

The current telecommunication technology employed by DMN utilizes the following connections:

- National Center National/Regional Centre: rented connection 512 Kb/s,
- Regional Center/Site radar: rented connection 256 Kb/s,

8.5.4. Regional Center/Station: commutated connection (ISDN).

The existing radar sites are connected to the Regional Centers by rented connections at the speed of 64Kb/s. The communication protocol utilizes TCP/IP. Data bandwidth must be sufficient to receive data from all 16 radars simultaneously. Data shall arrive at the Weather Forecast Office at DMN headquarters within one minute after the end of the scan, or sooner.

The Bidder must take into account the telecommunication infrastructure of DMN in the design of the proposed solution. The Bidder must justify the solution.

8.5.5. Electrical

The bidder will arrange for electrical service to the proposed radar site. This will include the establishing of the proper service required for the safe operation of the weather radar.

8.5.6. Environmental Control

The bidder will make all arrangements for environmental control as well as a suitable building to efficiently house the radar electronics.

8.6. Description and Specification of Radar Components

8.6.1. General

No	Item	Specification
a	Primary Power	220 VAC +10%, single Phase, 50 Hz

8.6.2. Transmitter

No	Item	Specification
	Type	Magnetron C-Band
b	Modulator	Solid-State, IGBT switched, Long Lifespan
c	Polarization	Dual
d	Peak Output Power	250 kW
e	Internal Protection	Arc Detector Sensor Module
f	RF Frequency	5.6 - 5.825GHz instantaneous
g	Frequency Stability	< 1 Hz
h	Frequency Modulation	Steady and Non-linear with Long Lifespan
i	PRF	250 - 3000 pps, pre-selected
j	Dual PRF ratio	1:2, 2:3, 3:4 and 4:5
k	Transmitter Recovery Time	< 1µs
l	Temperature	0 to 35° C
m	Relative Humidity	up to 80%, non-condensing

The bidder will provide the complete specifications of the transmitter being offered. This information will be taken into account during the evaluation of the offer. In particular, the following information must be provided:

- The construction of the modules and connections between modules will be provided in detail.
- Stability of the magnetron
- Devices or technologies used to protect the transmitter
- Stability of other modules and the system in whole
- Description of solid state modules and stability
- The MTBF (Mean Time Between Failure) of the magnetron
- Maximum transmitted power

8.6.3. Receiver

No	Item	Specification
a	Type	Superheterodyne, Single down conversion
b	Noise Figure	2 dB maximum
c	Linear Dynamic Range	~105 dB maximum
d	Coherent Receiver	Yes
e	IF Digitizer	16-Bit
f	Minimum Reflectivity at 50 km	-10 dBZ
g	Temperature	0 to 35° C
h	Relative Humidity	up to 80%, non-condensing

Bidder to provide all information on receiver being proposed. This information will be taken be evaluated with other offers. In particular, the following information must be provided:

- Receiver design and construction, highlighting the interconnections between the various modules. Such details as cable construction (coax type and shielding) must be noted.
- STALO (STAble Local Oscillator) construction and performance specifications, including information on adjusting the frequency through command sequence.
- LNA (low Noise Amplifier) detailed specifications.
- AFC (Automatic Frequency Control) and control of this device through command sequence.
- IF (Intermediate Frequency) module to include detailed specifications. How this module is connected to other modules will be provided in detailed, including the type and quality of connections.
- Specifications of any amplifiers used, including noise factor.
- A description of components used to reduce signal loss and/or distortion in the receiver along with a the justification of solutions employed.

8.6.4. Compressor-Dehydrator

A compressor-dehydrator is required to maintain pressure in the wave guides along with a method to stop the compressor once the desired overpressure is reached.

No	Item	Specification
a	Operation	Automatic
b	Flow Under Normal Pressure	0.5 $m^3 h^{-1}$
c	Overpressure	Automatic Stop
d	Maintenance	No Maintenance Required

8.6.5. Antenna

No	Item	Specification
a	Diameter	4.3 m
b	Gain	45 dB
c	Beam Width	0.95^0
d	Side Lobes (Secondary Lobes)	-30 dB or better
e	Cross-Polarization Rejection	-34 dB minimum
f	Type	Parabolic, prime focused reflector with scalar feed
g	Polarization	Horizontal, single pol / horizontal & vertical, dual pol mode
h	Temperature	- 10 to 55° C
I	Relative Humidity	up to 100%

8.6.6. Pedestal and Servomechanism

No	Item	Specification
a	Pedestal type	Elevation over Azimuth
b	Azimuth Movement	360° continuous
c	Elevation Movement	± 0.05°
d	Angular Positioning Range	-2° to +90°
e	Angular Positioning Accuracy	± 0.1°
f	Scanning Rates (in azimuth)	Programmable up to 30° sec^{-1} to 6 rpm
g	Scanning Rates (in elevation)	Programmable up to 20° sec^{-1}
h	Minimum position increment	0.1°
i	Temperature	- 10 to 55° C
j	Relative Humidity	up to 100%

Servo to be solid-state construction with numerical decoders to set the azimuth and elevation position accurately. Serve mechanism will have safety mechanisms to prevent damage of antenna, pedestal, and drive system. These mechanisms must be described in detail.

8.6.7. Radome

No	Item	Specification
a	Diameter	5.5 m
b	Construction	Fiberglass sandwich
c	Transmission Loss, Dry Condition, one-way	0.3 dB
d	Geometry	Faceted, truncated sphere
e	Temperature	- 10 to 55° C
f	Relative Humidity	up to 100%

The bidder will abide by the safety requirements of Morocco, in particular beaconing of the radome. The radome must be equipped with a ventilation system while allowing technicians to work safely within the radome, and at the level of the antenna.

Radome must withstand winds of more than 200 km hr^{-1} with attenuation less than 0.5 dB.

The radar installation must be protected against lightning, including the radome.

8.6.8. Radar Signal Processor

No	Item	Specification
a	Type	3 Multi-channel digital receiver (opt. 5 channel) 16-bit per polarization
b	IF Frequency	60MHz
c	IF Sampling	Multi-channel, up to 120 MHz sampling
d	Maximum Number of Processed Range bins	Up to 4000 per channel
e	Minimum Processing Resolution	25m.
f	Processing Mode	Pulse Pair (PP) or Discrete Fourier Transform (DFT/FFT) More than 20 real-time signal enhancement algorithms
g	Clutter Filters	Up to 16 Time Domain, > 16 Frequency Domain Adaptive filtering Second trip cancellation

8.6.9. Internal Radar Test Generator

The bidder must include an internal radar test generator for each radar unit specified. The purpose of the test generator is to carry out tests and calibration of the receiver. The Bidder must provide the specifications of the test generator, and include a description and cost of any options. In particular, the Bidder must provide relevant information concerning:

- Type of signals being transmitted
- Testing of frequency, including minimum and maximum values transmitted

- Testing of Amplitude, and recording the maximum value
- Precision of frequency and evaluation of transmitted frequency
- Precision of amplitude and evaluation of the transmitted amplitude signal
- Describe any other tests possible for the offered radar test generator

The test generator must be capable of remote use where the technician can perform tests at remote sites. These tests will normally be carried out from the regional concentrator location.

8.6.10. Built In Test Equipment (BITE) Processor

A modern system making use of latest technology for continuous monitoring of the operational status of functions and utilities of the radar system shall be supplied.

- A BITE Processor shall measure and process in real time analog and digital parameters in the radar system and generate and display an error message whenever their value falls outside the specified permissible range.
- The BITE processor shall continuously monitor input and output signals of the radar system's module/ PCB's for any deviation from the standard value. Whenever any error message is generated, the BITE Processor shall log sand archive failures or status from of the system.
- The BITE Processor shall cause the malfunctioning units to be switched off and provide an acoustical alarm for warning the operator.
- The maintenance/BITE utility shall allow visualizing the system graphically as a block diagram with red/green color indication of faulty blocks or faulty communication between modules.
- The BITE utility shall allow the online visualization of selectable BITE parameters together as a value-vs.-time graph (System Monitor) in order to compare potential sources of errors.
- The BITE utility shall allow configuring the parallel transmission of BITE messages to other destinations.
- The BITE utility shall monitor all power supplies. A list of power supplies is to be provided by the bidder.
- The Bite will monitor environmental conditions, such as air conditioning status, temperature, humidity in the radar equipment shelter
- BITE will monitor door alarm
- BITE will monitor transmitted power and quality parameters
- BITE will monitor Receiver Monitor Faults. Bidder to provide list of possible faults.
- BITE will monitor Mains Power Supply (Voltage and Amperage)
- BITE will monitor Radome Temperature

- BITE will monitor lubrication levels and/or conditions in all parts that require lubrication. Bidder to provide list of all parts requiring lubrication, and ability to measure the lubrication level or condition of lubricated part.
- BITE will monitor air pressure in wave guide

8.7. Radar Functionality

8.7.1. Modes of Operation

The system shall be capable of operation in Normal radar operation and maintenance/ calibration mode.

8.7.1.1. Normal Mode

The System shall be capable of the following:

- The system shall be capable of detecting all significant hydrometeors and measuring precipitation rates (at minimum 0.1 mm/h up to 200 mm/h) up to a maximum range from the radar of 250 km.
- Fully computer controlled operation with scan strategies and other variable parameters settable by operator through standard user interfaces from the Operator Workstation. The software design shall be client-server architecture.
- Operator console interaction for control of radar parameters and display parameters andselection of products.
- The system shall store and organize acquired data in a specified standard format that is made available to the user.
- The system shall display variable data at specified intervals of range, value and repetition time in color-coded graphical format.
- The system shall be capable of transmitting data in a known standard format at specified intervals to a remote site by using an efficient way of data compression. The processing center, which processes, displays, archives and distributes the radar data to a number of local and/or remote users, shall be located locally at the radar site.
- The system shall be equipped with a comprehensive state-of-the-art BITE (Built In Test Equipment) system that supports manual and automatic diagnostics.
- The normal mode of operation of the radar can be attended local control or unattended remote control, in continuous independent operation.

8.7.1.2. Maintenance Mode

Maintenance mode operation shall be independent of the normal mode computer and shall be capable of the following operations.

- Simultaneous display of BITE information's in all subunits of radar system shall be provided.

- Raw signal shall be averaged and range normalized and contoured into appropriate levels
  before display. Calibration and health monitoring shall be provided.
- Antenna position and reflectivity shall be displayed in a format stimulating conventional PPI / RHI.
- The system shall be equipped with a comprehensive state-of-the-art BITE (Built In Test Equipment) system that supports manual and automatic diagnostics.

8.7.2. Scan Modes

The System shall be capable of operation in the following modes.

No	Item
a	Azimuth Scan
b	RHI Scan
c	Volume Scan

8.7.3. Scan Strategy Function

The following scan strategies are required. The scans can be performed manually or automatically (pre-programmed) and executed at the choosing of the purchaser.

No	Item	Specification
a	Continuous	Continuous azimuth rotation at Selectable elevation angle
b	Sector	Sector scan with selectable width and center angle
c	Volume	Volume scan at selected elevation steps
d	Other	Programmable Scan Sequence utilizing any or all of the above

8.7.4. Parameters to be measured

No	Item
a	Reflectivity (Z)
b	Radial velocity (V) hereafter referred to as velocity.
c	Differential reflectivity (Z_{DR})
d	Specific differential phase (K_{DP})
e	Differential phase (Φ_{DP})
f	Cross correlation and Coefficient (ρ_{HV})
g	Hydrometeor classification

8.7.5.

8.7.6. Observation Range

No	Item	Range
a	Reflectivity	≥ 400 km
b	Velocity & Spectrum Width	250 km

8.7.7. Spatial Resolution

No	Item	Resolution
a	Reflectivity	≥ 150 km
b	Velocity & Spectrum Width	> 150 km

8.7.8. Measurement Accuracy

No	Item	Accuracy
a	Reflectivity	Minimum 1 dB absolute accuracy at 250 Km for rainfall equivalent to 23 dBZ (1 mm hr^{-1}) at antenna rotation of 2 revolutions per minute (RPM)
b	Velocity	Minimum 1 m sec^{-1} absolute accuracy at 250 km for rainfall equivalent to 23 dBZ reflectivity at antenna rotation of 2 RPM

8.7.9. Unambiguous Range

No	Item	Range
a	Reflectivity mode	≥ 400 km
b	Doppler mode	125

8.7.10. Ambiguity Resolution

No	Item	Resolution
a	In the Doppler mode, the system shall have facility for unfolding velocities four times the Nyquist velocity to overcome the restriction imposed by range-velocity dilemma, (Doppler dilemma). The algorithm proposed to be used shall have capability of unfolding velocities in cases of non-overlaid echoes as well as for overlaid echoes.	
b	Velocity (unambiguous single PRF mode)	125
c	Velocity Unfolding (Dual PRF mode)	Up to ± 64 m sec^{-1}

8.7.11. Calibration and Health Monitoring

8.7.11.1. Internal calibration

a. The BITE of the radar system shall be equipped with an auto-calibration function which is closed loop and requires no operator intervention. The tests shall be

- Closed-Loop System Level Tests
- Subsystem Level Tests
- Self-Calibrating
- Self-aligning
- Fault Detection to LRU
- No Special Tools or Test Equipment
- Records & Stores Test Results

At a minimum the following tests shall be performed after every volume scan

- Receiver Noise Level
- Receiver Noise Temperature
- Receiver Fast Linearity
- Receiver Dynamic Range
- Receiver Bias
- ZDR Offset

b. To provide accurate hydrometeor classification, the dual Polarimetric data quality must be free of any errors. The following processing tasks shall be provided

- Generation and application of elevation based noise scales along both horizontal and vertical polarizations to correct dual Polarimetric variables.
- Use of channel synchronous clutter filtering to remove ground and point clutter target contamination.
- Perform essential system calibrations (as listed above in point 4.10.1a) during the antenna retrace period following a volume coverage pattern execution to keep the radar perfectly calibrated at all times.
- Calibrating the initial system differential phase to correct for errors generated during the phase unwrapping process used to generate specific differential phase. Calibration to suit to polarimetric option

8.7.11.2. External Calibration

Provision shall be made for absolute external calibration using standard coherent source and standard measuring equipment for all major and minor subunits.

8.7.11.3. Sun Calibration

The system shall be made to point towards sun for establishing the gain or pointing accuracy.

8.8. Radar Product Generator

Radar will be capable of generating the following types of products.

No	Item
a	Base products
b	Primary products
c	Derived products
d	Warning and Forecast products
e	Polarimetric products

8.8.1. Product Range

No	Item	Specification
Base Products		
a	Reflectivity	≥ 400 km
b	Velocity	≥ 250 km
Primary and Derived Products		
c	Reflectivity based products	≥ 400 km
d	Velocity based products	≥ 250 km

8.8.2. Base Products

8.8.2.1. PPI (Plan Position Indicator)

The System shall compute and display Z, R, V, W, Z_{DR}, KDP, LDR, ϕ_{DP}, ρ_{HV}, in PPI mode.

8.8.2.2. RHI (Range Height Indicator)

The System shall compute and display Z, R, V, W, Z_{DR}, KDP, LDR, ϕ_{DP}, ρ_{HV}, in RHI mode.

8.8.2.3. Raw Data

Provision shall also be there to generate products offline using the archived raw data.

8.8.3. Primary Products

8.8.3.1. Maximum Display

The System shall compute and display maximum values of base data products Z,R, LDR, ϕ_{DP} in horizontal (East west and North South) and vertical columns between users defined heights and also display the partial images in a single frame.

8.8.3.2. CAPPI (Constant Altitude Plan Position Indicator)

The System shall interpolate from the volume scan data set for a horizontal place at user vertical defined height and display Z, R, V, W, Z_{DR}, KDP, LDR, ϕ_{DP}, ρ_{HV}.

8.8.3.3. PCAPPI (PSEUDO CAPPI)

The system shall incorporate data form the highest elevation scan near the radar and from lowest elevation scan for areas at far away from the radar for which radar beams are not intersected by user defined plane for CAPPI and display Z, R, V, W, Z_{DR}, KDP, LDR, ϕ_{DP}, ρ_{HV}.

8.8.3.4. Cross Section

The system shall interpolate all the base products (Z, V and σ) in any vertical plane passing through user defined two points and display the same for the user selectable parameters.

8.8.3.5. ECHO BASE

The system shall identify from the volume scan data the minimum height up to which the user defined threshold value for each base data exists and display them for user selectable data.

8.8.3.6. ECHO TOP

The system shall identify from the volume scan data the maximum height up to which the user defined threshold value for each base data exists and display them for user selectable data.

8.8.3.7. Rainfall intensity

The system shall convert reflectivity (dBZ) into rainfall rate (mm hr^{-1}) and display the same projected to a terrain surface. A provision for entry of appropriate raingauge / disdrometer data for calibration of rainfall rate shall be provided. User defined Z-R relationships shall be provided.

8.8.3.8. Rainfall accumulation

Provision shall also be made for display of weighted hourly precipitation, for operator specified time period, rainfall accumulation products in a user definable time period shall also be displayed. Based on rainfall accumulation, the System shall generate a warning message whenever the total rainfall over a specified area exceeds a predetermined level defined by user.

8.8.3.9. Vertically Integrated liquid water content

The system shall display an estimate of liquid water content residing in a user defined layer above ground, removing the contribution from bright band. Choice of M-Z relationship shall be provided, M being the liquid water content per unit volume.

8.8.3.10. Hail warning

Based on reliable hail warning algorithm, the system shall generate a hail warning symbol at the appropriate place in the PPI display in one or more of the operator chosen fields.

8.8.3.11. Hydrometeor Classification

The system shall be capable of generating a product for Hydrometeor Classification of hydrometeors based on Polarimetric parameters (Z_{DR}, K_{DP} and ρ_{HV})

8.8.4. Derived Meteorological Products

8.8.4.1. Velocity Products

The system shall generate and display following velocity products:

- Radial velocity versus the azimuth for a fixed elevation and a fixed slant range (VAD).
- Radial velocity at a fixed user defined range on height and azimuth angles (Radial velocity display for fixed range, azimuth angles for various height and azimuth.
- The system shall recognize thunderstorm cell, mesocyclone features, convergence, divergence and gust fronts, and generate and forecast their track. The system shall be able to generate mesocyclone and vergence products (divergence, convergence).

8.8.4.2. Hydrological Products

The system shall generate and display following hydrological products:

- Rainfall intensity using Z-R relationship in a user selectable surface layer with constant height above ground.
- Instantaneous estimation of water content (VIL) residing in a user defined atmosphere layer in the atmosphere to be displayed in PPI type of display.
- Rainfall intensity histogram at selectable locations within radar coverage during a user defined time period.
- Precipitation accumulation (PAC) in a user definable time period.
- Rainfall amount in user defined basins for user defined time span.
- Rainfall amount for any user defined past number of hours.
- Shall provide comparison between derived rainfall intensity form reflectivity and measured by rain gauge within the radar coverage area.
- Rainfall intensity and accumulation products shall have an option to be adjusted by raingauge or disdrometer data. Raingauge and disdrometer data shall display together with the radar data.
- Shall generate warning whenever user – selectable thresholds of rainfall intensity or rainfall accumulation are exceeded. This must also be possible for the catchments rainfall products.
- Tracking shall be used to provide short-time forecasts of rainfall intensity and accumulation maps. Tracking shall use radar velocity data or correlation techniques of the rainfall intensity data.
- Rainfall intensity using Polarimetric parameters in a user selectable surface layer with constant height above ground. Adjustment of rainfall rate by appropriate rain gauge or disdrometer data shall be possible.
- Precipitation accumulation (PAC) using Polarimetric parameters in a user definable time period.

8.8.4.3. Aviation Products

- The system shall evaluate derivatives of wind velocity in radial, azimuth, elevation, North South, East West directions and derive horizontal, vertical and three dimensional shears
- The system shall also be able to generate warning product on microburst.

- The system shall evaluate maximum turbulence within user defined atmospheric layer and display in top view.

8.8.5. Warning & Forecasting Products

8.8.5.1. Microburst Product

System shall be able to identify microburst associated with weather events and issue voice messages, SMS text, email, warning messages. The warning thresholds and warning distribution is required to be customizable by the purchaser

8.8.5.2. Gust Front

System shall be able to identify gust fronts signatures associated with storms and issue voice messages, SMS text, email, warning messages. The warning thresholds and warning distribution is required to be customizable by the purchaser.

8.8.5.3. Hail/Thunderstorm Warning

System shall generate hail thunderstorm warning symbols at the places likely to get affected by hail and thunderstorms using a reliable warning algorithm.

8.8.5.4. Cell and System Tracking

System shall be capable of evaluating speed and direction of movement of weather systems and cells.

8.8.5.5. Warning and Alarm

System shall also be capable of warning if any of the conditions defined by the user are reached or fulfilled on reflectivity, velocity, VIL and wind shear, along with other parameters described below. User can use more than one product while producing warning products that satisfy different threshold values. Alarms will be user configurable and provide warning by SMS Text message, email, audible sound, and voice callout.

8.8.5.6. Tornado

System shall be able to detect tornado vortex signatures associated with storms and issue voice messages, SMS text, email, warning messages. The warning thresholds and warning distribution is required to be customizable by the purchaser.

8.8.5.7. Storm Relative Velocity Product

The system has to generate a storm relative velocity product e.g. PPI, PCAPPI removing the bias of storm motion velocity.

8.8.6. Dual-Polarization Applications

8.8.6.1. Attenuation Correction

The system shall provide algorithms for an optimized correction of reflectivity data for attenuation effects from strong rain. Such algorithms shall make use of polarimetric

measurements such as Z_{DR}, ϕ_{DP}, K_{DP}, and Φ_{HV},. The system shall classify all measured reflectivity data to one of the following Rain, snow, hail, mixed etc.

8.8.6.2. Polarimetric rainfall intensity

The system shall convert data of reflectivity and polarimetric measurements to horizontal maps of rainfall intensity. The algorithms shall use the latest state-of-the-art polarimetric techniques and detail shall be provided by the manufacture. 1, 2, 3, ...48 hour total rainfall accumulation in mm will be calculated. Coefficients will be customizable by the purchaser.

8.8.6.3. Clutter elimination

The system shall provide algorithms which identify non-meteorological echoes such as sea clutter or chaff, based on the distribution of polarimetric measurements

8.8.6.4. Hydrometeor Classification Product

This product will be based on algorithms called "fuzzy logic" and artificial neural networks. Contractor must explain the algorithm in detail. The hydrometeor classification product will include the following:

- Dry Snow
- Wet Snow
- Stratiform Precipitation
- Convective Precipitation
- Hail
- Graupel
- Non-meteorological echo

Precipitation efficiency rate products:

- Light Precipitation
- Moderate Precipitation
- Heavy Precipitation
- Large Drops

8.8.7. Product Range

No	Item	Specification
	Base Products	
a	Reflectivity	≥ 400 km
b	Velocity	≥ 250 km
	Primary and Derived Products	
c	Reflectivity based products	≥ 400 km
d	Velocity based products	≥ 250 km

8.8.8. Product Dissemination

There will be software that will allow the automatic posting of a given product image or alert/alarm to a web site of the choosing of DMN. The automatic posting process will allow for the prior review of some products as determined by DMN.

8.9. Archival of Radar Data

8.9.1. Automatic Archive

Raw data and products are required to be archived automatically. Archiving will not require proprietary software to retrieve and use data from archive system. Archive media can be tapes and/or high volume disks. Information being archived will also include status from transmitter, receiver, radar/signal processor, antenna control unit, test equipment and peripherals such as UPS, generator, air conditioning, fuel level, generator working time.

8.9.2. Base Data

The base data (output of radar processor) shall be stored automatically on hard disk in compressed form. Four days cumulative data shall be available on the disc at a time.

8.9.3. Archive Retrieval

Selective transfer of compressed data from on-line storage (hard disc) to off-line storage (optical disc / magnetic tape) and vice versa shall be provided. The transfer shall not require more than 60 seconds for 1 GB data.

8.9.4. Printer

Plain paper high-resolution color printer for taking hard copies of images and products shall be provided. The hard copy shall be generated in not more than one minute.

8.9.5. Laser Printer

Laser printer for system and data management shall be provided. Laser Printer will be equipped with wireless card and connector for wired network connection. Laser Printer will be a color laser printer and allow for duplex (two-sided) copying. Printer will allow for A3 and A4 printing simultaneously (two tray system). Paper trays will hold a minimum of 200 sheets per tray. Two replacement toner cartridge sets (all colors) will be provided. Laser printer supplies such as Toner must be available in the Moroccan market, and distributed within Morocco. A printer that requires the international purchase of supplies will not be considered.

8.9.6. Data Format:

System shall be capable of archiving and transferring I and Q data in any format like binary etc.

8.9.7. Raw Data

System shall be capable of archiving and retrieving raw radar data (base data i.e. reflectivity, velocity and spectrum width) in a universal format to include:

- HDF5
- NETCDF
- XML
- GRIBI

- GRIBI2

8.9.8. WMO FM-94 BUFR

System shall be capable of generating Doppler Weather Radar products in WMO FM-94 BUFR edition 1,2, and 3 format. BUFR encoding and decoding software must also be provided.

8.9.9. HDF5

Platform independent software/utilities for converting I and Q data in binary and raw data (reflectivity, velocity and spectrum width) in HDF5 format in readable format ASCII may be provided.

8.9.10. GRIBI and GRIBI2

Archive routine will support GRIBI and GRIBI2, both encoding and decoding.

8.9.11. Coded Messages

The System shall have the capability for converting selected data/products into coded messages in user specified formats for transmission over telecommunication circuits.

8.10. Workstation Hardware Configuration

The Radar will come with a Computer Workstation, which will control radar operations and radar product generation on-site. There will also be a workstation at the Regional Center as well as the National Center required. The workstation will come with all hardware and software to provide full capability of radar control and radar product generation as described later in the specification.

8.10.1. Common Characteristics

All the workstations will have the following common characteristics:

- Processor with 3.2 GHz or more
- LINUX Operating System
- 22" color flatscreen monitor minimum
- A memory DRAM of 4GB or more (in several modules) except particular specification,
- The hard disks will have to be in several modules managed with a system of redundancy (**RAID1**) hardware,
- RAID controller will be hardware based
- 500 GB Hard Disk Drive
- The power supply will have to be redundant and hot replaceable,
- The screens will be of type LCD 23"
- AZERTY keyboard, optical Mouse + mousepad,
- Read/Write DVD

- 1 - Ethernet 10/100/1000,
- 1 - parallel port,
- 2 - serial ports in addition to the ports keyboard and mice,
- 4 ports USB 3.0 (backward compatible to USB 2.0)
- Temperature (operating) 20 to 30° C
- Relative humidity up to 70%, on-condensing

8.10.2. Data Storage – Offline

The tenderer shal provide a file storage system based on:

- A Network Attached Storage (NAS) solution, a Storage Area Network (SAN) solution, or a solution which leverages a combination of these technologies allowing automation of access to the various storage arrays via the facility network. Potential vendors for such a solution include but are not limited to the following:
  - Dell – Fluid File System product set which includes SAN and NAS solutions
  - HP – SAN and NAS solutions
  - EMC – Isilon product line solutions for SAN and NAS
  - NetApp – FAS and E-series solutions for SAN and NAS
  - IBM – Storwize product line for SAN and NAS

- Application aware software giving access to the data.

- A means of providing recurring automated off-site backup of the data to ensure protection against damage or destruction of the local facility and/or data storage equipment. Potential solutions shall include either an::
  - Automated cloud backup solution – would require reliable internet connection to a vendor backup facility allowing automated and unattended backup of data to an off-site facility for secure storage/archiving; or an
  - Automated tape backup solution – would require additional local hardware equipment, manual handling of tapes for backup execution, and personnel for taking backup tapes off-site to a secure storage location.

The file storage system shall include:

- Data storage capacity sufficient to support accumulation of up to 5 terabytes (TB) of data per year.
  - 30MB per volume scan
  - Volume scan every 5 minutes
  - 12 x 24 x 365 x 30MB = 3TB
  - Allow for 2TB of product data per year
  - Total of 5TB per year

- Must allow for reading of the data on standard readers.

- The software shall allow two modes of filing:
  - Carried out on request of the operator
  - Automatic: carried out according to criteria depending on a queue

- The software shall be equipped with tools of supervision, administration and alarm making it possible to follow the state of the stored data, in particular:
  - Rate of storage consumption across each array and across the entire file system
  - Alarm when remaining storage reaches administrator defined levels
  - Read/Write error on disk array
  - Physical error on disk array

- The software shall include ability to facilitate the means of providing automated recurring off-site backup based on the backup solution chosen.

8.11. Radar System Life and Reliability

8.11.1. Life/Operation

The useful life of the system shall be 20 years after acceptance at site. The system shall be capable of round-the-clock continuous operation during its useful life.

8.11.2. Components

All components of the system shall be of industry standard.

8.11.3. Modular Concept

The system shall be designed on a modular concept. When a fault has been located in a module, its replacement shall be possible without realignment and adjustment of the system.

8.11.4. UPS

The uninterrupted power supply (UPS) of adequate capacity for one hour back up for the entire system shall be supplied.

8.12. Tools, and Test Equipment

8.12.1. Tools

A set of standard and specialized tools required for repair, disassembly and assembly of the system shall be provided with the system.

8.12.2. Test Equipment

The supplier shall provide the adequate test equipment to maintain and support the maintenance of the system.

8.13. Installation

8.13.1. Pre-Installation Information Package

A pre-installation information package shall be provided within two months after contract signing for guidance in site preparation work.

8.13.2. Installation Material

All materials like wave guides, templates for pedestal and radome, interconnecting cables, grouting bolts etc. required for the installation of the system shall be supplied along with the equipment. The exact length of waveguide and cables required for each site shall be specified by the Indenter.

8.13.3. Install

The installation shall be carried out by the supplier.

8.13.4. Electrical

The Bidder will be responsible for electrical connection at the radar site and arranging such service to assure the electrical requirements of the radar and all ancillary equipment is met.

8.13.5. Electrical Backup

Bidder is required to provide an electrical backup system based on a diesel generator, fuel storage, and fuel to operate the system continuously for five days. The backup generator will be properly sized to maintain radar operation, environmental control, computer and UPS operation at no more than 70% capacity of the backup system, leaving the remaining capacity in reserve.

8.13.6. Structure

The supplier shall take into consideration that the system is required to be installed in over existing building/structures or on a standard tower constructed by the purchaser.

8.14. Acceptance Testing

8.14.1. Test Plans

The supplier shall submit detailed test plans for system acceptance testing prior to shipment and after installation at site. The test plan shall require mutual concurrence by the supplier and purchaser

8.14.2. Performance

The tests shall be the verifications of performance of the system as per the specifications and functional requirements.

8.14.3. Factory Acceptance Test

As per the mutually agreed test procedures, Factory Acceptance tests (FAT) shall be carried out at the supplier's premises prior to shipment. The equipment shall be shipped only after satisfactory conclusion of the pre-shipment FAT acceptance testing.

8.14.4. Site Acceptance Test

As per the mutually agreed test procedures, Site Acceptance Test (SAT) shall be carried out at site after installation.

8.14.5. Defects/Deviations

Any defects / deviations noticed during the site acceptance tests (SAT) shall be rectified within a maximum period of one month from the completion of the tests.

8.14.6. System Commissioning

After the satisfactory completion of the site acceptance tests, the supplier shall demonstrate the capability of the system to be operated continuously for a 7-day period, after which it will be said to be commissioned.

8.15. Maintenance

8.15.1. Warranty

The warranty for all components shall be for a period of 2 years from the date of commissioning. The warranty will include third party items/subsystems including radome.

8.15.2. Spares and Consumable

The supplier shall provide Consumables required for two years after commissioning. Spares must be held in Morocco. The supplier shall give an assurance for continued supply of spares and consumables for a period of 20 years from the date of commissioning of the system. All spares used during the warranty maintenance period will be replaced by the supplier at his own cost before the end of the warranty period.

DMN reserves the right to perform inspection of spares in storage at any time.

8.16. Training

8.16.1. General

Training shall consist of: (1) onsite training by the manufacturer; and (2) training modules on

electronic media.

The electronic media will allow the trainees to take the training at the time of their choosing, and will allow for retraining, if desired by the purchaser. Each training course mentioned below shall be provided as a training module with review and tests after each subsection. A test will also be provided at the end of each module.

The modules shall be provided on a portable hard drive(s) of sufficient capacity to hold all of the modules. The purchaser shall have unlimited rights to copy these training modules as well as take the training at any time the purchaser desires. The file format shall be .WMV and/or .MPG that can be simply viewed on any Windows Computer with a freely available media viewer, such as Windows Media Player.

The training modules shall include all subjects in similar detail as the on-site training provided by the bidder.

8.16.2. Radar Operation and Maintenance Course: On-site and Electronic Media (2 weeks duration), for radar engineers/technicians

This course shall give the trainees requisite knowledge of the functioning of the weather radar in association with its controlling programs. Upon completion of the course, trainees will be full trained to calibrate, operate and maintain the weather radar hardware using the systems utility software and test instrumentation.

Trainee level: engineers with experience of weather radar maintenance, and routine experience in electronics servicing.

8.16.3. Operational Software Training Course: On-site and Electronic Media (2 week), for system administrators

This course shall give the trainees a detailed knowledge of the function and interaction of the software modules comprising the radar systems programs. This course provides the detailed knowledge with the software interface to the radar system, the radar measurements, signal processing, and data transmission allowing the trainee to monitor the system performance and diagnose and correct typical faulty operating conditions, as well as carry out upgrades with new program versions.

Trainee level: programmers and experienced computer operators.

8.16.4. System User Training Course: On-Site and Electronic Media (2 weeks), for system users

This course shall give the trainees a detailed knowledge on the use of radar software and data in meteorology, hydrology, and aviation meteorology.

Trainee level: meteorologists and hydrologist with some skills in computer usage.

8.16.5. Training Material and Documentation

The supplier shall supply course material during all training courses. The course material will remain with the trainees for later reference. The course shall include the use of the actual handbooks that make up the official documentation of the radar system.

8.17. Documentation

The supplier shall provide two (2) complete sets of system documentation including:

1. Radar System Operation and Maintenance Manuals
2. System Software Manuals
3. User Operations Manuals

8.18. Evaluation of Bids

The bids will be evaluated as to meeting the specification of the tender. The table below provides the key specifications that can be used to evaluate the bids. It is recommended that the bidders respond to each item being evaluated and provide supporting documents that corroborates the claim of meeting specification. The bidder should be reminded that all specifications will be confirmed upon delivery with the bidder being obligated to replace items that don't meet specification with items that do meet specification. Also, the bidder will be solely responsible for changes/upgrades of equipment required to meet specification. This condition will last through the warranty period.

The three columns are for 1) Identifying the Specification; 2) the Bidder certifying that the specification is met, and 3) Verification by the Purchaser that the specification is met. Verification will be confirmed by printed literature provided with the bid, along with inspection of data sheets available on the manufacturer's web site.

Specification	Specification Met	Specification Verified
Equipment:		
C-Band Doppler Radar		
Dual Polarization		
Antenna Beam Width 0.95°		
Side Lobes (Secondary Lobe) -30 dB maximum to that of main lobe		
Antenna Azimuth Drive 0 to 360° uninterrupted		
Antenna Elevation Drive -2 to 90°		
Azimuthal Scan Rate 30° sec^{-1} Programmable		
Elevation Scan Rate 20° sec^{-1} Programmable		
Angular Position Accuracy ±0.1°		
Antenna Diameter 4.3m		
Antenna Gain 45 dB		
Radome 5.5m		
Construction Fiberglass Sandwich		
Automatic Waveguide Dehydrator Operation		
Magnetron C-Band Transmitter		
Solid-state, IGBT Switched, Long Lifespan Modulator		
250 kW Peak Output Power		
< 1 Hz Frequency Stability		
250 – 3000 pps Pulse Repetition Frequency		

Specification	Specification Met	Specification Verified
< 1 µs Transmitter Recovery Time		
Primary Power Input 220 VAC, 50 Hz		
Receiver Minimum Detectable Signal -110 dBm or better		
Receiver Noise Figure 2 dB		
Receiver Minimum Detectable Reflectivity at 50 km of -10 dBZ		
Signal Processor Type 3 – Multi-channel digital receiver		
Signal Processor IF Frequency 60 MHz		
Signal Processor IF Sampling Multi-channel, up to 120 MHz		
Signal Processor Minimum Processing Resolution 25 m		
Signal Processing Mode Pulse Pair (PP) or Discrete Fourier Transform (DFT/FFT) with more than 20 real-time signal enhancement algorithms		
Clutter Filters up to 16 Time Domain, > 16 Frequency Domain, Adaptive Filtering, Second Trip Cancellation		
Command and Control:		
Three levels of radar control. 1) National; 2) Regional; 3) Local		
User assignable radar systems which will accommodate the three levels or radar control		
Six Security Levels for access and control of radar network and products based on Username and Password		
All Radar tasks controlled by assignable security level		
BITE: A BITE Processor shall measure and process in real time analog and digital parameters in the radar system and generate and display an error message whenever their value falls outside the specified permissible range.		
BITE: The BITE processor shall continuously monitor input and output signals of the radar system's module/ PCB's for any deviation from the standard value. Whenever any error message is generated, the BITE Processor shall log sand archive failures or status from of the system.		
BITE: The BITE Processor shall cause the malfunctioning units to be switched off and provide an acoustical alarm for warning the operator.		
BITE: The maintenance/BITE utility shall allow visualizing the system graphically as a block diagram with red/green color indication of faulty blocks or faulty communication between modules.		
BITE: The BITE utility shall allow configuring the parallel transmission of BITE messages to other destinations.		
BITE: Monitor all power supplies. Provide List of all power supplies.		
BITE: Monitor environmental conditions Such As Air Conditioning Status, Temperature, Humidity in radar equipment shelter, including door alarm		
BITE: Transmitted Power and quality parameters		

Specification	Specification Met	Specification Verified
BITE: Received Signal Faults (provide list)		
BITE: Power supply Voltage and Amperage		
BITE: Temperature in the Radome		
BITE: Lubrication Liquid Condition		
BITE: Air Pressure in Wave Guide		
Product Generation:		
PPI		
RHI		
Maximum Display Reflectivity		
Maximum Display ϕ_{DP}		
Maximum Display Radial Velocity		
CAPPI Z		
CAPPI R		
CAPPI V		
CAPPI W		
CAPPI Z_{DR}		
CAPPI KDP		
CAPPI LDR		
CAPPI ϕ_{DP}		
CAPPI ,ρ_{HV}		
Cross Section Z		
Cross Section V		
Cross Section σ		
Echo Base		
Echo Top		
Rainfall Intensity		
Rainfall Accumulation User Settable 1 hour to five days		
Vertically Integrated Water Content		
Hail		
Hydrometeor Classification		
VAD (Velocity)		
Mesocyclone Identification		
Gust Front Identification		
Convergence/Divergence Identification		
Thunderstorm Cell of MCC		
Quantitative Precipitation Estimation for any point or area within the radar network		
Microburst Identification		
Maximum turbulence within user defined atmospheric layer		
Vortex Signatures (Tornado)		
Storm Relative Velocity		
Polarimetric rainfall intensity		
Software:		

Specification	Specification Met	Specification Verified
Integration of rainfall data into radar products through open source WMO data format		
Integration of satellite imagery into radar products through open source WMO data format		
Integration of numerical weather prediction models through open source WMO data format		
Storm/Cell Tracking Software		
Bright Band Detection Software		
Precipitation Rate Correction by Altitude Software		
Precipitation Rate Correction to Rain Gauge Network		
Automatic Dissemination of Radar Images in JPEG to Web Site		
Automatic Dissemination of Radar Alarms as Text Product to Web Site		

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9. Development Impact (Task 8)

The establishment of an effective national system for forecasting and responding to environmental crises will stabilize national security and stability. Specific sectors of society have varying needs for meteorological, hydrological and allied services. These needs will continue to grow to meet the demands of environmental changes and development.

Weather and climate influence agricultural production, transport (air, sea and surface), energy generation, water resources, disaster management, building and construction, commerce and industry, recreation and tourism and environmental management. Factoring weather and climate services into social and economic policy formulation and development plans is the key to achieving sustainable development. In planning of economic and social systems and infrastructures there is need to take into consideration the potential impacts of severe weather and extreme climate events in order to avoid the associated negative impacts. The social and economic systems and infrastructure must be robust to withstand weather and climate extremes and resilient for rapid recovery following disasters.

9.1. Infrastructure

9.1.1. Public Weather Services Network

Public weather services aim at developing capacity to meet the needs of the community through provision of comprehensive weather, climate and related services, with particular emphasis on protection of life and property, sustainable development and public welfare. Public weather services are one of the most visible programs of DMN. The demand for public weather services is increasing due to expansion of economic activities and to the growth in demand from the public. In efforts to satisfy this demand the DMN has proposed to adopt improved science and technology within meteorology and the improved capability to present and deliver accurate and timely products utilizing modern information and communication technology. This project proposes construction of nine new radar systems with state of the art technology. Establishing and meeting of user requirements and timely dissemination of the information is of paramount importance.

9.1.2. Agrometeorological Services Network

The agriculture sector is just one of many groups that will be positively impacted by the development of an enhanced DMN meteorological system. Data on environmental conditions will be gathered, processed, and disseminated back to the agricultural community in real time. This can ultimately be expanded to the use of crop models which will help guide optimum practices in producing the higher volumes of product

Agriculture holds a high priority in Morocco. Agrometeorological services are required in the day-to-day activities such as scheduling of farming operations including planning, irrigation, spraying, prevention of diseases and harvesting. Crop and livestock production are also affected by weather and climate. Timelier and better agro meteorological services will help minimize the adverse effects of extreme climate events while taking full advantage of favorable weather conditions at the different stages of production. Weather forecasts are increasingly

critical for optimal planting, spraying, harvesting, and storage and to the protection from pests and diseases.

The issue of food security, hunger and malnutrition is of importance in Morocco where a considerable proportion of the society is undernourished, especially children. The fundamental link between agriculture and food security on the one hand and weather and climate, on the other hand, is obvious and the need to eradicate hunger and malnutrition and achieve lasting food security for all has become essential.

Food security has been a major concern in the 80's and 90's because of the recurrent droughts and floods. Agriculture forms a key element o the economy of Morocco, so rainfall, or lack of it is critical to the health of the economies. As the population increases more people are living in high risk areas and marginal lands. Weather and climate forecasts form the most important tools for improving agricultural production and early warning for preparedness including identification of appropriate seeds so as to take full advantage of seasonal rains.

9.1.3. Improvements to Transport

Aviation, water and surface transport play vital roles in the economy of Morocco and are all-dependent on weather. In particular, the safe and efficient operation of aviation and shipping is dependent upon the availability of reliable weather information. Modern, well equipped weather services are important to aviation taking into account the wide range of aircraft operated (from small single engine to large wide bodied jets carrying large numbers of people and cargo) and the possible range of severe weather in Morocco. Planning of airports, ports and roads takes into account meteorological conditions.

Meteorological services are widely used by the transport and communication sector. Of these, civil aviation takes a major share of the use of meteorological services by both airport operators and the Air Traffic Management Services. Services in form of flight documentation for both flight planning and operation are issued to each departing aircraft. Also provided is "take-off data" and "trend type" forecast for landing. In addition to regular information and services there are also warnings issued.

Improved weather forecasts at airports can reduce operational costs through better optimization flight patterns and reducing times on runways. The civil aviation community will also have an impact with more timely information of weather events, especially those events that cause an interruption to civil aviation. It is expected that this information will not only lead to more efficient civil aviation practices but also improved safety in general.

9.1.4. Improvements to Energy Generation and Distribution

Weather and climate elements, in particular rainfall, wind and solar radiation influence the exploitation of the main energy resources in Morocco. It is, therefore, important that reliable data and information on these elements are made available to the relevant sectors to ensure sustainable exploitation of these resources. Similarly in the energy generation industry, improving the predictive ability of forecasts can result in more efficient use of power generating resources and mean hundreds of thousands of dollars saved each year for electric utilities

through better planning of electric power demand and better management of capacity and resources.

Hydroelectric power continues to be the major source of energy for domestic and industrial consumption in Morocco. The generation and distribution of hydroelectric energy is highly dependent on rainfall and other meteorological elements. The Region is affected by the variability of rainfall which cause fluctuations in water availability needed to generate electricity. The variability of rainfall has a great effect on the economy of Morocco mainly through a slowdown of industrial production leading to loss of jobs and livelihood as a result of power rationing. There is also the increase in production costs associated with higher costs of alternative power generation.

Wind has been recognized as an alternative affordable source of energy. However, in Morocco, very little exploitation of this energy resource has taken place, despite the fact that data is available. Meteorological information is essential for identifying locations with wind energy potential for large-scale tapping of wind energy to supplement energy levels to support industrial and domestic activities to avoid the negative impacts of hydro-electric power shortfalls and enhanced access to power especially in rural areas.

The potential for solar energy generation in Morocco is much more than in Europe and other temperate regions, where the use of solar power is substantial. The utilization of meteorological information could help in mapping the availability of solar energy, which is dependent on the amount of available solar radiation.

9.1.5. Improvements in Building and Construction

The design and construction of buildings, roads, railways, airports, bridges and dams requires climate information in the planning stage, to enable them withstand severe weather and extreme climate effects.

9.1.6. Real-time Data Collection

A prime objective of the telecommunications modernization system is to provide the capacity to relay real-time observations from the DMN meteorological and hydrologic observation system. This includes surface meteorological, hydromet, agrimet, climate, radiosonde, and radar data collection facilities.

9.1.7. Real-time Information Dissemination

Not only is real-time data communication benefitted by the modernized DMN system. Improved real-time dissemination will allow necessary information to travel to localities that must act on the meteorological information.

9.2. Human Capacity Building

9.2.1. Installation and Construction

The proposed project will create a significant need for construction workers to establish the radar systems. The proposed project will create approximately between 200 and 300 temporary construction jobs. Both skilled and unskilled labor will be involved. Several hundred workers to several thousand workers would be required for the construction phase, depending on the period of construction. Construction workers will include the following:

- Excavators
- Structure Foundation
- Portage
- Civil Maintenance
- Building and Construction
- Painters
- Electronic Technicians
- Electricians
- Network Administrators

The above indicates the jobs that would be required during construction, installation, and commissioning.

9.2.2. System

Permanent job creation shall follow as the project moves forward. These positions shall involve the operation and maintenance of the radar and are currently estimated to reach 18 jobs. Jobs required as part of the routine maintenance of the radar systems include the following:

- Civil Maintenance
- Painters
- Electricians
- Electronic Technicians
- Network Administrators

DMN has the capacity to maintain the existing network. The new network will require additional electronic technicians/engineers to maintain the system. DMN may choose to outsource these activities as it has in the past. In summary, the operation and maintenance of the modernized radar system would require significant expansion of technicians. Outsourcing may be favorable because the technicians and technical help can be redeployed easier without much concern if displacing government workers.

9.2.3. Training

There will be a very significant training component where over 20 technicians and operators will be needed to be trained to operate the modernized radar system.

9.2.4. Employment Migration

There will be an employment migration to fill the new capacity of installing, operating and maintaining the new telecommunication network. In addition, there will be opportunities to export this work to other countries that want to take advantage of the success demonstrated by DMN. Since this capacity is largely new for DMN, it is not apparent that there would be significant number jobs lost.

9.3. Technology Transfer and Productivity Impacts

For governments this project will result in tangible benefits in managing public resources, assistance programs, disasters and emergencies while reducing operational costs.

9.3.1. New Technology

There does not appear to be any anticipated new technology that will be developed for this modernization project as designed. The modernization is based on technology transfer of well-established standards in telecommunication, taking into account and utilizing the rapid advances of the telecommunications industry over the last 10 years.

9.3.2. Efficiency and Productivity

The modernized advanced radar network will improve the efficiency and productivity of the DMN forecast team, and will lead to improved information distribution which will lead directly to improved forecasts. The improved weather forecasts will impact virtually every industry and every person in Morocco. Improved forecasts will lead to the use of weather data for making decisions from commerce, transportation, energy, construction to name a few. There will not be an industry that will go untouched with the gains in efficiency and productivity that will be demonstrated with improved communication.

9.3.3. Economic Benefits of Improved Marine Activities

Weather information and forecasts are important to the increased offshore drilling activity in Morocco, and to the ocean shipping operations. This information is also important in marine operations such as fishing and passenger vessel operations in the Ocean. Many marine accidents have occurred that could be avoided through proper utilization of meteorological information for safety of navigation.

9.3.4. Economic Benefits of Improved Commerce, Industry and Insurance

Weather and climate have significant impacts on production and transport systems, storage and comfort. There is therefore an increasing need to insure against possible losses due to weather and climate effects such as wind damage, droughts, floods, lightning, frost, humidity and hail damage, among others. The insurance companies need meteorological information in order to arrive at appropriate meteorological insurance rates. The requirement to insure against adverse

weather and extreme climate events is increasing in many countries. To this end, the use of weather and climate information could contribute to the cost-effectiveness in the production, sale and consumption of most industrial products.

Providing better information concerning the probabilities of weather-related events also enables the emergence of markets that help mitigate the economic and financial consequences of uncertainty. These markets, which allow the consequences of uncertainties to be "priced" in the form of insurance and hedge contracts, are able to function because information about weather and climate makes it possible to attach probabilities to uncertain events.

9.3.5. Economic Benefits of Improved Health Sector

Occurrences of extreme climate events such as prolonged droughts and floods have had impact on the health sector through outbreaks of water borne diseases such as cholera, typhoid and dysentery as well as respiratory diseases. Changes in weather are also frequently followed by outbreaks of malaria, which remains one of the most common killer diseases known for a very long time. Disease vectors are influenced by weather and climate conditions. Most of the vectors can only survive in certain weather and climate conditions. Unique diseases are at times observed in the event of a climate extreme. Utilization of meteorological information and data is indispensable in planning mitigation measures in the health sector for many of the diseases highlighted above.

9.3.6. Economic Benefits of Improved Recreation and Tourism

Weather is a major determinant of low and high tourism seasons. Weather and climate information is important to the exploitation of recreation and tourism resources in Morocco. Complementary sectors, which support recreation and tourism, such as Civil Aviation, Tour Operators and the Hotel Industry, among others all depend on weather and climate information.

9.4. Market–oriented Reform

9.4.1. Facilitation of Project Implementation, Operation and Maintenance

The financial structure for the project will be required to conform to the legal and regulatory regime involving foreign investment. The impact of which shall be to further strengthen the trade and financing processes under way in Morocco further encouraging foreign trade and investment.

There are no clear market-oriented reforms that would facilitate the implementation of the Project, or result from the implementation of the Project. DMN could make the infrastructure (towers) available to other industries that could enhance privatized services, though it is not recommended that the DMN services be privatized.

9.4.2. Competitive Assessment

The radar modernization will develop considerable expertise within Morocco if the work is kept within the country. Any capacity and institutional development achieved during the course of this

project can potentially be used in other sectors in Morocco, as well as providing expertise to neighboring countries.

9.5. Other

9.5.1. Indirect Impacts

Some of the development impact of the proposed radar system upgrades is very difficult to estimate because they are spread throughout the economy and through a wide variety of entities, including local communities, families, and diverse businesses. These impacts derive from the fact that weather and climate information can help reduce uncertainty in several ways. There will be several indirect developmental impacts of the recommendation for an improved meteorological and hydrological telecommunication system. These impacts include the following:

- Improvements in Public Safety
- Indirect Job Creation
- Demonstration Effects
- Regional Support and Technology Transfer to Developing Countries
- Improvements to the Environment

9.5.2. Improvements in Public Safety

Indirect impact on citizens are improved safety, improved quality of life, reduced loss of life due to severe weather events, and better choices in daily activities. One of the main roles of the radar modernization project is to bring meteorological and hydrological information to places within Morocco that have not had reliable timely weather information. The meteorological and hydrological information has direct application to public safety as related to protecting life, property, and commercial industry from the impacts of weather.

9.5.3. Improvements in Natural Disasters Management

Better prediction of weather and climate cannot reduce the likelihood that severe weather events will occur, but can help substantially lower the costs to society of such events. These cost savings come in two forms: 1) people are more likely to invest in loss-reduction activities when better information is available; 2) Better information can also reduce economic costs that arise when uncertainty about adverse weather causes government authorities, people, and business to "err on the side of caution" and undertake what later turn out to be unnecessary loss-reduction activities.

Morocco is affected by a range of weather and climate related hazards that often translate into natural disasters – principally arising from drought, severe storms, tropical depressions and floods. Heavy floods have washed away roads, bridges and railway tracks and destroyed many hectares of crops. DMN contributes to the disaster management through its forecasts, advisories and warnings of severe weather, and the monitoring of climate especially rainfall. Some of the suffering that arise due to natural disasters could be alleviated or minimized through planning based on reliable weather and climate prediction, information and advisory. Droughts or floods cannot be stopped, but the timely availability of a scientifically based early

warning of the most probable nature of the forthcoming rainy season would assist in making contingency plans thus avoiding crisis management in responding to the natural disaster.

9.5.4. Indirect Job Creation

The radar modernization program for DMN will have far reaching effects on indirect job creation. New areas of the country will now have modernized radar to bring important information on weather related events. This information will be distributed to the people of the Morocco with a goal of reaching 100% of the population by redistributed products, such as forecasts and warnings by local government as well as media. With information distributed to these regions there will be opportunity for those that will work with this information that never had had this information before. This could result in opportunities for thousands of jobs in addition to tens of thousands of jobs for people in ancillary positions that will need to be trained to properly use this information within their industry.

9.5.5. Demonstration Effects

DMN, and to a larger extent, the Government of Morocco will have a leading example of a modernized radar system using the latest technologies and protocols. This will bring great interest from other countries wishing to perform a similar task.

9.5.6. Regional Expertise and Support to Developing Countries

Once DMN, and the various staff members learn from developing the modernized telecommunication system, their expertise can be used to help developing countries perform a similar activity. This could either bring financial compensation for such assistance, or increased attention to the Morocco in regards to technical expertise in developing a comprehensive terrestrial telecommunications system.

9.5.7. Improvements to the Environment

Improved data collection, interpretation, and dissemination will have far reaching effects on the environment in general. Endeavors such as air pollution, water pollution, and exceptional events will be able to take advantage of the radar system. It is widely recognized and acknowledged that the climate is changing mainly as a result of direct human activities (burning of fossil fuels, bush clearing, and deforestation). Available scientific information reveals that global warming is this century's most serious environmental problem with far reaching social, political and economic consequences.

The main effects of climate change to the society include sea level rise leading to flooding and submerging of coastal zones and settlements, increase in frequency and severity of natural disasters, change of seasons and rainfall patterns. The heightened awareness of the importance of climate change to a range of economic, planning and social concerns has given new emphasis to one of a DMN's most basic functions – the collection and maintenance of high quality climate record for the national good. Not only is the demand for data increasing but also so is the demand for analysis, studies, research and expert opinion on climate change and global warming issues.

9.5.8. Improvements to Water Resources Management

Management of water resources is one of the most critical issues facing Morocco. Availability of fresh water for industrial and domestic use is vital for the health of the population. There is, therefore, need to adopt optimum ways of sustainably utilizing the available but dwindling fresh water resources in the Morocco. This scarcity could be attributed to frequent droughts, population pressure, deforestation and land degradation. Flooding could contaminate available fresh water resources and also cause damage to water systems leading to possible outbreaks of water-borne diseases. Accurate daily and seasonal weather forecasts assist in the assessment and use of water resources. It is therefore imperative for DMN to acquire appropriate infrastructure and capacity necessary for the generation of sufficient information and data to facilitate the provision of accurate forecasts and assessments.

9.5.9. Improvements to Land Use

Weather and climate information is essential for the sustainable exploitation and conservation of land as a resource. Indiscriminate land use practices are known to lead to land degradation, particularly if weather and climate information have not been factored in the land use planning process. Severe weather and extreme climate events constitute some of the most serious problems contributing to land degradation in Morocco. With the increase of the population, more land in the marginal areas is opened up for agriculture and livestock development. Problems of indiscriminate land clearing; deforestation and wetlands land degradation has had serious impacts on the land use. The extension of agricultural activities to marginal areas would require more utilization of meteorological information.

Climate information is of tremendous importance for long-term land use planning. For example the siting of industries, agricultural projects, human settlements among others, should take into account meteorological conditions to avoid pollution, heavy financial losses, health hazards, accelerated land and environmental degradation.

Appendix A

Baron Services Radar Training Manual

Baron Services

Radar Training Manual

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Chapter 1

Radar Principles

Since the beginning of the decade, technological advancements in the field of meteorology have been astounding. The acquisition of satellite facsimile equipment, digital barometers, direct readout of cloud height displays, and more have made the job of forecasting and observing the weather easier. Aside from simplifying the process, these advancements have increased our ability to provide more accurate and timely support. However, it doesn't stop here. This is a training document for the VHDD-300C Radar System, hereafter called the VHDD or VHDD Radar.

Conventional Radar Principals

For more than a century, meteorologists have used existing weather conditions in an attempt to forecast the weather. In most cases, the current weather information was based on the conditions visible to the naked eye from designated points on the ground. This resulted in large voids between observation points. Then, with the invention of weather radar, came the ability to fill these undesirable gaps.

Radar observations are very often the basis for issuing a local weather advisory or warning. With conventional radar, these observations are only useful after severe storms develop and often must be supplemented with other data. Doppler radar has the capability to detect atmospheric motions, as well as motions within a storm cell or system. Imagine the benefits of being able to see convective scale dynamics in real time. This eliminates much of the guesswork involved in pinpointing severe weather.

Radar systems used in meteorological research and operations provide information, which could not be obtained over the same wide areas in any other way. To understand and apply this unique information, it is necessary to understand the radar's characteristics, which determine its ability to detect and display atmospheric targets. You should also understand the ability of the radar to detect and display echo coverage, height, and intensity is limited by design and cost factors of the system. A good understanding of the operation of a radar system helps you become proficient at radar operation and interpretation. Therefore, you must have a complete understanding of conventional radar principles before moving on to Doppler principles.

To ensure you have a complete understanding of Doppler principles, this study guide/workbook begins with a review of conventional radar principles. From there you learn about the Doppler principal.

Development and Basic Theory of Radar

The idea for radar actually came about during testing of a radio navigation system in June of 1930. Lawrence Hyland was conducting a test near Washington D.C. when he noted that a radio signal meter was showing periodic and unexplained peaks. He soon realized airplanes in the traffic pattern at Boiling Field were reflecting a small part of the radio energy-- an electromagnetic echo. From Hyland's discovery came development of a system to detect targets using a narrow beam of electromagnetic energy. Of course, this is what we now call radar.

The radar beam is actually a series of short electromagnetic pulses directed along a path by a dish-shaped (parabolic) antenna. Targets struck by the pulse send a portion of the energy back to the antenna. In the time between pulses, the returned signal is detected, amplified, and processed for display on various screens. The position of the antenna measures the azimuth (direction) of a target, and the time duration between emitted and detected pulses measures the range of a target.

Although this is a very simple concept, the characteristics of electromagnetic energy can cause several different types of problems.

Characteristics of Electromagnetic Energy

Objective

Given characteristics of electromagnetic energy, select facts about the radar detection process.

Introduction

Our ability to use radar for weather detection depends on the theory of electromagnetic energy. No matter how sophisticated the hardware, we are faced with theoretical limitations.

In this section, you will learn some facts about electromagnetic energy, which gives you an understanding of why the radar can do what it does. And, just as important, why the radar is limited in what it can do.

After completing this objective, you will be able to select correct facts about the:

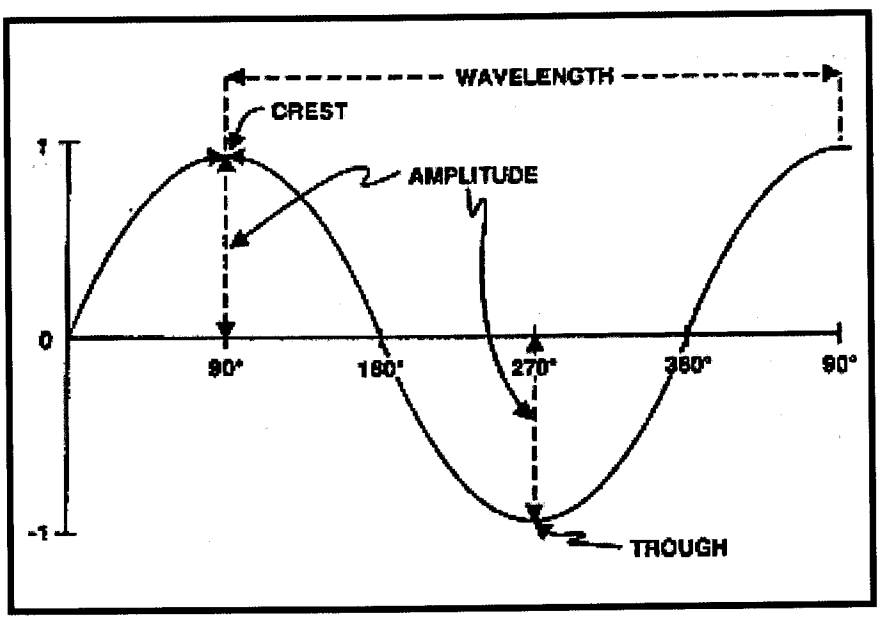
- Principles of electromagnetic energy, and the relationship between wavelength and frequency.
- Attenuation caused by scattering and absorption.
- Relationship between wavelength and capability to detect different size particles.
- Detection of backscattered radiation.

Information

Electromagnetic Energy

You are probably familiar with the term electromagnetism. Electrical current passing through a wire coiled around a metal tar induces a magnetic field. As the magnetic field is induced, the metal bar becomes polarized (equal and opposite charges on either end). The bar is then known as a dipole. If you change the direction of current flow through the coiled wire, the polarity of the magnetic field reverses. The reversal in magnetic polarity induces another electrical field, which propagates away from the dipole at the speed of light (3×10^8 meters per second) in the form of waves. If visible, these waves would look like a series of sine waves as shown in Figure 1.

Figure 1: Characteristic Sine Waves



This principle is employed in any device, which radiates electromagnetic energy including radar. Electromagnetic energy has three important characteristics, which affect radar performance--wavelength, frequency, and amplitude.

Wavelength

As stated earlier, electromagnetic energy propagates away from a dipole in sine waves. The wavelength of the energy is measured between successive troughs or crests in the sine waves (see figure 1). The height or amplitude of these waves represents power. Mathematically, wavelength is represented by the Greek character lambda (%} Wavelengths are typically expressed in centimeters (cm).

Figure 2: Various Radar Wavelengths

Band	Typical Wavelength (cm)	Primary Application
K		Cloud Physics
X	3	Airborne
C	5	Local Warning
S	10	Network
L	23	Air Traffic Control

Modern radars used for meteorological purposes operate in a portion of the microwave region of the electromagnetic, or radio, spectrum from less than 1 cm to approximately 11 cm (figure 2).

Other factors being equal, the echo return from clouds or precipitation increases with shorter wavelengths. Within the range of wavelengths used for weather radar, the smaller droplets are more visible to the radar at the shorter wavelengths and are more transparent at the longer wavelengths.

When detection of clouds is required, short wavelengths are desirable. For the detection of snow, or light to moderate rain, use of the 3-cm wavelength radars appears optimal. However, 3-cm radiation is severely affected by heavy rain. Thus, in regions where large thunderstorms or hurricanes occur frequently, the use of a 5-cm or greater wavelength is more desirable. Attenuation or weakening of the energy in the beam, through rain, increases at shorter wavelengths.

In addition, if the size of the antenna stays the same, the beam width is narrower when the wavelength of the beam is shorter.

Hence, the choice of a radars operating wavelength depends upon its intended use. We will see some specific examples of the importance in choosing the correct wavelength later in this section.

Frequency

The frequency of electromagnetic energy is the number of repetitions of the sine wave (cycle) per unit time. If one cycle is generated in one second, the frequency is one cycle per second. The more common unit of expression is one hertz, named after the discoverer of electromagnetic radiation--Heinrich Hertz. One hertz is equal to one cycle per second.

Wavelengths and frequency are related. As the polarity of the dipole makes two complete changes in polarity, one wavelength is generated. The rate at which the dipole repeats this cycle is the frequency. As successive waves are generated, the previous wave is one wavelength away from the dipole. Because the speed of the wave is constant (the speed of light), an inverse relationship exists between frequency and wavelength. Mathematically, it looks like this:

Frequency =c/wavelength

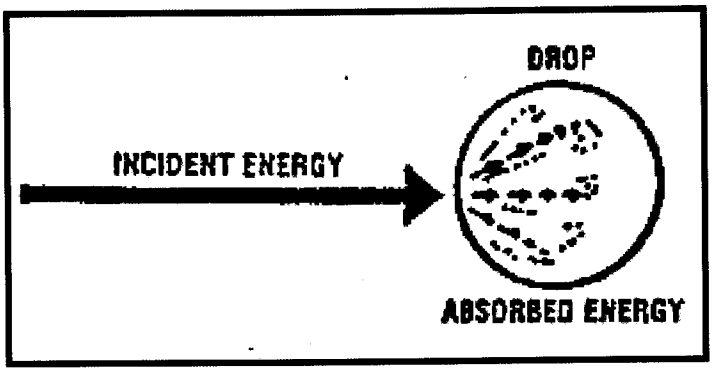
Because the speed of propagation (c) remains constant, the frequency of the radiating device is the same, if the wavelength remains unchanged. For example, to have a wavelength of 10 centimeters, the radar must have an oscillating frequency of 3×10^9 hertz or 3,000 megahertz. Engineers usually speak in terms of frequency, but meteorologists prefer wavelength because of its relationship to the size of water droplet detection.

Atmospheric Attenuation

As electromagnetic waves emitted from a radar travel through the atmosphere, some of their energy is lost. This is the result of interaction with atmospheric phenomena such as hydrometeors (clouds and precipitation), gases, and lithometeors (smoke, dust, haze, etc). This loss of energy due to interaction with atmospheric phenomena is called attenuation.

Attenuation of radar waves is dependent on two related factors; the wavelength of the emitted radio waves and the size and composition of the particle encountered by these waves. Depending on the relationship between these two factors, the emitted energy is attenuated by absorption or scattering.

Figure 3: Absorption



Attenuation Due to Absorption

Absorption occurs when electromagnetic energy encounters a particle, interacts with molecules of the particle, and disturbs the motion of its bound electrons (Figure 3). The electrons absorb some of the electromagnetic energy and the atoms within the molecule are said to be in an excited state. This is how a microwave oven heats food. Radar energy is transmitted into food containing water molecules. The water molecules absorb some of the energy and heat up (they enter a more excited state).

Energy absorbed by a molecule may be re-radiated by the particle at a later time. However, when this energy is at a different wavelength (such as heat), the energy is unrecognizable to the radar, which originally transmitted it.

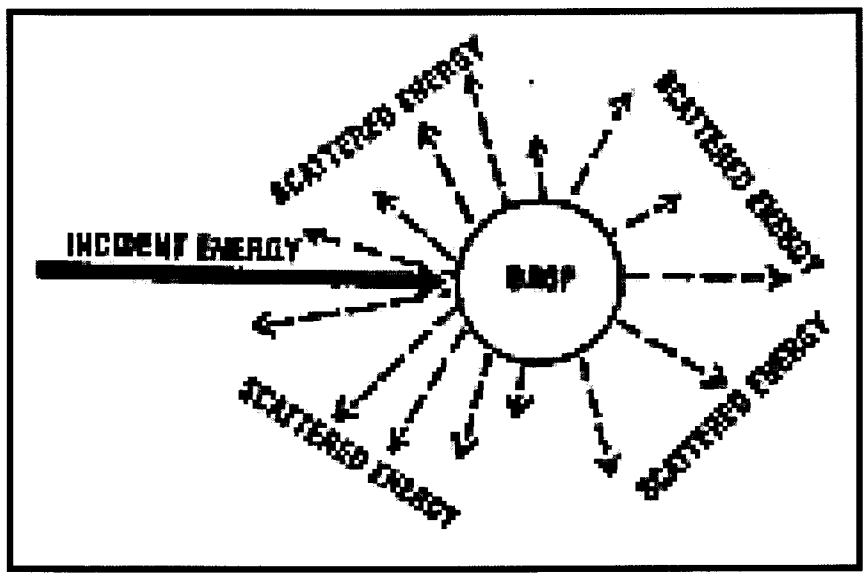
In general, absorption by gases is negligible for radars with wavelengths equal to or greater than one centimeter. For radars with wavelengths equal to or greater than five centimeters, absorption by cloud droplets is negligible. And for radars with wavelengths equal to or greater than 10 centimeters, absorption by precipitation particles is very small.

The wavelength for weather radars is chosen to minimize atmospheric absorption, while at the same time, preserving enough sensitivity to small particles to detect weather phenomena.

Attenuation Due to Scattering

As stated previously, bound electrons of atoms and molecules absorb electromagnetic radiation that has been emitted from the radar. The molecules act as forced oscillating dipoles, and the excited atom or molecule emits some of the electromagnetic energy at the same wavelength that struck it. This process is called scattering.

Figure 4: Backscatter vs. Lost Scattering



When an atmospheric particle scatters electromagnetic energy, it redirects the energy in many different directions, including directly back at the radiating antenna. This energy return is called backscattering and is what the radar detects (See Figure 4). The remainder of the energy is then said to be "lost" in other words, attenuated due to scattering. (Only a small fraction of the incident energy is returned to the antenna for detection).

The relationship between the wavelength and target diameter is also critical when considering attenuation due to scattering. As long as the target diameter is smaller than .02 of the wavelength of the emitted energy, it will "scatter" energy in all directions. This is called **Rayleigh** scattering and the particle is referred to as isotropic. That is, scattering in all directions is equal.

As the target diameter increases (with respect to the wavelength), Rayleigh scattering increases much faster than the size of the particle would suggest. Thus, we get dramatically stronger backscattering from larger particles.

However, the increase in backscattering does not continue forever. As the particle reaches a size equal to 0.2 of the wavelength, another type of scattering occurs – **Mie Scattering**. With Mie scattering, most of the energy is forward scattered and thus lost to the radar for detection. This is a problem in shorter wavelength radars.

Review Questions on Chapter 1

Instructions:

From memory, answer the following questions. Check your answers against the text.

1. (T / F) Attenuation of radar waves is dependant upon the wavelength of the emitted waves and the size and composition of the particles encountered.

2. (T / F) Backscattered energy represents only a small portion of the total radiated energy.

3. Explain why absorbed energy that is re-radiated back to the antenna is not recognized.

Chapter 2

Characteristics of Pulsed Electromagnetic Energy

Objective

Given characteristics of pulsed electromagnetic energy, select facts about the radar detection process.

Introduction

Having discussed some of the basic ideas dealing with electromagnetic energy, it is time to take a closer look at the characteristics of a pulsed radar beam. Recall from the introduction that radars emit electromagnetic energy in short powerful pulses. Pulsed energy allows for a system to determine the range or distance to a target. This is done by measuring the elapsed time between transmission of a pulse and detection of returned energy from a target.

After completing this section, you will be able to select facts about:

- Pulsed electromagnetic energy.
- Pulse length.
- Pulse repetition frequency (PRF).
- Relationship between PRF and maximum unambiguous range.
- Range folded echoes.

INFORMATION

RADAR PULSE CHARACTERISTICS

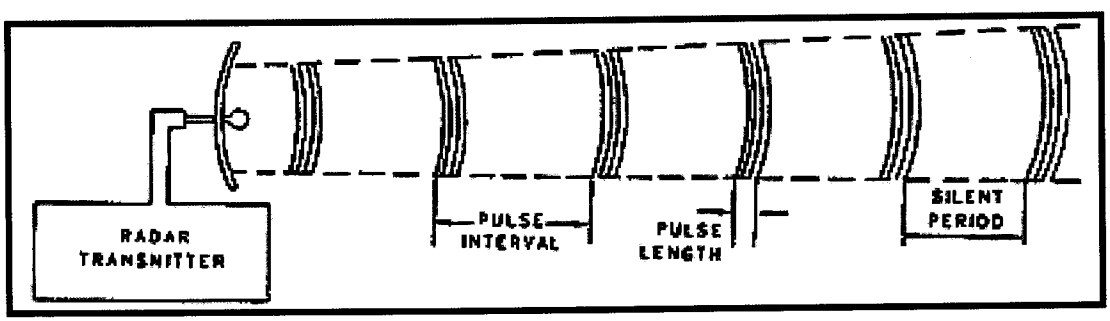
The fundamental characteristics of the radar pulse beam are shown in figure 5. An important aspect of radar is the transmission of definite pulses of energy at prescribed intervals which includes a silent period or "listening time" between pulses.

Pulse Length

The pulse length is measured as the distance from the front (leading) edge to the back (trailing) edge of the pulse as it travels in space. Also, the pulse length may be measured in the unit of time it takes the transmitter to send one pulse.

To avoid any confusion as we proceed in discussing the various motions and measurements involved in radar, let's relate the emission of pulses of a given duration to the velocity of the radio energy through space.

Figure 5: Radar Pulse Characteristics



The velocity of propagation of radio energy is equal to that of light—approximately 186000 miles per second. Because the second (time) is too long to use conveniently in radar computations, time is usually expressed in microseconds, symbolized by μsec or microsec. A microsecond is one-millionth of a second; therefore, the speed of light may be expressed as 0.186 miles/microsec. When this is converted to the metric system, we can express the speed of light as 300 meters/microsec.

Pulse length then can be expressed in either microsec or meters. The duration of the pulse, for example, might be 2.0 microsec, representing a pulse length of approximately 600 meters. We should remember that pulse length, no matter whether long or short, does not affect the velocity of the emitted radio energy.

The pulse length does, however, affect the amount of power returned from a target. The amount of energy in each transmitted radar pulse depends, among other things, upon the duration or length of the pulse. In other words, if one pulse is 10 times the length of another pulse, it has 10 times the energy. This would allow more reinforcement of an echo and a stronger signal returned to the radar. However, as we will see later, this causes resolution to suffer, and determining the characteristics of a target may become impossible. Pulse length also determines the minimum, range of the radar, since the transmitter must shut off by the time the signal returns.

The ideal radar would use short, powerful pulses; however, it is impossible to get powerful pulses that are short without large physical equipment. Another way in which the amount of energy can be transmitted by the radar is to increase the number of pulses transmitted per second.

Pulse Repetition Frequency (PRF)

The PRF is defined as the rate at which the pulses are transmitted--the number of pulses per second (PPS). Weather radar systems use only one antenna. During the transmission of the pulse, the antenna serves as the method of focusing the pulse and directing it in a concentrated beam. After the pulse has been transmitted, the antenna serves as the "ear" to listen for any returning signals from targets that may have been intercepted.

Listening Time: The period of waiting for a returned signal, the listening time, determines the maximum range of the radar. The listening time permits the energy, which has been backscattered from the target to be received before the next pulse is transmitted. The listening time must be long enough for a transmitted pulse to reach the target and return. The range of a radar is equal to one half the maximum distance (round trip) the signal can travel during the listening time--the time between pulses.

The radar is dependent upon this combination of pulse length and listening time. They determine some of the capabilities of the radar to detect the weather.

Choosing The Correct PRF: Although the PRF must be kept low to allow for the maximum range desired, it must also be kept high enough to allow a sufficient number of pulses to be returned from a distant target. Remember, the power of the returned signal is very low and many returns are needed to present a target accurately and with enough detail to be interpreted. If only one pulse were transmitted to and received from a given target, the reliability of the radar presentation would be poor. Therefore, radars are designed so that many pulses are returned from a single target.

Antenna Motion: An important consideration in determining the number of pulses reflected from a target is the rate of angular motion of the antenna. If the antenna moves through too great an angle between pulses, not only is the number of pulses per target too low but also there may be regions not probed for targets. The antenna motion may also be expressed by the number of pulses per degree of antenna rotation.

Maximum Unambiguous Range

The maximum distance electromagnetic energy can travel round trip between pulses defines the maximum range of a radar system. This range limit, called the unambiguous range, is limited by how often pulses are broadcast--the PRF. The reciprocal of PRF (1/PRF) is referred to as the pulse repetition time (PRT) and is the time between pulses.

The greater the PRF (pulses per second), the shorter the PRT, and the shorter the unambiguous range of the radar. This can be shown using the formula below:

Ru = [c(1/PRF)]/2 or [c(PRT)]/2

Where Ru = Unambiguous range in kilometers

c = Speed of light (3 x 108 km/sec)

PRF = Pulse repetition frequency in seconds

PRT = Pulse repetition time in seconds

Therefore, if a radar had a PRF equal to 1300 pps, its unambiguous range would be approximately 115 kilometers (slightly more than 60 nautical miles). A PRF of one half that (650) would yield a range of 230 kilometers or 120 nautical miles.

Short intervals between pulses restrict the range of the radar. Short pulses and short pulse intervals provide the utmost accuracy and detail of targets. Long pulse intervals increase the range of the radar and long pulses increase radar sensitivity.

Range Folding (Second—Trip Echoes)

As you know, a pulsed radar system measures distance by keeping track of pulse travel time. However, the radar cannot distinguish one pulse from another. That is, all returned pulses look the same to the receiver--it cannot distinguish energy of a previous pulse from a more recent pulse. The radar depicts a target as though the energy were returned from the most recent pulse.

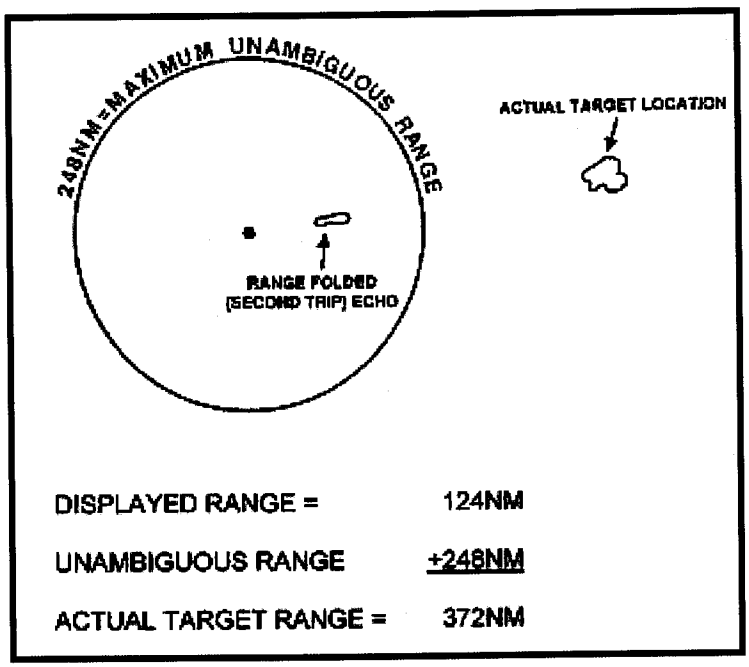
When energy is received from an old pulse after transmission of the next pulse, the radar assumes the returned energy is from the latest pulse--it gave up looking for the old pulse and sent a new one. Therefore, the displayed echo is at a distance equal to 1/2 the distance traveled by the latest pulse. The target azimuth is correct but the range is incorrect. This phenomenon is known as range folding, or second—trip echoes as we have called it in the past.

The basic concept of range folding is illustrated in figure 6. The fictitious echo is indicated at a range equal to its distance beyond the unambiguous range of the radar.

Pulse I is transmitted. It strikes a target beyond the unambiguous range of the radar and a portion of the energy is backscattered. However, before the backscatter reaches the antenna, pulse 2 is transmitted. When pulse *I* reaches the antenna, it is processed as though it were pulse 2. The result is a target at the proper azimuth but at a false range.

Range folded echoes can be identified if you are aware of their characteristics. They are typically elongated along a radial, indistinct in appearance, but most intense on the side nearest the radar. They disappear with a change in antenna elevation angle, and change display range if the PRF is changed.

Figure 6: Range Folding



Echoes displaying second--trip characteristics can be unfolded in range by adding there indicated range to the unambiguous range of the radar. (See Figure 6) The echo appears at a distance equal to its distance beyond the unambiguous range.

Review Questions Chapter 2

Instructions

Match the radar term in Column B with its description in Column A.

Answer	Column A	Column B
	1. Measured from the leading edge to the back edge of the pulse.	A. Listening Time
	2. The rate at which pulses are transmitted.	B. Range Folding
	3. The period of waiting for a returned pulse.	C. Pulse Repetition Frequency
	4. Is limited by how often pulses are broadcast.	D. Pulse Length
	5. Occurs when energy is received from an old pulse after transmission of the next pulse.	E. Maximum Unambiguous Range

Chapter 3

The Effect of Radar Beam Characteristics on Radar Performance

Objective

Given characteristics of the radar beam, select facts about the radar detection process.

Introduction

We have already said that electromagnetic energy from the radar travels in a focused beam. Now we will examine some specific characteristics of the radar beam that affect how the radar "sees' a target. As a radar operator, you must always be aware that the image you see displayed by the radar is not necessarily a perfect representation of the actual situation. In fact, it's not a bad idea to be suspicious and assume that the radar may be lying to you.

This section helps you appreciate some of the physical restraints that affect just how well the radar can present a correct display of the weather. After completing this section, you will be able to select correct facts about:

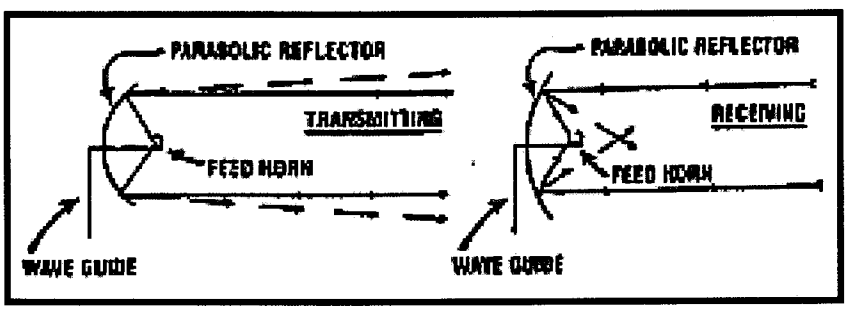
- The beam width, how it changes with distance, and how this affects the accuracy of the radar.
- Consequences of partial beam filling, beam blockage, and below beam effects.
- Resolution and distortion.
- Sidelobes

Information

The Radar Beam

Electromagnetic energy is carried to the antenna from the transmitter via a metal duct called a wave guide. The wave guide terminates at a device called a feed horn, which is located at the focal point of a parabolic reflector or dish.

Figure 7: Pencil Beam



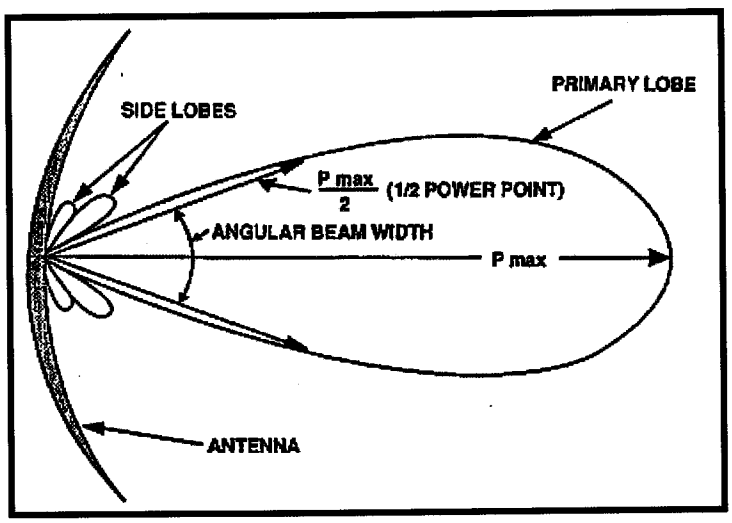
Ideally, energy leaving the feed horn is directed at and reflected off the dish in a "pencil beam," as shown in figure 7. However, due to refraction of the energy at the edge of the dish, the radar beam is actually more cone-shaped.

Backscattered energy follows much the same path in reverse. Notice in figure 7 that some of the energy misses the focal point and the feed horn due to diffraction at the edge of the antenna. Actual loss of energy due to this diffraction is quite small; however, keep in mind that the beam is not perfect. Later, when we discuss side lobes, we see that some of this diffraction can be important.

Beam Width

To properly interpret data from the weather radar, it is necessary to define the radar beam in terms of half-power points. To illustrate this, look at Figure 8 as we explain:

Figure 8: Half-Power Points



Maximum power density (power per unit area) exists along the centerline of the beam. To each side of this beam centerline the power drops off gradually at first, then more sharply as the distance from the centerline increases. A half-power point exists at a distance where power density is one-half that of the centerline, for a given range. As a result of this power concentration along the centerline, however, nearly 80% (.707) of the total radar energy actually is contained inside these half-power points. Since the beam is cone-shaped, half-power points combine to make a circle. The diameter of this circle is the beam width or diameter. This bounded area constitutes the 'radar beam". Under most circumstances, this "radar beam' is the area where enough backscattered energy is available to detect a target. Backscattered radiation from outside this area is usually too weak to be detected by the radar.

Angular distance between the half-power points of a radar beam is called the angular beam width. It is measured in degrees. Since the beam is conical, the angular beam width is the same whether measured vertically or horizontally. Angular beam width varies directly with wavelength and inversely with diameter of the parabolic reflector. This means that we can get a narrower beam width by either choosing a shorter wavelength or by building a larger antenna

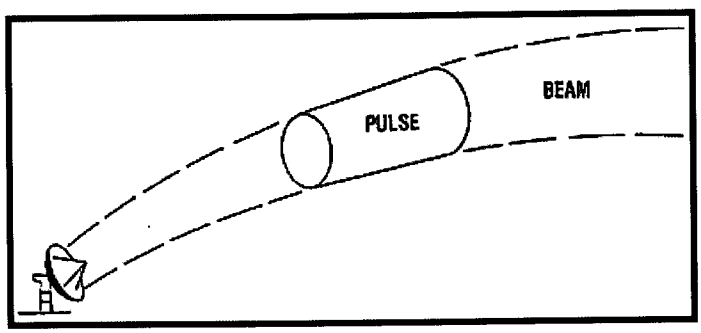
Even though the angular beam width remains constant with distance from the radar, the distance between half-power points (diameter of the beam) increases. For example, a radar with an angular beam width of 1° has a diameter of 2654 feet at a distance of 25 nautical miles from the antenna. At 50 nautical mile range, this same beam has a diameter of 5308 feet. Remember, this increasing diameter reduces the power density of the radar beam (mils=1/k).

For most purposes, the smaller the angular beam width, the more desirable the radar system. This is because the energy concentration per volume can be maintained at greater distances and it improves azimuth and height resolution, which is discussed later.

Beam Illumination

The portion of the beam through which the pulse is traveling is said to be illuminated by the pulse or to be the illuminated volume of the beam.

Figure 9: Pulse Volume



Pulse Volume: The radar beam is a path along which the electromagnetic energy pulse travels, as shown in figure 9. Unlike a flashlight, which is continuously radiating energy, only a short segment of the radar beam contains electromagnetic energy at any instant. This segment which contains energy (the pulse) is the pulse volume. It has the dimensions of one pulse length in range and one beam diameter in width and height.

You may also consider pulse volume to be the volume of the atmosphere, which is occupied by the radar pulse. The shape of the pulse volume is that of a frustum--the shape created if you cut the point off a cone.

The pulse volume increases with increasing range even though pulse length remains constant. The increase in volume is caused by the increase in beam diameter with distance. As a result, power density decreases within the pulse volume as distance from the radar increases. This is one factor, which contributes to the decreased sensitivity of the radar at increased ranges.

Echoing Volume: We defined the purse volume as the volume of the atmosphere occupied by the pulse of electromagnetic energy. But what about the volume of atmosphere which is instantaneously sampled by the radar? This is called the echoing volume. It is equal to 1/2 pulse length and the beam diameter. We'll look at this in more detail in the next study guide.

Since the echoing volume is relatively large, individual targets are much smaller than the echoing volume. This means that all targets within that volume contribute to the backscattered radiation received by the radar. In other words, the individual character of a target is averaged among the characteristics of other targets. If all the targets are similar to each other, this is not a problem. However, if a few targets are very different, their special characteristics can be lost among the total average.

Partial Beam Filling

Partial beam filling is defined as the effect when a target fills only a small portion of the radar beam. Keep in mind that, as the radar beam propagates away from the radar, it continually becomes wider--quite wide at distant ranges. As a result, targets occupy a much smaller portion of the beam at these distant ranges. This results in the return of relatively small amounts of energy--our displayed echo is weaker than the true echo. Anytime a target occupies only a small portion of the beam, the true characteristics of that target may be hidden or altered during display.

In shallow precipitation regimes, the effect is even greater. Due to relatively low vertical extent of precipitation echoes, only a small portion of the beam may be encountering targets at distant ranges. The result could be an absence of precipitation echoes being displayed even though substantial rainfall is occurring.

While detecting showers or thunderstorms, beam filling must be considered both horizontally and vertically. Some showers are less than I mile in width and may not completely fill a narrow 1-degree beam at ranges beyond 60 miles. In addition, the most intense core of a storm may cover only a small percentage of the entire storm. This also results in a comparatively weaker return.

Below Beam Effect

Below beam effects are the result of evaporation or growth of precipitation below the radar beam. At greater ranges with larger sampling volumes and increasing beam heights, the accuracy of these measurements diminishes-radar estimates of rainfall rates become less reliable at greater distances.

Virga, the total evaporation of precipitating water, is an extreme example of below beam effects. This is illustrated in figure 10.

In this situation, precipitation displayed at long range by the radar is not reaching the ground. Only from actual surface observations could you tell that precipitation was not reaching the ground.

Figure 10: Virga

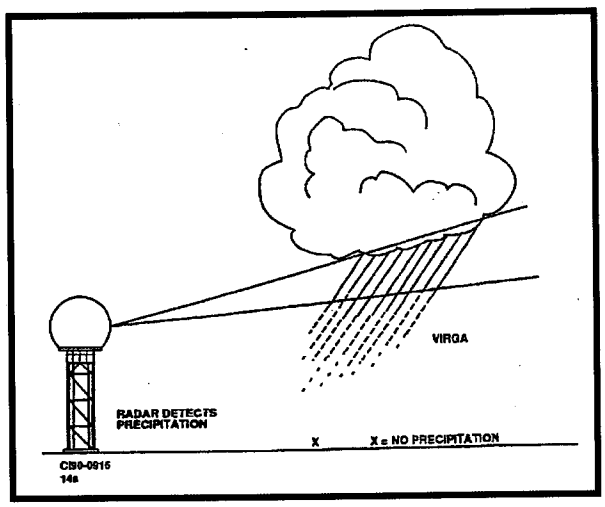
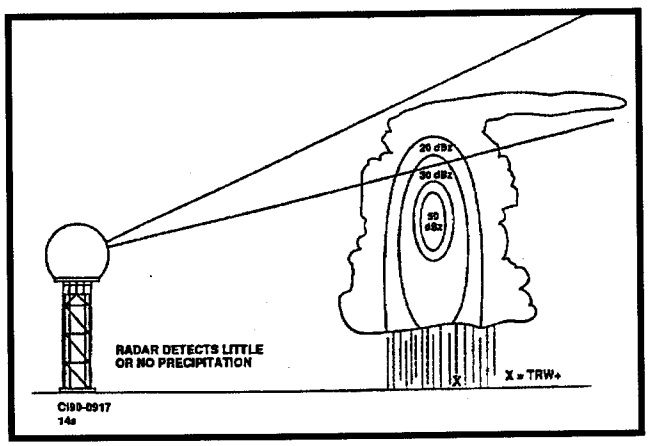


Figure 11: Thunderstorms Rainfall



Large, low-based thunderstorms can cause the opposite effect (figure 11). In this case, the area of maximum reflectivity is below the radar beam. Therefore, little or no precipitation is being indicated. In fact, surface observations would indicate heavy rainfall rates.

With these examples in mind, you should see the value of consulting other data sources to confirm radar displays. Surface observations, PIREPs, satellite imagery, and nearby radar reports are all helpful in overcoming this limitation.

Beam Blockage

Beam blockage is another potentially serious source of error affecting the radar beam. Blockage is not a shortcoming of the radar. Rather, it is caused by obstructions of the beam by targets close to the antenna. The result of blockage can often be seen as part of the ground clutter pattern.

Blockage is usually only a problem at short ranges. As the radar beam propagates, it becomes wider. Hence, ground targets fill a smaller and smaller portion of the beam. However, blockage results in a reduction of the effective transmitted power of the radar, thus less energy is available to reach targets beyond the source of blockage.

Resolution and Distortion

Resolution describes the ability of the radar to show or display targets separately. Two resolution problems exist--angles and range resolution. Distortion, while not the same as resolution, is affected by the same factors, which determine the radar's resolution. Just as with resolution, there are two separate problems--angles and range distortion.

Angle Resolution

Angle (often called bearing) resolution is the ability of the radar to distinguish between two targets at the same range, but at different azimuths or angles from the radar. This ability to resolve targets at different angles but identical ranges is a function of beam width.

When the radar detects backscattered energy, it assumes it is being returned from a target on the centerline of the radar beam. However, the radar begins detecting backscattered energy as soon as the target is within the echoing volume and continues detecting it as long as it remains within these ½ power points in the echoing volume.

Therefore, if two targets are side—by—side at the same range and are spaced less than the beam diameter apart, they appear as one target. If the targets are separated by a distance greater than the beam diameter, then the radar resolves them as individual targets. This is shown in Figure 12.

Angle resolution changes with target distance from the radar. Because the beam diameter is less at closer ranges, the ability to "resolve the angle" of two closely spaced targets improves at shorter ranges, as shown in Figure 12.

Remember, angle resolution is dependent upon the diameter of the radar beam. Therefore, it refers to resolution of targets at different azimuth and elevations. That is, targets at the same range but different elevations must be separated vertically by greater than one beam width to be resolved as separate targets.

Figure 12: Azimuth Resolution

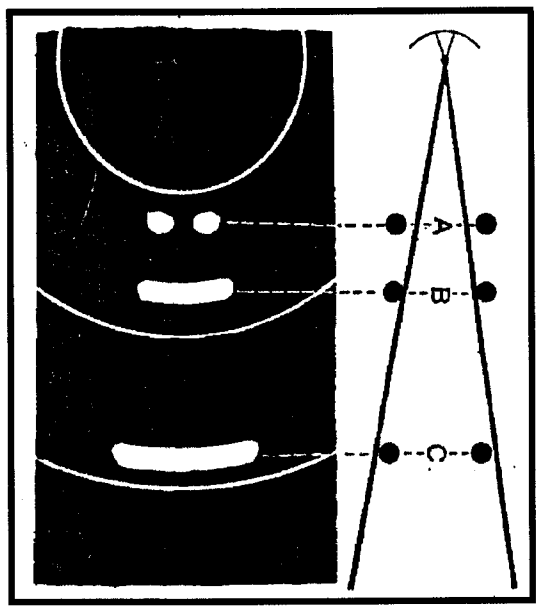
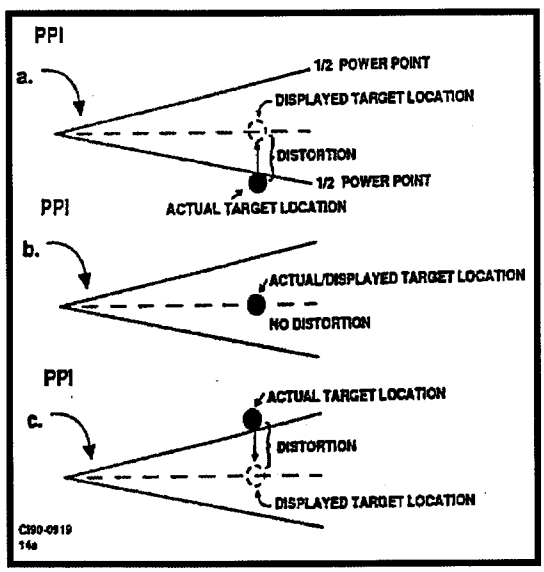


Figure 13: Azimuth Distortion



Azimuth (Beam Width) Distortion

The result of the radar's limited azimuth resolution is distortion. Azimuth or beam width distortion is defined as an apparent stretching of a target in azimuth. Just as with azimuth resolution, it is a function of the beam width (see figure 13).

Recall that the radar detects backscattered energy as soon as a target is within the 1/2 power points of the radar beam. It assumes the target is on the centerline of the beam. In other words, as the half-power point encounters a target, a return is detected as though it were in the center of the beam. This is an error of ½ the beam width. As the radar beams sweeps through the target, it continues to detect returns as if they were at the beam centerline. This continues until the target is out of the opposite half-power point, resulting in another error on the opposite side of the target equal to 1/2 beam width. Therefore, displayed echoes are distorted (stretched) in azimuth by a total of I beam width.

Because the diameter of the beam increases with distance from the radar, azimuth distortion is greater at long ranges. However, distortion can only be estimated. For instance, if the target is at great distance from the radar, the effective beam width may be less than the assumed half-power points due to low power density.

Although distortion is technically different from resolution, the effect on the radar operator is to limit the ability to resolve two targets. Most often, operators refer to both azimuth resolution and azimuth distortion collectively as resolution problems.

Range Resolution

Range resolution is the ability of the radar to distinguish between two targets at the same direction from the radar but at different ranges.

Earlier, we saw how the pulse length determines the size of the echo volume, which the radar is simultaneously sampling. The same type of reasoning demonstrates why the smallest precipitation (or cloud) area which can be resolved by a radar along an azimuth is equal to one half the pulse length. Echoes within this distance reach the radar receiver at the same time and display as one target.

Figure 14 illustrates how range resolution is dependent upon half the pulse length for exactly the same reasons.

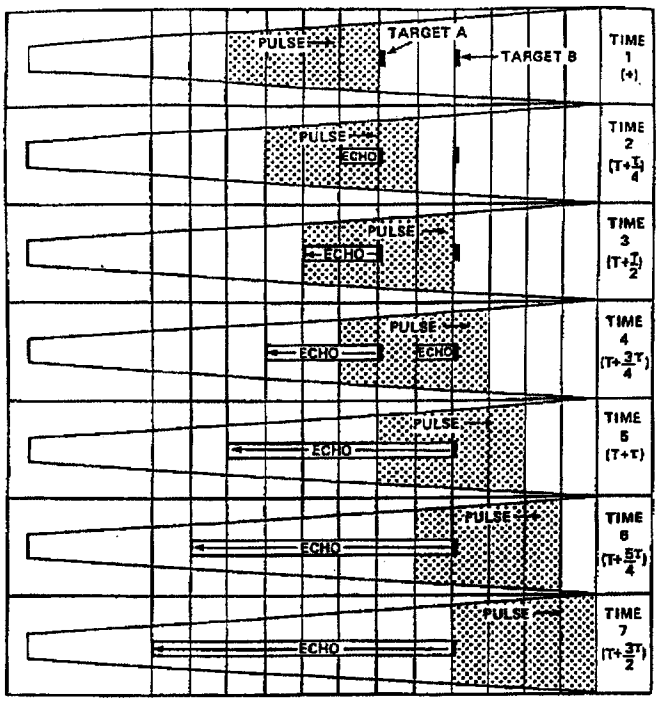
Since there is only *112* pulse length between the two targets in figure 14, the signal returned from the leading edge of the pulse striking the more distant target, (target B), returns to the first target, (target B), lust as the backscattered energy of the trailing edge of the pulse is leaving the nearer target. The result is that the energy backscattered from both targets travels back to the radar together and one large target appears on the display, even though two targets actually exist.

Conversely, if two targets are separated by more than 1/2 pulse length in distance, both echoes are displayed as individual returns. By the time the leading edge of the radar pulse strikes the more distant of the two targets, the trailing edge of backscattered energy has already left the nearer target.

This results in two separate areas of backscattered energy returning to the radar and two separate radar echoes being displayed.

Range resolution is a function of pulse length. The shortest distance between two targets must be more than 1/2 the pulse length in order for the echoes to appear separate on the display.

Figure 14: Range Resolution



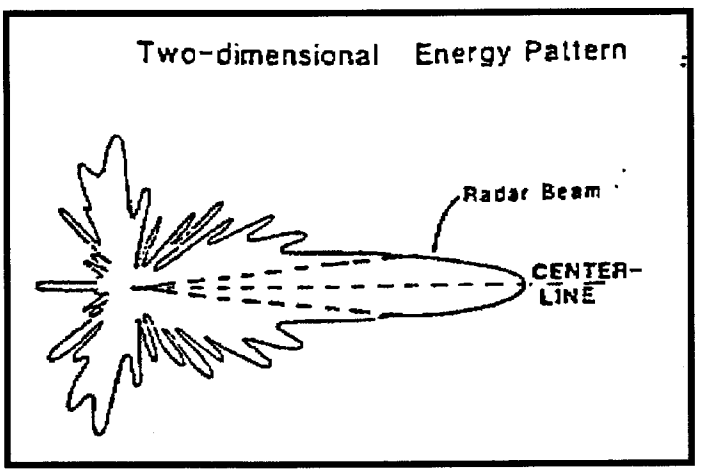
Unlike azimuth resolution, range resolution is the same at any distance. This is because pulse length does not vary with range; the separation necessary for resolution is the same at any range.

Sidelobes

Due to diffraction of the electromagnetic energy at the edges of the antenna, only about 80% of the radiated energy is contained between the half-power points of the radar beam. Most of the remaining 20% of the energy is broadcast in other directions in spikes or side lobes. These lobes extend outward only a short distance with power densities far less than are found between the half-power points. Figure 15 shows an example of a radiating pattern from a radar dish.

Side lobes are presently an unavoidable and detrimental part of any weather radar system. While side lobe patterns for radars are similar, each type of system has its own unique pattern.

Figure 15: Sidelobes



Side lobes cause certain side effects of which you should be aware. They do contain low power density and thus their effective range is quite short, so the majority of their effects are seen only at close range. Here are some of the effects:

- Multiple displays of a single target
- Ground Clutter
- False echo tops

Review Questions Chapter 3

Instructions

From memory, answer the following questions. Check your answers against the text.

1. (T / F) The maximum power density of the radar beam can be found along the centerline of the beam.

2. The radar beam will normally (increase / decrease) in height as it moves away from the antenna.

3. (T / F) Beam blockage is a result of the radar beam striking large obstructions near the antenna site.

4. The ability of the radar to distinguish between two targets in the same but at different ranges is referred to as _____.

5. _____ occurs when a target occupies only a small portion of the beam, thus the true characteristics of the target may be hidden or altered during the display.

6. (T / F) Two targets must be separated by greater than one beamwidth to be displayed as separate targets.

7. Below beam effects refer to:

    a. Missed targets below the beam.
    b. Ground clutter from sidelobes
    c. Distortion from azimuth resolution.

Chapter 4

Effects of Atmospheric Refraction

Objective

Given characteristics of the atmosphere, distinguish the effects of refraction on radar beam propagation.

Introduction

The detection of weather phenomena by a radar is quite different from other detection processes. We cannot move our radar to the location of a thunderstorm to detect the strength. Instead, we must remain many miles away and make "indirect" measurements.

Because we have so much space between our radar and the weather phenomena we need to detect, many things can very the results. This section is going to review some of the atmospheric effects, which can alter the path of our radar beam. And, since this radar beam is our only source of information, we should suspect that our displayed information may also have been altered in some way.

After completing this objective, you will be able to select correct facts about:

- Atmospheric refraction; why and when it occurs.
- Superrefraction and subrefraction, and the results of each.

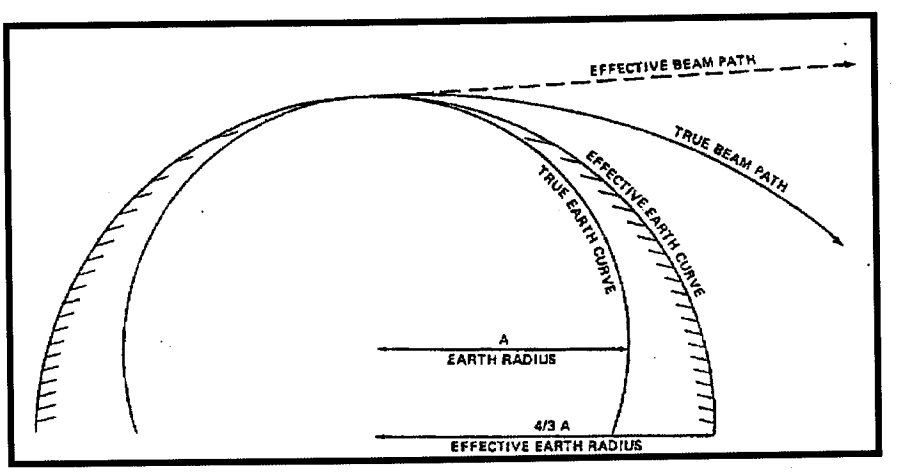
Information

Propagation of the Radar Beam

The propagation of energy along a radar beam does not coincide with a straight-line path from the transmitter. Figure 16 illustrates the difference between the propagation of a radar beam and the straight-line path along which the beam is directed. Note that the actual path of the radar beam is curved. This curved path is the effect of refraction, or bending, as the beam passes through the atmosphere.

The most common method of estimating the height of the beam above the earth's surface, at a distance from the radar's antenna is as follows. Assume that the change of refractive index (air density) is constant with height and that the beam reaches a curve larger than the curve of the earth. In order for the beam to actually travel in a straight line, the earth's curvature would have to be enlarged to 4/3 its true value. This is called the "effective earth radius model" or 4/3 earth radius model." See Figure 16.

Figure 16: Radar Beam Propagation



In the real atmosphere, the refractive index does not remain constant with height. Therefore, under normal conditions the radar beams a true curvature is slightly less than that of the earth's surface (figure *16).* This explains why the radar beam gets higher above the ground, even if the angle of the antenna is zero, as its distance increases from the antenna.

Standard Refraction

The bending of a radar beam through the atmosphere is caused by air density differences. Under normal atmospheric conditions, the temperature and water vapor content gradually decrease as height increases. Under normal conditions, the radius of curvature of the radar beam for nearly horizontal propagation is about one third greater than the radius of the earth's curvature.

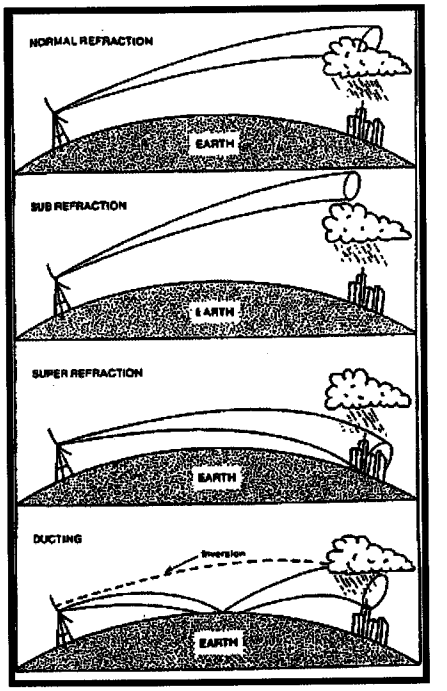
Non-Standard Refraction/Anomalous Propagation

Anomalous means abnormal, unusual, or irregular. Wave propagation that deviates from a standard deviation occurs under special conditions. When wave propagation differs from standard, it is known as nonstandard refraction or anomalous propagation (AP).

Under certain atmospheric conditions, the refraction of the beam is so distorted that the radar displays echoes when there is no echo causing phenomena. The most significant effect of AP is to display targets at a shorter or more distant range than the actual target. Conditions' causing the curvature of the radar beam to be greater than normal result in what is termed superrefraction.

Superrefraction: When warm, dry air overlies relatively cool, moist air, as in an inversion, superrefraction may occur. In this case, the radar beam is refracted below its normal path, as illustrated in Figure 17.

Figure 17: Anomalous Propagation



The greater the increase of temperature and decrease of moisture, or both, with height, the greater degree of superrefraction. In an extreme case, a radar beam becomes trapped in a "duct" beneath the inversion and may travel for long distances without appreciable attenuations.

Figure 17 illustrates the ducting phenomenon. Under such conditions, low level targets a few hundred miles distant and not normally detected, may be displayed by the radar.

Several meteorological conditions may lead to superrefraction. Over land, superrefraction is most noticeable at night under conditions favoring strong radiation of heat from the earth. Superrefraction may occur in the late afternoon or evening when warm air drifts over the cool sea. The cool air outflow from a thunderstorm may also produce favorable superrefraction conditions. However, during precipitation, the conditions necessary for superrefraction are normally absent. Ducting occurs frequently in subtropical, high-pressure zones. It is useful for each radar location to collect color hardcopies during such abnormal (AR) conditions for future reference in identifying targets and distinguishing AP from precipitation echoes.

Range Folded or Second Trip Echoes

Superrefraction may also cause precipitation echoes to be observed on the display at locations where no precipitation exists. Recall, these are called range folded echoes or echoes detected from a previous pulse. The nature of radar is such that all echoes are detected in the interval between transmitted pulses. During superrefraction, echoes detected at long ranges by a previous pulse may appear on the graphic display at short range.

Subrefraction: Straightening of the beam upward, or subrefraction, may occur during atmospheric conditions where the water vapor content increases with height and the temperature decreases with height. This subrefraction, shown in figure *17* is the opposite of superrefraction.

Subrefraction reduces the maximum range of detection of low—level targets because the beam quickly overshoots these low targets. Such a condition may occur in certain types of fog, but it does not occur in precipitation. This abnormal condition is relatively unimportant for storm detection.

Review Questions Chapter 4

Instructions

From memory, answer the following questions. Check your answers against the text.

1. List the two types of anomalous propagation (AP) and briefly describe the atmospheric conditions that cause each to occur.

2. When the radar beam is being refracted below its normal path, this process is referred to as:_____.

3. Straightening of the radar beam upward is referred to as:

_____.

Chapter 5

The Doppler Dilemma

Objective

Given information concerning the doppler dilemma, identify the relationship between pulse repetition frequency and velocity/range.

Introduction

Weather radar measures the reflected radar transmitted signal from meteorological targets. The pulsed-Doppler radar measures the frequency shift between the transmitted and received signals caused by the movement of the meteorological targets. The frequency shift measures the velocities of the targets along the radar beam. However, the pulsed-Doppler radar has certain limits beyond which range and velocities cannot be measured accurately (precisely). The maximum, precise range measurement is limited by the pulse repetition frequency (PRF), while the maximum, precise velocity measurement is limited by the wavelength of the radar and pulse repetition frequency.

Information

Doppler Spectrum

Pulsed-Doppler radars are controlled by a very accurate clock that synchronizes the system and generates a train of RF pulses at the desired PRF. The transmitted pulse is reflected by the weather target back to the radar receiver. The receiver detects and processes the reflected RF into a series of voltages that contain information about the phase shift due to target motion, as well as amplitude of the returned power.

The returned pulses are sampled approximately every microsecond to get information for about every 150 meters in range. Each received signal contains an ensemble (group) of phase shifts due to the different motions of the weather targets within the ensemble. This ensemble from the return of several signals is called the Doppler spectrum and is power-weighted distribution of the radial velocities within the sample volume.

The receiver employs the superhetrodyne technique, to down convert the received signal to a 30 MHz Intermediate frequency (IF). The 30 MHz IF signal is digitized for direct processing by the RVP 7 Signal Processor. This signal processor outputs Z, V & W moments. These data moments are coupled to the Radar Product Generator.

The spectrum width (W) is related to the spread of terminal velocities, turbulence, shear of the wind along or across the beam, and the signal-to-noise ratio. It is believed that Turbulence is the largest contributor to the spectrum width (finger print).

Velocity-Range Wavelength Relationship

The Doppler Dilemma

Range Folding: Each transmitted pulse is separated by a distance A (range) which is related to the radar PRF. The maximum unambiguous range before the next pulse is transmitted is only half the distance that the radio wave can travel between pulses. An echo from a target that is within the maximum unambiguous range gives precise measurements. However, echoes at greater ranges appear to be located within the unambiguous range, since the radar cannot distinguish the return of the most recent pulse from those more distant returns from a prior pulse.

It is possible to recognize the range folded echoes (more distant echoes) by changing the PRF. The range folded echoes appear to move as the PRF changes, whereas the echoes within the first trip remain stationary (RVP 7 can remove second trip echo).

Velocity Aliasing Velocity is a measure of frequency change between the transmitted frequency and received frequency. In Doppler radar, a transmitted frequency produces the same waveform with the Doppler shift. Observed velocity is related to the frequency shift. Maximum observable unambiguous Doppler velocity is:

$$V=\pm PRF\ (\lambda/4)$$

If the radar measures a velocity value, which exceeds the maximum unambiguous velocity, limits, velocity dealiasing is required to resolve the erroneous aliased velocities.

Doppler Dilemma: Increasing the PRF to extend the range of observable velocities decreases the maximum unambiguous range. Thus, it is clear that longer wavelength radars have the advantage for a given PRF; they enjoy larger unambiguous velocities and, for a given unambiguous velocity (lower PRF), it is possible to obtain larger unambiguous range.

Chapter 6

Doppler Radar Principles

In 1842, Austrian physicist Johann Christian Doppler first related the observed frequency changes in sound and light to motion of the source or observer. Doppler developed mathematical formulas to describe this phenomenon, which is now called the "Doppler Effect." The first radar to employ Doppler's discovery was developed during World War II. This radar was capable of detecting the location and velocity of enemy targets.

The meteorological application of Doppler radar came about in the late 1950's. Using a modified military surplus radar, the Weather Bureau detected 200—mile per hour winds apparently associated with a tornado near El Dorado, Kansas on June 10, 1958. During this same period, Doppler radars were used in Europe to gather data on velocities and droplet size distribution in precipitation.

Research and development on meteorological Doppler radars continued. By the early 1970's integrated circuitry and advanced computer processing appeared in a new class of high-powered Doppler weather radars. Later in the decade, real-time processors were linked to color displays. Unlike previous systems, this allowed instantaneous output of Doppler derived data.

Sensitivity and Doppler Detection

Doppler weather radars are still quite similar to conventional radars. We still have a radar, which sends out a pulse of energy and then listens for a return signal. The time required for the return signal to arrive at the antenna and the signal strength are still used to determine range and intensity.

Beam Width

The VHDD-300C has an angular beam width of approximately 0.75 degrees. This is a much narrower beam width than is used by the WSR-88D or FPS-106 (1.6~). The narrow beam helps provide a significantly higher power density.

This higher power density allows "deeper looks' into large convective systems. In addition, the narrower beam width improves azimuth and height resolution, giving you a more accurate picture of storms.

Pulse Length

The pulse length of a radar determines its range resolution. The WSR—88D (Nextrad) uses a variable pulse length as short as 1.57 microseconds (1,545 feet) compared to the fixed 2.0 microsecond (1,968 feet) pulse length of the FPS-77. Therefore, the WSR-88D is capable of resolving smaller and more closely spaced targets than the FPS-77.

The VHDD-350C is pulse width agile, capable of transmitting pulse widths over the range of 0.4 — 2.0 microseconds.

Sensitivity/Signal-to-Noise-Ratio

Radar's sensitivity, or signal-to-noise-ratio, is a measure of its internal interference against the minimum signal it can detect. This is similar to the idea of one person whispering a message to another person inside a crowded auditorium. The listener may have ears sensitive enough to hear what the speaker is saying, but the noise of the auditorium overcomes the whisper. In order to hear the whisper, one of two things must happen. Either the whisper must get louder or the auditorium must get quieter.

The VHDD-350C Systems approach to this problem combines a very sensitive receiver (ear) with advanced signal processor (which produce very little internal noise) to attain a good signal-to-noise-ratio. Because of this, the VHDD-350C is capable of detecting very weak returns--even in clear air, process these returns, and provide you with useful information. The RVP7/RVP8 Digital Signal Processor enhances this extreme sensitivity.

The ability to detect small particles is very helpful when looking at reflectivity displays. However, the real importance is that sensitivity is required for Doppler radars to detect and display atmospheric motions.

Doppler Radar Detection

Objective

Given Doppler radar principles, select facts about the radar detection process.

Introduction

In the preface, we provided some reasons why we need a powerful and sensitive radar, and also described some possible methods by which these requirements could be reached. A precise combination of beam width, pulse length, and internal design provides the required operating characteristics.

This section introduces some of the basic principles the VHDD uses during its detection of velocity. After completing this objective, you will be able to select correct facts about:

- The Doppler shift and how the VHDD uses this to estimate wind speeds,
- The special characteristics of a coherent radar, and
- The use of pulse-paired processing in the VHDD.

Information

The Doppler Shift

You have probably experienced the Doppler shift at one time or another in your life. For example, the change in pitch of the sound of a trains whistle as it passes in the distance is the result of the Doppler shift, sometimes called the Doppler effect. It is an observed change, or shift, in the frequency of sound or light waves due to the relative motion of the source and/or observer.

Doppler radars like the VHDD make use of this phenomenon. The apparent shift in the electromagnetic waves is used to determine velocities. Let's take a simplified look at an electromagnetic (EM) wave and see what type of problems and information we can obtain from its interaction with the atmosphere.

Backscattered Radiation

We described backscattered radiation as that energy which is re-radiated from a dipole toward the radar antenna. in the weather radar business, the dipoles we are talking about are usually precipitation particles. When this backscattering occurs, the energy backscattered from the particle and received by the radar is at the same frequency as originally transmitted. In other words, the incident and backscattered electromagnetic energy is of the same wavelength.

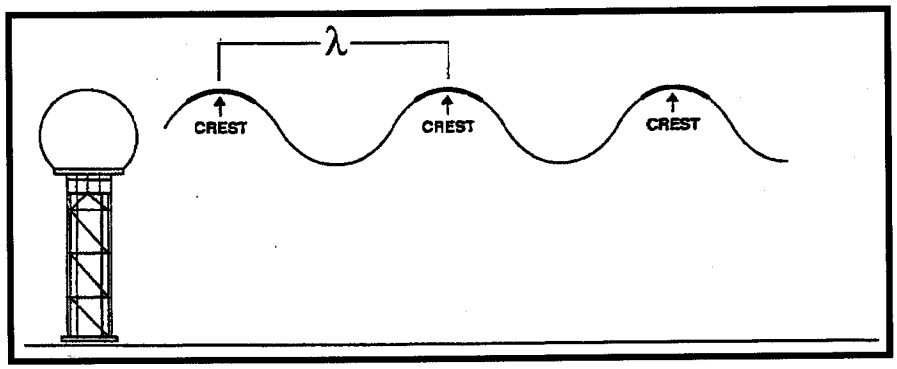
When the radar samples the atmosphere, it sends out a pulse of energy and then detects the returning energy. Let's suppose we could slow the process down so we can track one individual wave as it's transmitted, strikes a target, and returns.

Recall how electromagnetic energy traveling through the atmosphere was represented as a sine wave. A new wave consisting of a crest and trough was generated each time the dipole completed a cycle of two change reversals.

This energy traveled away from the dipole at the speed of light. Thus, after one full cycle, one wavelength had been transmitted into the atmosphere. This wave had a wavelength and frequency, which were related by the same equation:

Wavelength= (speed of light)/frequency

Figure 18: Depiction of EM Radiation



Let's use the crest of the wave in our figures as a point of reference (Figure 18).

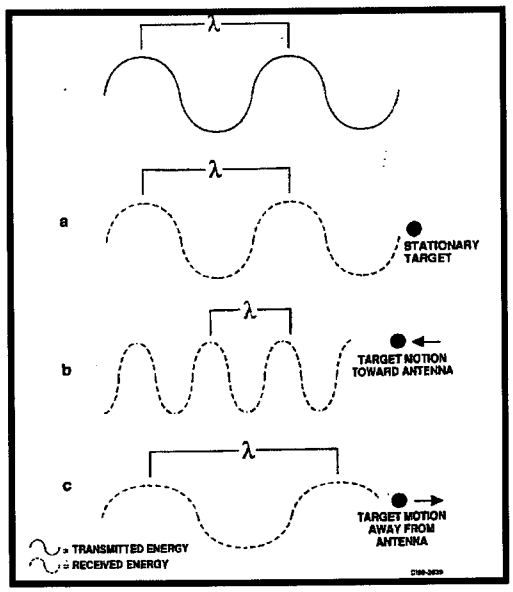
The frequency of the wave can then be detected at the antenna by determining bow many full cycles of a returning wave pass by the antenna in a specified amount of time. (If the crest of a wave passes the antenna five times in one second, we have a frequency of five cycles per second.)

Let's take a look at three examples of dipoles (which are actually precipitation targets in the atmosphere) and see how they can affect the characteristics of the backscattered radiation. The first example is of a stationary target and the second two examples are of moving targets.

STATIONARY TARGETS: Recall how the backscattered energy is generated. The radar transmits a pulse of energy at a specific frequency and energizes the target.

This target then re—radiates that energy at the same frequency. If our radar sends out numerous pulses of energy at the same frequency, the backscattered radiation from the target is also at the same frequency (Figure 19).

Figure 19: Incident vs. Backscattered Radiation



Obviously, if the target and antenna always remain an equal distance apart, the time required for the wave to travel from the target to the antenna also remains constant. In other words, the crest of each wave passes the antenna at a constant frequency.

We can also look at this from another point of view. First, if we sample the backscattered radiation from a target and find that the frequency is constant over time, we can assume that each wave has had to cover the same distance from target to antenna during that time. And second, if the backscattered radiation has traveled the same distance during that time, then the target must have remained in the same place--it is not moving.

Moving Targets: Now, let's look at moving targets. Each backscattered wave appears at a slightly different wavelength and therefore a slightly different frequency for that moving target.

First, we'll look at a target moving toward the radar. Each backscattered wave, as the target continues to move, is generated slightly closer and takes slightly less time to reach the antenna (figure 19b).

Compare the crests we are using as reference points in both figures 19a and 19b. Note in figure 19a, since the target is stationary, the returning energy is the same frequency as the transmitted energy. Now in figure 19b, the radar encounters a target moving toward the radar. In this case, notice the wavelength has decreased and the frequency at which the crests strike the antenna has increased. Due to the Doppler Effect, an increase in frequency equates to motion toward the radar.

Our radar expects a specific frequency to arrive at the antenna. It can compare this expected frequency to the actual received frequency and determine whether a change in frequency has in fact occurred.

Next, we'll look at a target moving away from the radar. Each backscattered wave, as the target continues to move, generates slightly farther away and takes slightly more time to reach the antenna (figure 19c).

Compare the crests we are using as reference points in both figures 19a and 19c. Note in figure 19a, since the target is stationary, the returning energy is the same frequency as the transmitted energy. Now in figure 19c, the radar encounters a target moving away from the radar. In this case, notice the wavelength increases and the frequency at which the crests strike the antenna decreases. Due to the Doppler effect, a decrease in frequency equates to motion away from the radar.

Let's summarize. Doppler radar systems determine target motion by analyzing the frequency of the returning energy.

If the target is stationary,

- Wavelength remains the same.
- Frequency remains the same.

If target is moving toward the radar,

- Wavelength decreases.
- Frequency increases.

If target is moving away from the radar,

- Wavelength increases.
- Frequency decreases.

Velocity Determination

By processing a series of waves or frequency shift information, the radar tells us whether a target is moving or stationary. The VHDD analyzes a series of backscattered waves and applies a multitude of computer processing to extract frequency shift information. From the discussion we just completed, we have seen that a method exists by which a radar can determine whether a target is stationary or moving. If we have determined that a target is moving, the next important consideration is "How fast is that movement?

If we could look directly at the target, measurement of speed would be very simple. We would look at its position at time A and compare it to the position at time B. This comparison would be "How far has it traveled in a specific amount of time'? For example, miles per hour, or meters per second.

Although the radar can determine a target's position simply by knowing the antenna's azimuth and the out and back time of a pulse, it can't directly determine the target's speed. But it can detect its backscattered radiation. So instead of directly comparing two successive positions of the target to determine speed, the radar compares the frequency shift between two successive samples. This frequency shift is often referred to as the Doppler frequency. The measurement of the frequency shift is equivalent to a measure of velocity since frequency is linearly related to velocity by the Doppler equation:

$$fd=(2Vr)/wavelength$$

Where fd is the frequency shift, and Vr is the radial velocity

The radar knows the exact length of the radar wave. Since the wavelength is constant, the radial velocity can be calculated once the size of the frequency shift is known.

The result is a measurement, which relates the change detected in the frequency of a backscattered wave to the actual movement of the target.

The radar has no direct information about the target or its motion. From the radars point of view, it is the position of the backscattered wave, which has moved. We call this change in position of the wave the Doppler shift.

Of course, since wavelength and frequency are related, the Doppler shift can also be referred to as a frequency shift. For operational purposes, you should translate this to mean radial velocity detection.

Radar Coherency: In order to make these Doppler measurements, radar must have the ability to produce each pulse at exactly the same frequency as the preceding ones or have a digital processor to make the corrections. Just as important, the radar must have the ability to "remember" a specific frequency. Coherent radars such as the WSR-88D and Radar's with coherent processors have the ability to compare the frequency of successive received signals in order to determine the frequency shift, and hence, the radial velocity.

Pulse-Pair Processing: The RVP7 digital processor takes advantage of coherency by comparing the frequency of each new pulse with that of the pulse immediately preceding it. Anytime we measure the speed of something, whether it's a car, runner, or precipitation particle, we must compare at least two positions. In other words, we must sample it at least twice. The more often we take a measurement or sample, the more accurate our reading will be. Doppler radar must do the same thing. In order for it to make a measurement of speed, the radar must calculate the difference between at least two successive samples.

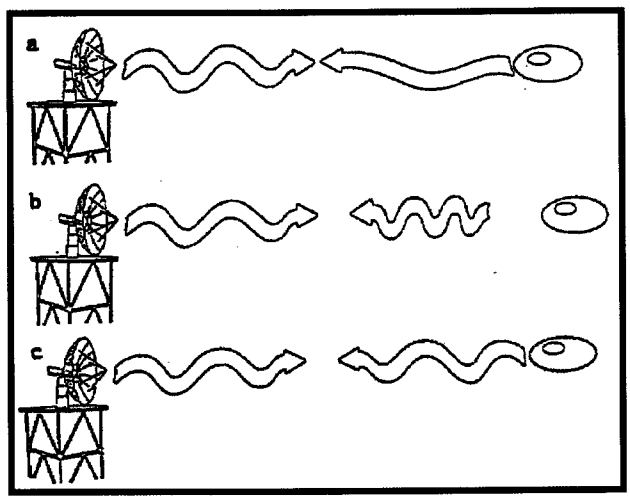
This is known as pulse-pair processing because the radar compares the frequencies of each pulse pair. The RVP7 is also capable of making the measurements using Fast Fourier Transform (FFT) processing, where signals can be changed from the Time Domain to the Frequency Domain and vice-versa.

Review Questions Chapter 6

Instructions

Use the diagram below to complete the following questions.

Figure 20: Chapter 6 Diagram



1. Letter ____ represents motion towards the radar.

2. At letter _____, the radar is detecting a stationary target.

3. A target moving toward the radar causes the energy to be backscattered at a (higher / lower) frequency.

4. The ability of the radar to compare the frequency of each new pulse with that of the preceding pulse is known as:

    a. Pulse-pair processing
    b. Dual pulse processing
    c. Doppler Shift

Chapter 7

Atmospheric Motions & Radial Velocity Determination

Objective

Given descriptions of atmospheric motions, select facts about radial velocity determination.

Introduction

We now know that the VHDD350C Radar System's sensitivity enables it to detect extremely weak reflectivities. This sensitivity allows the radar to determine the wind speed from the size of the frequency shift--a result of the Doppler effect. A combination of the radar's sensitivity and the presence of pollution particles, insects, dust, and differences in atmospheric density, allows it to detect wind speeds even in optically clear air.

Can the VHDD display the rotation within convective cells? Or measure the crosswind near the runway? Yes, but unfortunately, the VHDD will not always detect every motion in the atmosphere, nor will it always display them with little or no confusion. Therefore, the operator is required to know the radar's limitations in order to accurately interpret velocity displays.

This section describes some of the limitations inherent in velocity determination. Through a clear understanding of what the radar "sees' and why the displays appear as they do, you will be able to construct a three-dimensional model of the current atmosphere.

After completing this objective, you will be able to select correct facts about:

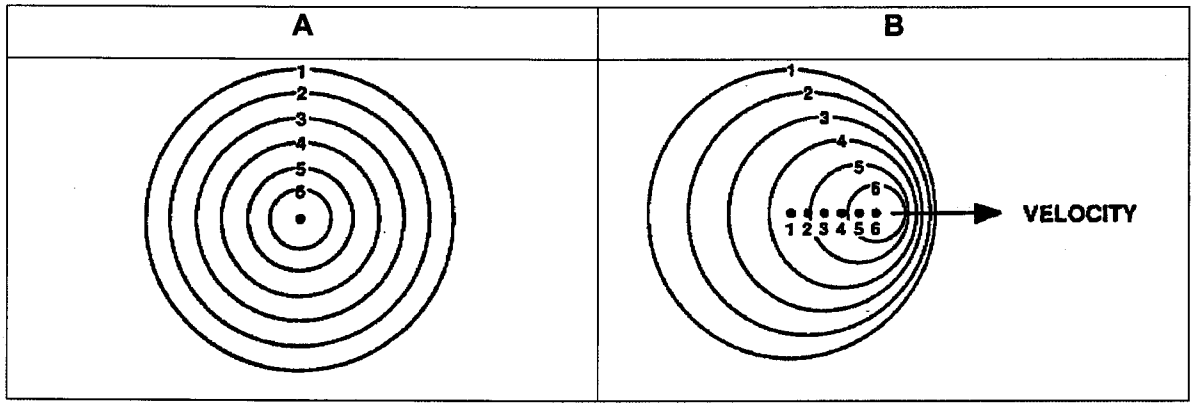
- Why velocity can only be detected along the radar beam
- The radial velocity and the radial component, and
- The difference between true velocity and radial velocity.

Information

Frequency Shift and a Single Dipole

Remember from our discussion on the Doppler shift that all the VHDD can actually detect is the frequency shift caused by a target's motion toward or away from the radar. Refer to figure 21, which illustrates changes in electromagnetic waves reflected from a dipole. In figure 21a, notice the dipole is stationary. Scattered electromagnetic waves remain constant in all directions; forward, backward, and sideways. in this case, the radar recognizes no motion.

Figure 21 a & b: Radiating Dipole



Now consider figure 21 b. In this example our dipole is moving. Notice how the waves emitted from the dipole are compressed in the direction of motion, and spread out in the opposite direction. More importantly, notice the aspect of the waves perpendicular to the direction of movement does not change. This is why the radar only detects a frequency change, or for our purposes a velocity change, if the motion is toward or away from the radar. The component of motion directly toward or away from the radar is known as the radial component.

If the motion is across or perpendicular to the viewing angle of the radar, you can see from the diagram that no frequency shift is detected. More importantly for the radar operator--zero velocity is detected.

Unfortunately, in the real world, motion is not always directly parallel or perpendicular to the radars viewing angle. What happens when the radar encounters motions, which are not? Notice in figure 21 b that as you move from directly toward to directly perpendicular to the viewing angle, a smaller and smaller portion of the shift is detected.

If what you've just read about the radiating dipole is a bit confusing, we understand--we were a little foggy too, at first. So, let's take another look but this time well look at the dipole with respect to the radar antenna.

The radar is quite limited in its ability to detect motion--only the component of the motion toward or away from the radar is measured. Lets see bow this affects radar measurements.

Remember, a dipole radiates energy in all directions.

The waves are either compressed or stretched depending on the relative movement of the dipole. This compression or stretching results in an apparent frequency shift which the radar translates into speed.

Motion Directly Along the Radial

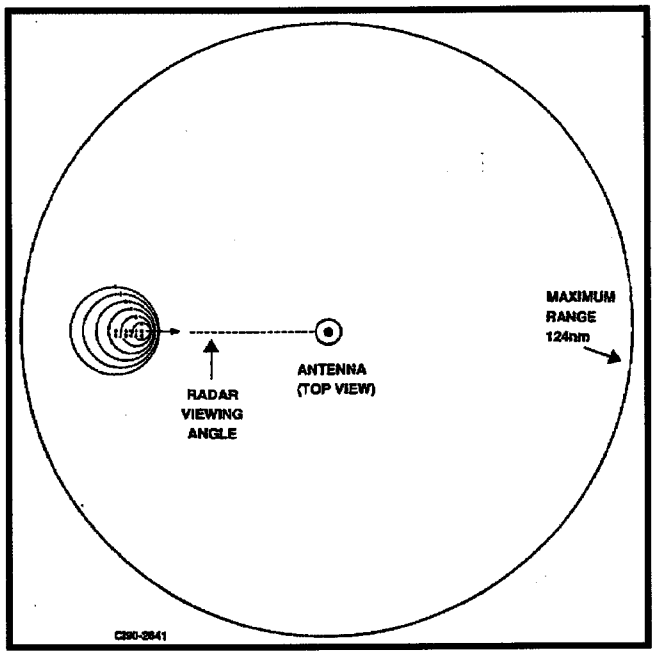
If the dipole is moving directly toward the radar, the maximum amount of compression is sampled. Thus, the maximum frequency shift is occurring along the radar beam (see figure 5).

This maximum frequency shift is correctly translated into the TRUE speed of the dipole.

We can also see that the true speed is detected when the dipole is moving away from the radar, directly along the radar beam. In this case, the waves are stretched and the frequency appears lower. But once again, the beam is sampling an area where the maximum frequency shift is occurring and radar calculates a speed, which is equal to the true speed of the dipole.

However, we must not forget that this true speed is detected **ONLY** in the instances where the target's motion (the dipole) is directly toward or away from the radar's antenna.

Figure 22: Movement toward the Antenna

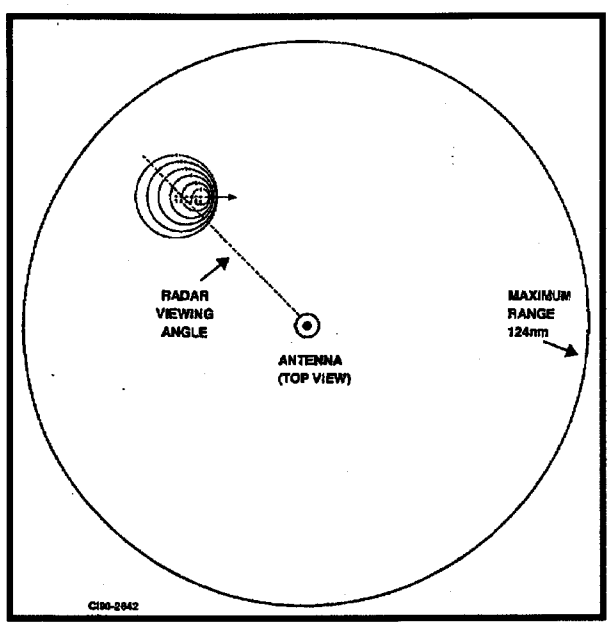


Motion across the Radial

Now let's change the position of our dipole in relation to the antenna. This time the radiating dipole is not moving directly toward the radar, but instead is moving at an angle (see figure 23). As always, the maximum compression of the waves still occurs along the target's direction of movement. Since the radar is now viewing this dipole from an angle, it detects waves, which have been compressed less than the maximum amount we see along the target s direction of movement.

The, radar doesn't have any information about the dipole; it doesn't know where it came from, where it is going, or how it gets to where it is going. The only information the radar can obtain is the size of the frequency shift where the sample is being taken--along the radar beam.

Figure 23: Angular Movement of Dipole

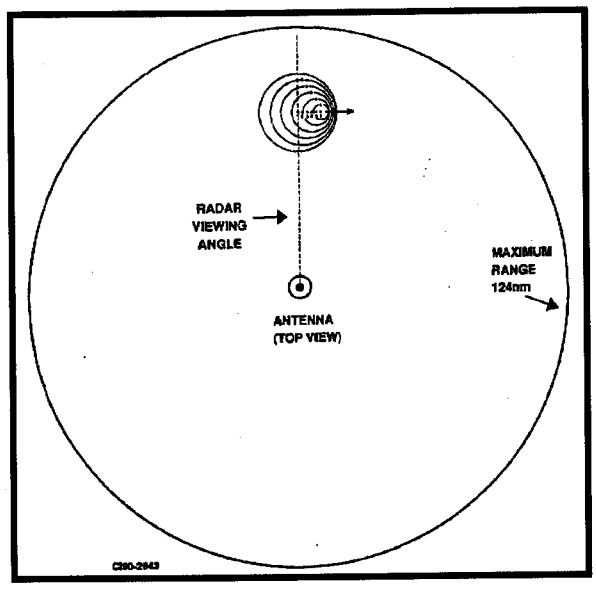


Since this frequency is less than the maximum shift we saw earlier, the radar translates this frequency into a correspondingly lower speed. The true speed of our target has not changed; only the speed detected by the radar has changed.

Motion Perpendicular to the Radial

The extreme case is if the dipole is moving perpendicular to the radar beam. Once again, we'll use the same dipole, but move its position in relation to our antenna (figure 24).

Figure 24: Perpendicular Movement of Dipole



Now our radar is sampling energy from a target, which has **NO** motion away or toward the antenna.

Notice that the radiation from the dipole is not shifted in the area where the radar is sampling--in this area the apparent frequency of the moving dipole is no different than that of a Stationary dipole (figure 21a).

Once again, the radar doesn't have any information about the real motion of the dipole. It only ~'knows" what it can sample about the size of the frequency shift. And in this case, due to the viewing angle, no frequency shift is detected.

Since the radar has not detected a frequency shift, it has not detected any motion. From the radar's point of view, the frequency shift is the same as the speed of the target. This is why the radar indicates a stationary target if that target is moving perpendicular to the antenna (Doppler Zero).

Frequency Shift and Target Motion

The three examples we have just described show three different possibilities.

1. If the target (or wind) is directly toward or away from the radar, the true wind speed is detected.

2. If the target (or wind) is moving across the bee at an angle, the detected wind speed is less than the true wind speed; and finally,

3. If the target (or wind) is directly across the radar beam, the detected wind speed is zero regardless of the true wind speed.

Understanding radial velocity proves to be the most important concept you will learn about Doppler velocity interpretation. Since the VHDD has only one antenna, it can only measure the component of the wind, which is parallel to the beam. The direction in which the beam is pointed is known as the radial, thus the term "radial velocity."

For simplicity, our discussion of motion and the Doppler frequency shift has so far involved only a single target. However, Doppler weather radars actually depict the overall motion of the many raindrops, snowflakes, or other scatterers within the radar's range.

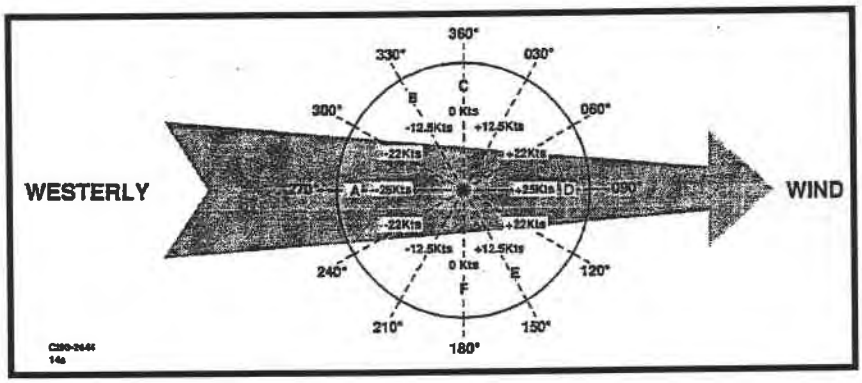
Our new radar gives us displays, which instantaneously depict the entire radar coverage area. In our next discussion we look at how the radar views the wind field using the many atmospheric scatterers present.

Interpretation of Radial Velocity

Refer to figure 25, which represents a uniform, horizontal wind blowing from the west (270 degrees) at 25 knots.

When the antenna is pointing due west (point A), the wind is parallel to the beam and the radar can measure the entire 25 knots. Since the wind is blowing toward the radar, this is expressed as -25 knots. By convention, motions toward the radar are expressed as negative values while motions away are expressed as positives.

Figure 25: Radial Velocity



Now, notice the velocity at point B is shown as -12.5 knots. We said earlier that our wind was uniform from the west at 25 knots. Why are we only measuring 12.5 knots? This is the critical point to understanding radial velocity. Let's look closely at this example.

First, remember that we express motions toward the radar as negative, therefore our value is negative. But why is it only 12.5 knots? You must always remember that the radar can only measure the component of the wind that is parallel to the beam. Recall figure 23 in our previous discussion of a single dipole. When the radar beam encounters a component of the wind that is less than the full component, only a portion of the true wind will be measured--in this case 12.5 knots toward the antenna.

Next, refer to point C. Notice the velocity is now measured as zero. Did our 25-knot wind all of a sudden go calm? Not hardly. Now, since the antenna is pointing toward 360 degrees, the radar beam is directly perpendicular to our westerly wind. Therefore, the parallel component is zero and as a result, the radar detects zero velocity. In addition, notice when the antenna points toward 180 degrees (point F) the beam is once again perpendicular to the westerly wind flow and zero velocity is again detected. Later, we'll learn how important this zero velocity is for determination of the wind direction.

Now refer to point D. Notice the radar measures the full 25 knots here just as it did at point A. This is because the full component of the wind is once again parallel to the radar bean as it points to the east. This is expressed as +25 knots since motions are away from the antenna. Remember, motions toward are expressed as negative while motions away are expressed as positive.

One final example is point E. Here, the antenna points toward 150 degrees. This example, like point B, is similar to figure 23 of our previous single dipole discussion. Since we are only measuring a portion of the frequency shift, then only a portion of the wind is detected--in this case 12.5 knots away from the antenna. The value is expressed as positive because it represents motions away from the radar.

Looking back at figures 22 through 24, it should be easy to see how the radar only detects a portion of the total frequency change. You may still wonder how we arrived at the particular wind speeds. For you mathematicians out there, the following equation was used to derive these radial velocities and is further illustrated in figure 26.

$Va = Vr / \cos Ø$

Where:

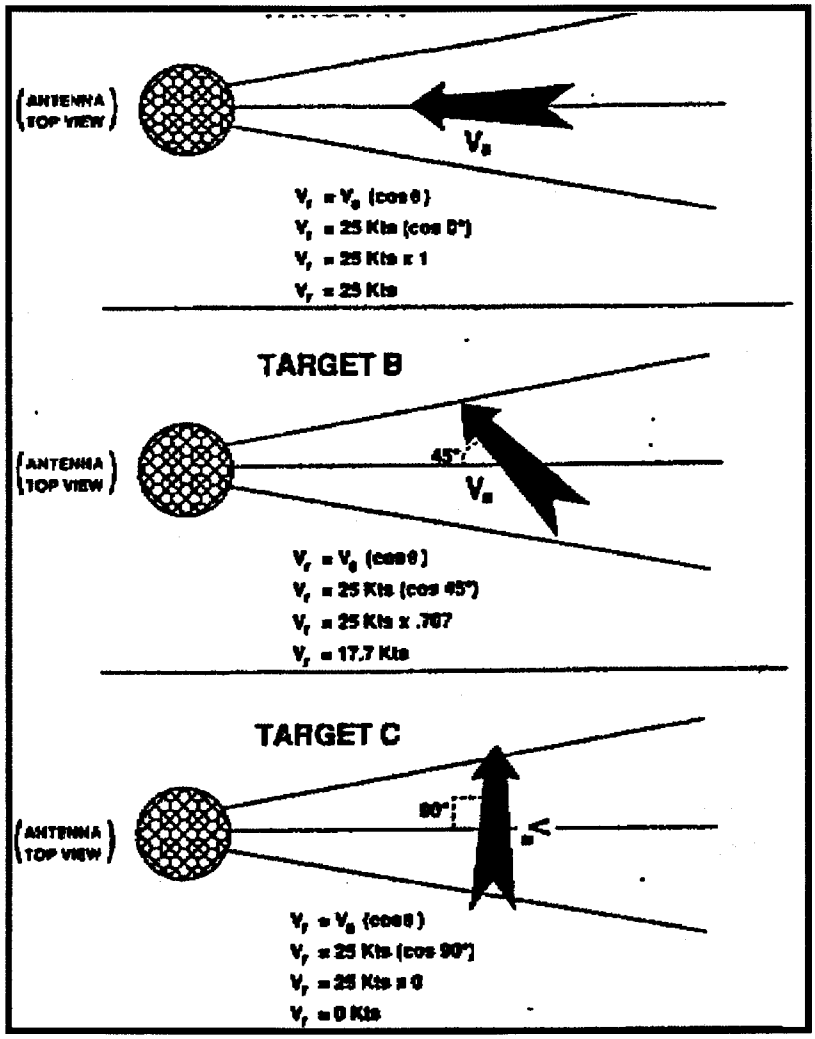
Vr radial velocity

Va= actual wind velocity

Ø = angle between full wind component and the antenna radial

From our discussion of radial velocity, you should now understand that the VHDD, or any other single antenna Doppler radar, can only measure the component of the wind, which is parallel to the radar beam. In later study guides, you'll learn about velocity products, which take this into account and provide you with a wealth of information.

Figure 26: Radial Component



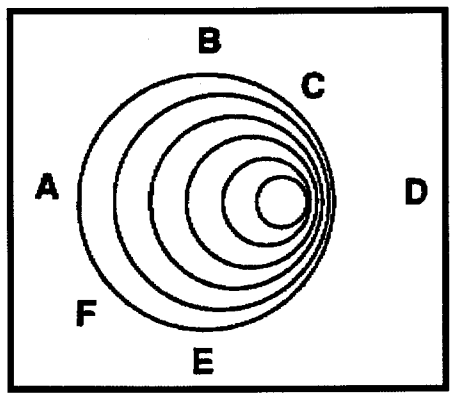
Review Questions Chapter 7

Instructions

From memory, answer the following questions. Check answers against the text.

1. By convention, velocities toward the radar are expressed as _____ values while velocities away from the radar are expressed as _____ values.

The Diagram below represents a single dipole exhibiting a frequency shift. Use this diagram to complete questions 2 through 5.



2. If the antenna is located at point B and facing directly toward E, the radar detects?
   a. The full target velocity
   b. A portion of the target velocity
   c. The target as stationary

3. If the antenna is located at point A and facing directly toward D, the radar detects

   a. The full target velocity

   b. A portion of the target velocity

   c. The target as stationary

4. If the antenna is located at point P and facing directly toward C, the radar detects

   a. The full target velocity.

   b. A portion of the target velocity.

   c. The target as stationary

5. If the antenna is located at point D and facing directly toward A, the radar detects

   a. The full target velocity

   b. A portion of the target velocity

   c. The target as a stationary

6. If the environmental wind is from 240 degrees at 30 kts and the antenna is pointing towards 180 degrees, the radar detects

   a. —15 kts of velocity

   b. +15 kts of velocity

   c. —26 kts of velocity

   d. +26 kts of velocity

Chapter 8

Characteristics of Velocity Aliasing

Objective

Given characteristics of Doppler radar, select facts about velocity aliasing.

Introduction

During the previous discussion of conventional radar principles, the term "range folding" was used. Range folded (second trip) echoes; result from the radar hearing a previous pulse while listening for the most recent pulse. Reducing the PRF and allowing for longer listening time can alleviate this problem. However, in Doppler radars, this low PRF creates a problem in determining radial velocities. This problem is called velocity aliasing.

The VHDD Radar System is equipped with sophisticated computers, which solve this velocity aliasing problem. The operator needs to have the ability to identify when aliasing might occur, and recognize aliasing when it does occur in order to correctly interpret the displays.

After completing this section, you will be able to select correct facts about:

- The cause of velocity aliasing;
- Relationship between phasors, EM waves, and velocity aliasing;
- The Nyquist interval and recognizing potential aliasing problems;
- Methods of reducing velocity aliasing.

Information

Velocity Aliasing

During earlier discussions of the Doppler shift and mean radial velocity, we overlooked one small item: We might not always obtain the correct velocity.

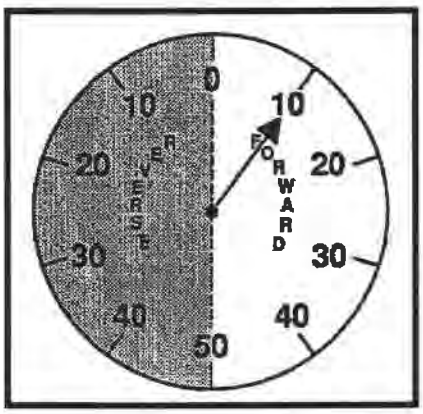
Doppler radars use the Doppler shift (change in the frequency of the returned signal) to detect velocities. The radar can use this information to make very precise measurements of speed. However, limitations in velocity measurements do exist. Let's take a look at a simple example of velocity measurement and see what can go wrong.

The Locomotive Example

Imagine riding along in the engine of a freight train. Have you ever noticed the engines may be hooked together facing opposite directions? This does not present a problem because train engines have the unique ability to go just as fast in reverse as they can forward.

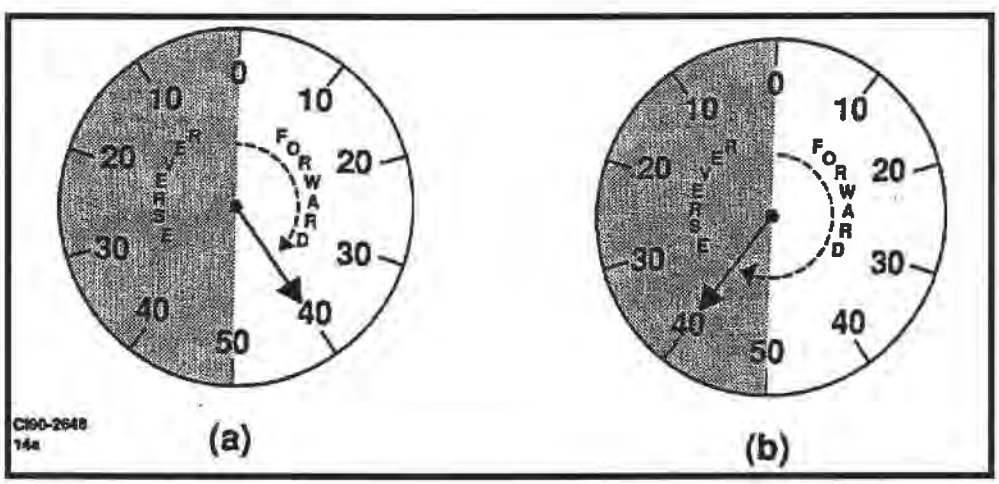
Imagine the locomotive has a speedometer that looks like figure 27. This speedometer was designed to show both forward and reverse speeds. The forward speeds are located to the right while the reverse speeds are on the left side of the speedometer.

Figure 27: Speedometer I



Notice that reading speeds of 0-49 mph in either forward or reverse is easy and leads to little or no confusion. Just as with the train's speedometer, the radar has a limit to speeds it can measure without error. These speeds are known as unambiguous velocities. We will look more at unambiguous velocities later in this section.

Figure 28: Speedometer II



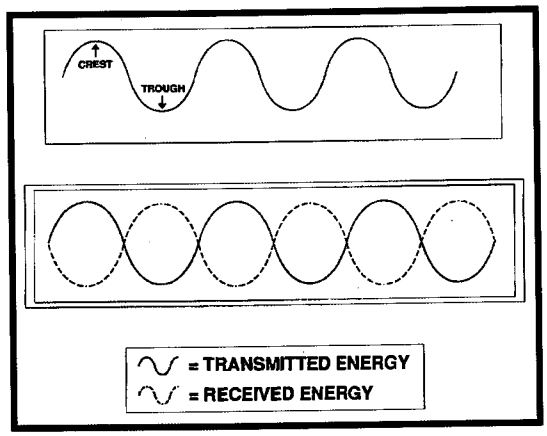
Let's put our train in motion until it is traveling at 40 mph in the forward direction (figure 28a). Notice the speedometer correctly displays the true speed of 40 mph. Now, let's add 20 mph to the forward speed so the train is traveling 60 mph (figure 28b). Notice that the speedometer now reads 40 mph in reverse. What happened? No, the train didn't stop and reverse its direction. What really happened is that we have exceeded the maximum forward limit on the speedometer. Therefore, speeds of 49 mph or less, in this example, are unambiguous. In radar terms, speeds that exceed the maximum unambiguous velocity are said to be aliased and are referred to as aliased velocities.

Since our radar obviously doesn't use a speedometer to measure velocities, it must employ another method. Instead of using a speedometer, the radar tracks the phase change of backscattered electromagnetic waves. Let's look at these waves and determine exactly what a phase change is and how it relates to velocity detection.

Electromagnetic Waves

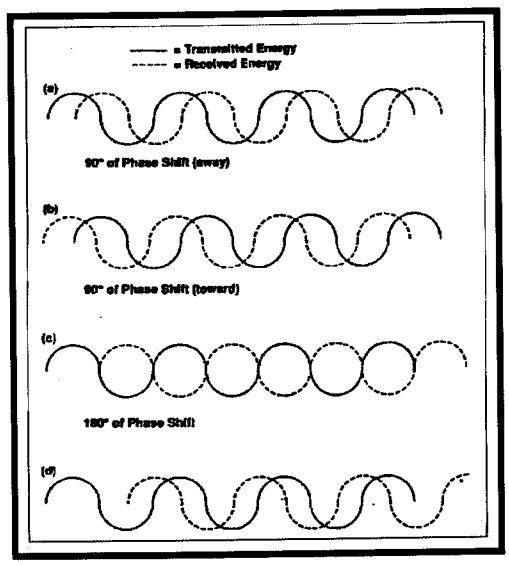
Earlier we showed that Doppler radars determine velocity from the detection of the frequency shift of backscattered radiation. Remember, each wave is transmitted as an arrangement of a crest and trough as shown in figure 29. If the returning waves have been displaced, they are said to have undergone a phase shift (figure 30).

Figure 30: Displaced Wave



As long as the phase shift is less than 180 degrees (one—half wavelength), the amount of change can be related to a correct velocity. But, at 180 degrees of phase shift and beyond, the velocities become ambiguous--interpretable as two or more very different values. Let's look at some examples of transmitted and received waveforms, which have undergone a phase shift. These examples should help illustrate this point.

Figure 31: Several Phase Shifts



If the transmitted energy strikes a stationary target, the electromagnetic energy experiences no phase shift, and its waveform looks identical to the original wave.

If the energy strikes a moving target, then the backscattered waves exhibit some amount of phase shift. Example 31a depicts a 90-degree phase shift resulting from energy striking a target, which is moving away from the radar. Since this phase shift is less than 180 degrees, or one-half wavelength, we can unambiguously measure this shift.

Example 31b is the same as before except this time the energy strikes a target moving toward the radar. Once again, we can unambiguously measure this shift.

Example 31 c now depicts a phase shift of 180 degrees. Here is where the problems begin. Remember, to unambiguously measure the phase shift, the shift must be less than one-half the wavelength. In this case we cannot distinguish whether the 180-degree shift represents motions toward or away from the radar. This measurement is ambiguous.

One final example; 31d, depicts a phase shift of 270 degrees resulting from energy striking a target, which is moving away from the radar. Since a shift of 270 degrees is more than one-half wavelength (180 degrees)--it is ambiguous. This 270-degree shift is seen as a 90-degree phase shift of motions toward the radar. This could result in an aliased velocity being displayed.

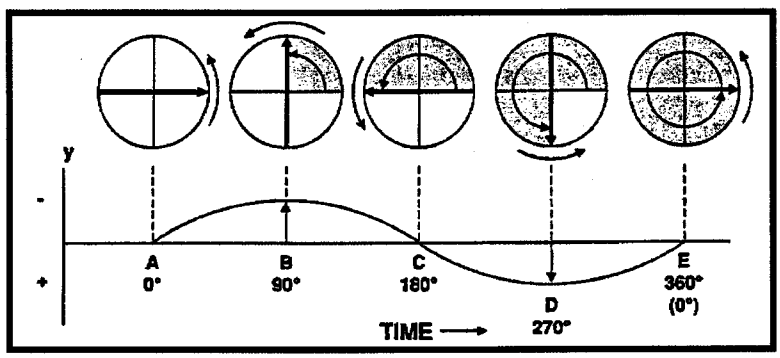
In the previous discussion we used sine waves to represent various phase shifts. If you are a little uncomfortable with this idea, don't worry. Next, we'll take another look at phase shifts by using a circle to represent the sine waves.

Phasors and Electromagnetic Waves

Drawing sine waves to describe radar waves can be very tedious, so another method of describing waves is often used.

Phasors: The phase of an electromagnetic wave is defined as the fraction of a cycle through which a wave has passed at any instant. The phase is often measured as an angle where 360 degrees represents one complete cycle. Figure 32 depicts a sine wave and the corresponding rotation of a phasor, in relation to a circle, which is represented by an arrow.

Figure 32: Sine Wave



Point A (figure 32) on the sine wave represents the beginning of the wave and therefore represents zero degrees on the circle. Notice at point B the phasor has rotated 90 degrees. Point B also represents 90 degrees on the sine wave. The phasor continues to rotate while we move along to point E on the sine wave. Point E represents 360 degrees on both the sine wave and the circle.

Figure 32 illustrates how points on a sine wave can be related to points on a circle. From this you can see that displacement or shifts of the sine wave can be represented by rotation of the phasor. With this understanding, let's now relate the rotation of these phasors to the ambiguous and unambiguous measurement of velocity.

Figure 33: Phasor on X-Y Axis

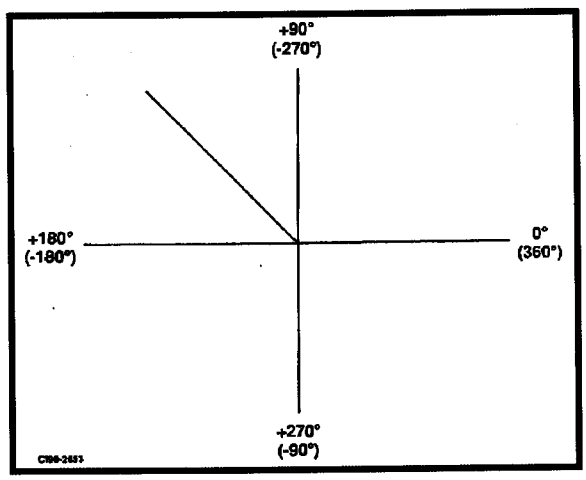
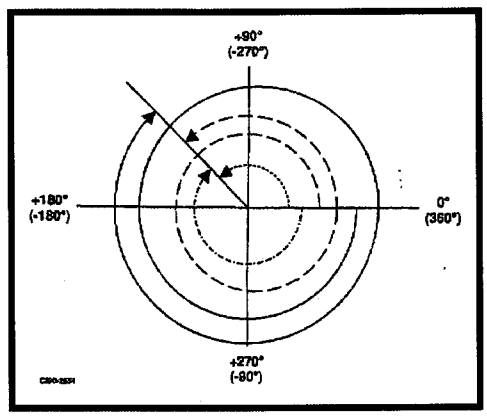


Figure 33 shows a phasor drawn on an axis. We have drawn the X—Y axis to give you a point of reference. If we asked ten people how many degrees this phasor has rotated, we could end up with ten possible answers. This is because there is simply not enough information provided. There are an infinite number of possibilities, which would result in the phasor being located where shown (figure 34). It could have rotated:

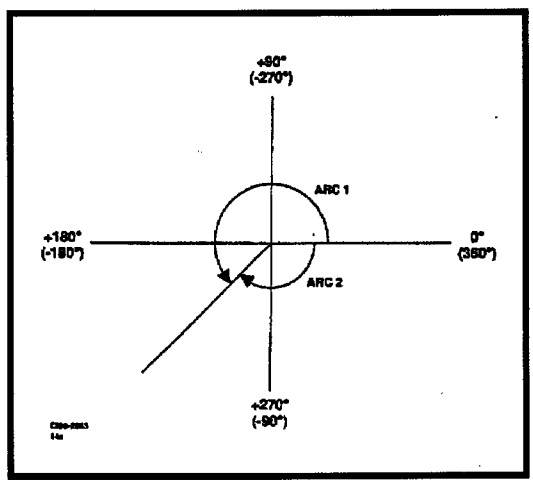
- Counterclockwise 135 degrees,
- Clockwise 225 degrees,
- Counterclockwise 495 degrees (360 + 135),
- Clockwise 585 degrees (360 + 225),
- And so on.

Figure 34: Several Possible Phasor Rotations



Our radar can only see the counterclockwise shift of 135 degrees since it is limited to shifts of less than one—half wavelength (180 degrees). Obviously this can lead to problems if shifts of greater than or equal to 180 degrees occur. Let's finish our discussion by using these phasors to show how the radar sees a shift greater than or equal to our limit of 180 degrees. Figure 35 shows a shift of 225 degrees.

Figure 35: Phasor that Radar Sees



Notice the actual displacement or shift of 225 degrees is shown by arc 1. However, as you know, many other possibilities exist. The only possibility for our radar is arc 2, since arc 2 is the only one less than 180 degrees. Since our radar has only one possibility, when shifts of 180 degrees or more occur, velocity aliasing results.

We've discussed velocity aliasing from three different perspectives; the train's speedometer, the EM waveform, and the rotation of phasors. Your ability to recognize velocity aliasing is crucial to proper interpretation. Later we'll look at how the VHDD Signal Processor helps us solve the aliasing problem.

Wavelength and Frequency: By now you should realize that velocity detection is limited by the wavelength of the radar. As soon as we pass the 1/2 wavelength limit, the determination of velocity becomes ambiguous--the radar may not display the true velocity.

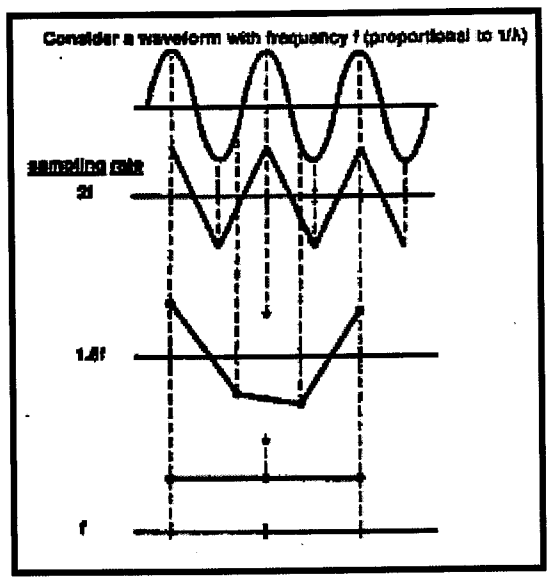
Of course, anytime we speak of wavelength, the same arguments hold for frequency, since both are inversely related by the speed of light. In addition to referring to the limits for unambiguous velocity detection as 1/2 wavelength, we can also say the maximum frequency shift that the radar can discern is two times the radar frequency.

Nyquist Frequency

We have just seen that the unambiguous velocity is dependent upon the wavelength or frequency of the radar. But one more input must be considered.

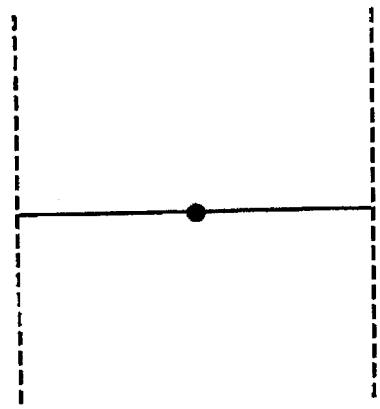
The radar sends out a pulse of energy and then uses the frequency of the returned signal to determine velocity. Sampling of a wave must occur at least twice during its length, or at twice the frequency of the wave. Refer to figure 36 and see why this is true.

Figure 36: Nyquist Velocity



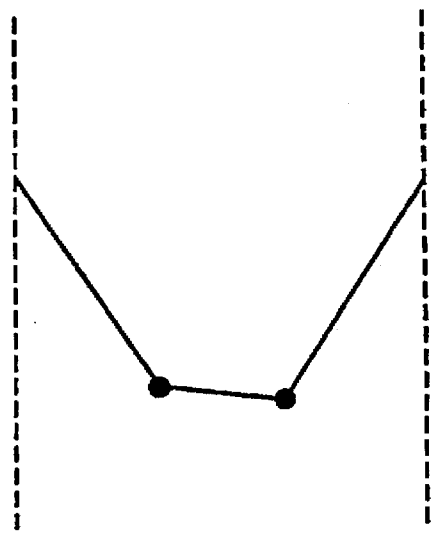
Let's suppose we sample only one point and are asked to recreate a series of waves that contain this point (figure 36a). The best we can do is to estimate the wave with a straight line that passes through the point. This sampling rate is useless for our purposes because the characteristics of a wave are not identified --the radar could never determine whether a shift has occurred.

Figure 36a: Sample of One Point



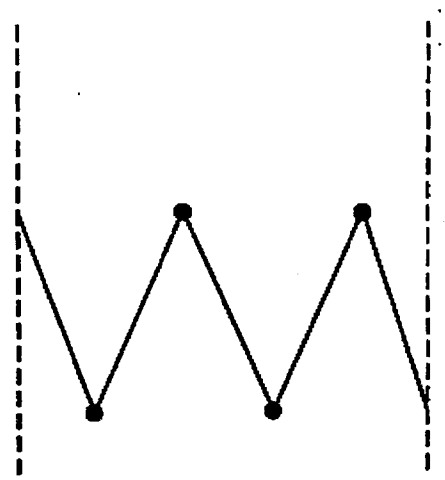
Next, in figure 36b we sample a second point to estimate this series of waves. Now we have more information, and using both points, our" wave "begins to acquire sine characteristics, which resemble a true sine wave.

Figure 36b: Sample of Two Points



In figure 36c we have sampled a third point. This is still a rough looking wave, but we now have at least described the wavelength (and thus the frequency). Note that two points were required within one wavelength. Our sampling frequency must be 1/2 the wavelength or two times the frequency.

Figure 36c: Sample of Three Points



We obviously want our radar to detect relatively high wind velocities. Since we must sample the returning energy at least twice per wavelength for an accurate description, our minimum sampling rate to determine the true velocity must also be relatively high--at least twice the frequency of the backscattered wave.

The way in which we obtain our samples is by transmitting pulses from the radar. Thus, the frequency at which these pulses are transmitted (PRF) must be at least twice the frequency of the waveform we wish to detect. Remember, this frequency is used to determine the degree of shift, and the shift is used to determine velocity.

Therefore, the PRF determines the maximum speed we can detect without confusion. The maximum velocity, which can be detected at a given PRF, is called the Nyquist velocity. The Nyquist interval is those velocities from zero up to and including the Nyquist velocity. The Nyquist co-interval is the entire range of detectable velocities both negative and positive. For example, if the Nyquist velocity is 25 knots$_1$ then the Nyquist interval is 0-25 knots and the Nyquist co-interval is -25 through +25 knots.

Since the VHDD has a fixed wavelength, we can compute the Nyquist velocity, Nyquist interval, and the Nyquist co-interval for any given PRF from the equation.

$$vmax — \frac{(PRF)\ (Wavelength)}{4}$$

Where: Vmax= Maximum unambiguous velocity

PRF = Pulse Repetition Frequency (pulse per second)

Then:

Let's work an example using our VHDD-350C wavelength of 5.35 cm and an arbitrary PRF of 1000.

$$Vmax — \frac{(1000\ per\ sec)\ (5.35cm)}{4}$$

$$Vmax — \frac{5300cm/sec}{4}$$

Vmax 1325cm/sec or 13.25 m/s or about 47.7 kts

Therefore:

The Nyquist velocity is 47.7 knots

The Nyquist interval is 0-47 km/h

The Nyquist co-interval is -47 km/h through +47 km/h

When the velocities detected by the Doppler radar are within the Nyquist co-interval, they can be displayed and interpreted without confusion. At times, velocities occur outside of the Nyquist co-interval. When this happens, the velocity display may need further interpretive skills by the operator. Because of this, you need to be aware of several related items.

First of all, you need to know the operating PRF. Once the PRF is known, then the Nyquist velocity can be determined. Knowing the Nyquist co-interval alerts you to the rage of velocities where you should look for aliasing (1200 PRF = ± 600 Hz).

Reducing the Aliasing Problems

From the previous section you can see that interpreting a velocity display with high winds could get pretty confusing if the radar displayed all velocities exactly as it detected them. The radar's computers usually solve this problem for us by determining the actual velocities whenever they exceed the Nyquist velocity.

Velocity Dealiasing: To compensate for the radar's inability to detect frequency shifts of greater than one—half wavelength, the radar's computers employ a velocity dealiasing technique. Velocity dealiasing is accomplished by testing for velocity continuity along a given radial. It uses the assumption that true wind velocities are more or less continuous. In other words, adjacent velocities should not change drastically over a small linear distance.

Figure 37b illustrates the need for velocity dealiasing. Phasor information has been provided with each velocity sample for clarification.

Figure 37: Dealiasing along a Radial

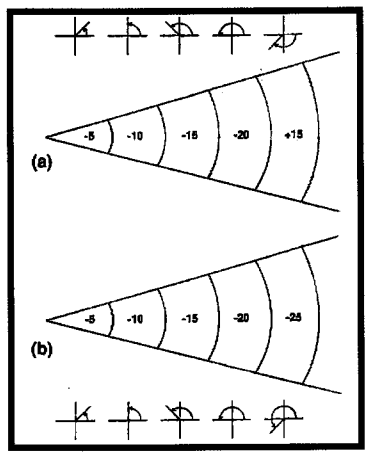


Figure 37a depicts detected velocities along a single radial. Notice the velocities increase uniformly until we reach the fifth sample where a velocity of 15 knots away from the radar is detected. Compare this to the fourth sample where we see a velocity of 20 knots toward the radar. We would not normally expect this to happen. Obviously the radar has incorrectly interpreted the wind. Without the use of dealiasing, these aliased values would be incorporated into the velocity product leading to a confusing display.

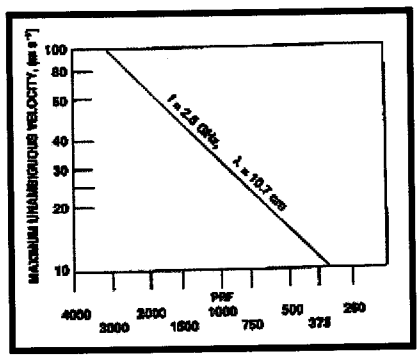
Figure 37b depicts the same radial except this time velocity dealiasing was employed. In this case, the radar's computer is able to correctly measure the velocity even though it exceeds the one-half wavelength limit. This is because the radar's computers are using a velocity dealiasing technique, which compares the current aliased velocity with the preceding values and adjusts accordingly.

This is a very simplified explanation of the dealiasing technique used by the Doppler radar. Later, we take a closer look at dealiasing. For now it is important you realize that when velocity differences greater than a specified value occur from sample to sample, velocity aliasing is assumed to have occurred and the radar attempts to solve this problem through dealiasing.

Aliasing and PRF: We have now seen that aliasing, the misrepresentation of velocities, is dependent upon both the wavelength and the PRF. The longer the wavelength, the greater the allowable shift before aliasing occurs. The sampling frequency, or PRF, determines how well we can resolve the actual frequency shift.

The wavelength remains fixed in the radar, so another method of reducing aliasing is to increase the PRF. Increasing the PRF increases the Nyquist co-interval, which decreases the chances of aliasing. Figure 38 depicts some of the maximum velocities that different PRF's allow for a given wavelength (or frequency).

Figure 38: Maximum Velocities and PRF



The apparent solution to velocity detection is to increase the PRF to a level, which provides us with the desired velocity measurements. Unfortunately, many of the desired features of radars cannot be easily incorporated. Most features, which are desirable for one reason, tend to impact negatively in other areas. In other words, radar design is a continual compromise. One of the most prevalent compromises in radar meteorology is--The Doppler Dilemma.

Review Question Chapter 8

Instructions

From memory, answer the following questions. Check answers against the text.

1. A shift in frequency of electromagnetic energy can be represented by a (an)

   a. Displacement of the electromagnetic waves.
   b. Increase in amplitude of electromagnetic waves.
   c. Clockwise or counterclockwise rotation of a phasor.
   d. Both a and c.

2. The Digital Doppler processors are able to dealiasing wind velocities by:

   a. Reducing velocities by 5 kts along each radial.
   b. Discarding every fifth sample along a radial.
   c. Comparing samples along each radial to ensure reasonable continuity exists.

3. Given a PRF of 1500 pulses per second and a wavelength of 5.35 cm, determine the Nyquist velocity, Nyquist interval, and Nyquist co-interval in meters per second.

4. Increasing the PRF will (increase / decrease) the Nyquist co-interval which will (increase / decrease) the chance of aliasing.

Chapter 9

Range-Velocity

Objective

Given characteristics of the Doppler Dilemma, select facts about their effect on the radar detection process.

Introduction

Have you noticed that life sees to be a series of give and take situations? Guess what--Doppler radar is no different. The radar operator wants to see as far away as possible yet still be able to correctly detect very high wind velocities. Unfortunately we can't have our cake and eat it too. This interdependency of range and velocity on the PRF is often called "The Doppler Dilemma."

After completing the objective, you will be able to select correct facts about:

- Maximum unambiguous range,
- Maximum unambiguous velocity, and
- PRF effects on the Doppler Dilemma.

Information

The Effects of PRF Changes

From the radar principles discussed so far, we know of two features, which are very desirable for radar operations--relatively long ranges and high velocity measurements.

Maximum Unambiguous Range

In conventional radar principles, range folding was described as occurring when a pulse transmitted from the radar exceeds the maximum unambiguous range, strikes a target and returns to the radar after a subsequent pulse has been transmitted.

Thus, the radar incorrectly plots the target within the unambiguous range because it is now listening for the second pulse. This range-folding problem can be solved if the PRF is decreased until the maximum unambiguous range is beyond all scattering regions. This can be shown by an equation:

Max range = c/(2/PRF)
Where:
c = Speed of Light
PRF = Pulse Repetition Frequency

Maximum Unambiguous Velocity

Now compare this to the velocity aliasing problem we just discussed. The solution to the aliasing problem is to increase the PRF until all actual velocities are within the Nyquist co— interval.

Max velocity = (PRF x wavelength) /4

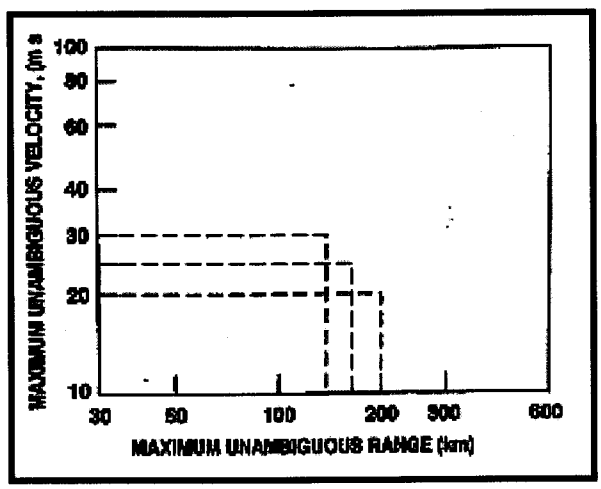
As you have probably guessed by now, maximum range and velocity are ideal; however, the PRF changes are inversely proportioned to max range. This leads us to the infamous Doppler Dilemma.

The Doppler Dilemma

High PRF's are required for high velocity measurements, and low PRFs are required for long ranges. Thus, the Doppler Dilemma--finding a balance between the effects of velocity aliasing and the effects of range folding. As an example we will use the US Nextrad.

In order for the Nextrad to detect radial velocities of 200 mph without aliasing, the PRF would have to be about 4000 pulses per second. However, this would reduce the maximum unambiguous range of the radar to about 20 nautical miles. To have an unambiguous range of 100 nautical miles, the PRF would have to be approximately 810 pulses per second. This would cause the maximum unambiguous velocity to decrease to 45 mph. Figure 39 shows the various velocity/range values.

Figure 39: Unambiguous Range-Velocity Relationship



The Doppler Dilemma can also be described by an equation:

(Max velocity) X (Max range) (Wavelength x c)/8

From this equation you can see that maximum unambiguous velocity and maximum unambiguous range are inversely related. The right side of the equation is constant for our radar since its wavelength and the speed of light do not change. To maintain equality, if the maximum unambiguous velocity Increases, then maximum range decreases and vice versa.

Physical laws of nature cause the Doppler Dilemma. To solve this dilemma, the Doppler radar systems use several methods to work around these restrictions. For example, one method the WSR-88D employs is to operate at variable PRF's, collecting reflectivity information at low PRF's and velocity information at high PRF's. The two sets of information collected are then compared and processed to estimate true radial velocities and ranges. Well look at this in more detail in our next chapter.

Remember, however, that the Doppler Dilemma still exists, the radar is limited, and a compromise between maximum range and maximum velocity detection is almost always a factor.

Review Questions Chapter 9

Instructions

From memory, answer the following questions. Check your answers against the text.

1. T / F Increasing the PRF not only helps accurately measure strong winds which exceed the Nyquist velocity, t also increases the maximum range of the radar.

2. The Doppler Dilemma is a compromise between _____ and _____.

3. A PRF of 4,000 pulses per second results in:

   a. High velocity detection and short range
   b. Low velocity detection and short range
   c. High velocity detection and long range
   d. Low velocity detection and long range

4. The Doppler Dilemma is best defined as:

a. The trade-off between radar frequency and wavelength
b. The trade-off where an increase in PRF increases the maximum unambiguous velocity but decreases the maximum unambiguous range.
c. The trade-off where an increase in PRF decreases the maximum unambiguous velocity but increases the maximum unambiguous range.

Chapter 10

The True Meaning of Echo Volume

Objective

Given characteristics of a sample volume (echo volume), select facts about the information contained in a sample volume.

Introduction

To help you further understand atmospheric sampling by the VHDD radar system, we will now look at the data, which is being received by the radar at any one instant. Recall from our discussion of conventional radar principles that a sample volume (echo volume) is the volume of the atmosphere, equals to 1/2 the pulse length times I beam width. In this section, we will add to our understanding of a sample volume, see what is contained within this volume, and then, see what the radar does with this information.

After completing this section, you will:

- Be able to explain the concept of sample volume,
- Describe a Doppler spectra, and
- Explain the significance of Doppler spectra.

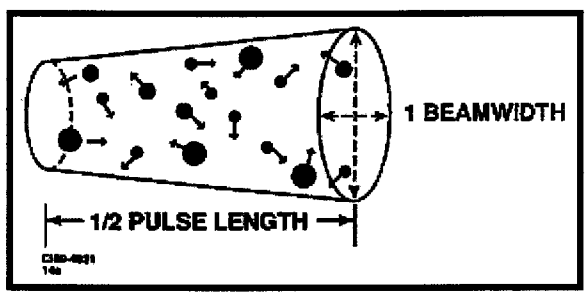
Information

We defined the pulse volume as the volume of the atmosphere occupied by the pulse of electromagnetic energy. But what about the volume of atmosphere that is instantaneously sampled by the radar? This is called the sample volume, or sometimes, the echo volume. It is equal to 1/2 pulse length and the beam diameter. The sample volume is very important to interpretation.

A sample volume contains many particles. For example, if the target is precipitation, the volume contains particles of varying size, shape, and water/ice composition. Figure 40 shows an example where each of these particles may be moving in different directions--some upward, some downward, and some laterally, etc.

Although a pulse volume is easy to imagine--an actual pulse of energy traveling through the atmosphere--the sample volume is a little different. The sample volume actually represents a volume of the atmosphere from which backscattered energy has originated. Energy sampled at any specific instant by the antenna has actually originated from slightly different locations.

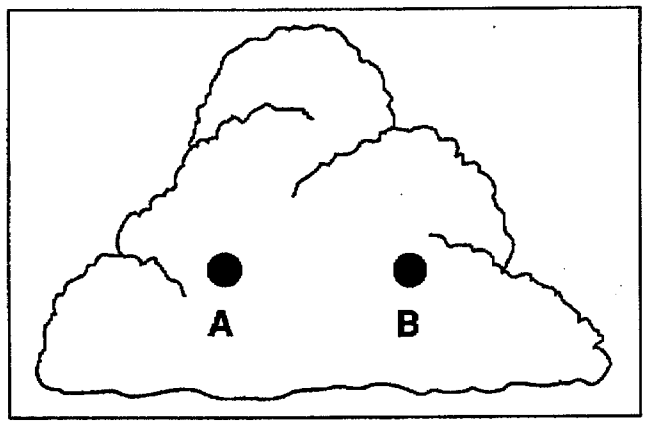
Figure 40: Sample Volume



Two-Water Droplet Example

When we sample energy returning from a target, we do not know exactly from where this signal is coming. Is it a signal coming from the front of the radar pulse or from the rear of the pulse? We can see why this confusion occurs by looking at a simplified diagram. Assume we have a rain shower composed of only two water droplets (figure 41).

Figure 41: Two-Drop rain Shower



Let's take a close look at the inside of this rain shower and trace the route of backscattered radiation.

Figure 42: The pulse of radar energy emitted from the radar makes first contact with water droplet A. At this instant, water droplet A begins to radiate energy—some of which is directed back to the antenna (backscattered radiation).

Figure 42: Step One

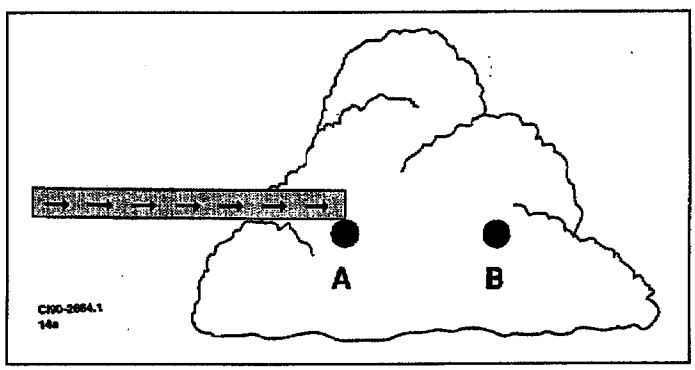


Figure 43: As the pulse continues past water droplet A, the water droplet continues to be energized; thus, it continues to send backscattered radiation to the antenna. Of course, since water droplet B hasn't yet been energized by the pulse, backscattered radiation is not being emitted by it.

Figure 43: Step Two

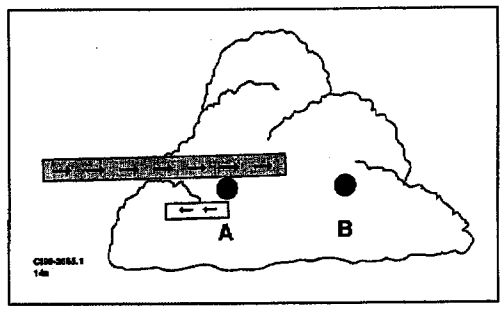


Figure 44. The radar pulse continues onward and eventually reaches water droplet B. At this time, water droplet B is energized and it also begins to send energy back to the antenna. During this entire period, of course, water droplet A has continued to send its own backscattered radiation since it is still being energized by the *rear* half of the pulse.

Figure 44: Step Three

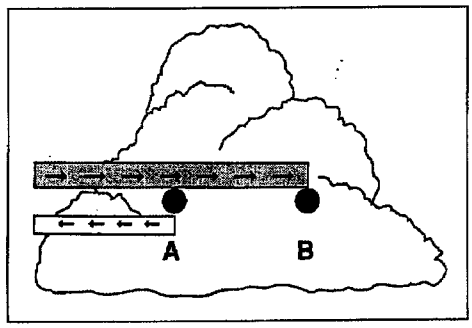


Figure 45: Another small amount of time has elapsed and the pulse continues to move forward and is still energizing both water droplets A and B. At the same time, the backscattered energy from water droplets A and B continues traveling back to the antenna. Note that the energy emitted from water droplet B is moving towards water droplet A as it travels to the antenna.

Figure 45: Step Four

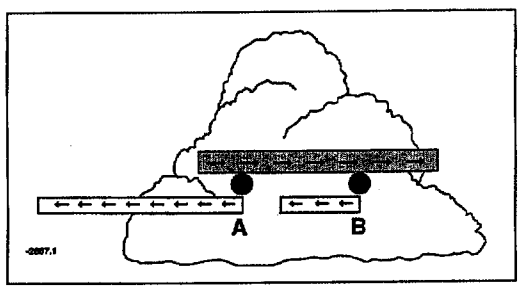
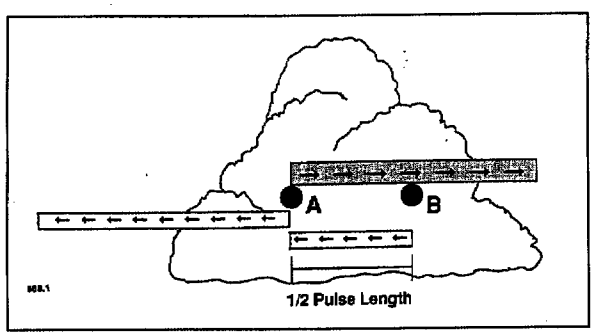


Figure 46. The pulse continues to move forward and the backscattered energy from the water droplets continues to move back to the antenna. Note, however, that two things happen together. First, the pulse has continued to energize water droplet A, thus backscattered radiation is emitted. And second, the backscattered radiation from water droplet B has reached the same location occupied by water droplet A.

Figure 46: Step Five



Result: Backscattered radiation from water droplet A and water droplet B are both occupying the same space. We can now make some deductions:

- Energy from both water droplets (A and B) occupy the same space.
- Energy from both water droplets are traveling at the same speed (speed of light) back toward the antenna.
- Energy from both water droplets will reach the antenna at the same time.

Food for thought: Backscattered energy from both water droplets reaches the antenna at the same instant. So, how will the radar know which energy came from which water droplet?

Look at Figure 46 again and note the distance between A and B. You should be able to see that we chose a distance that is about 1/2 the length of the radar pulse.

If we had positioned these droplets any farther apart, the backscattered radiation from each water droplet couldn't have reached the antenna at the same instant. But if we positioned them closer together, or had more droplets in between, we could have a situation where backscattered radiation from all the droplets reaches the antenna at the same time. Suppose we had thousands or millions of droplets located between water droplets A and B.

Multi-Water Droplet Example

Let's look at a simple example of this (figure 47), and represent all these extra water droplets by a third point and call it water droplet Z.

Figure 47: Multi Drop

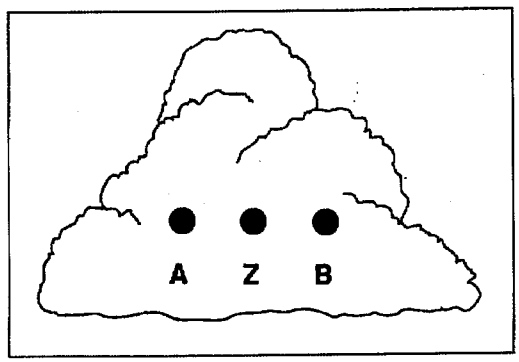


Figure 48: The pulse of radar energy emitted from the radar makes first contact with a water droplet. At this instant, water droplet A begins to radiate energy--some of which is directed back to the antenna (backscattered radiation). Neither Z nor B has been energized yet, so they are not returning any radiation.

Figure 48: Step One

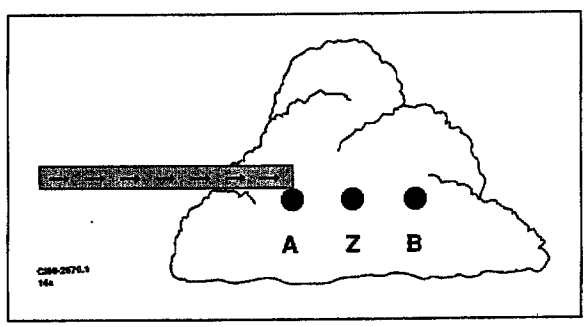


Figure 49: As the radar pulse continues past water droplet A, the water droplet continues to be energized, thus, it continues to send backscattered radiation to the antenna. The pulse has also reached water droplet Z, so, backscatter radiation begins to be emitted from it. Of course, since water droplet B hasn't yet been energized by the pulse, backscatter radiation is not being emitted.

Figure 49: Step Two

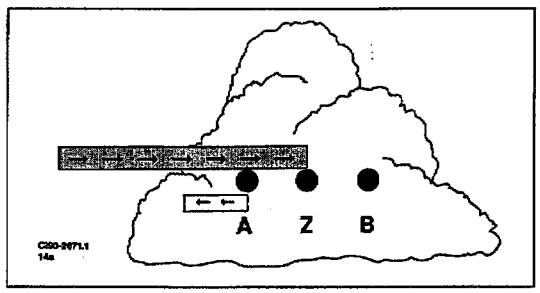


Figure 50: The pulse continues onward and eventually reaches water droplet B. At this time, water droplet B is energized and it also begins to emit energy back to the antenna. During this entire period, water droplet A and water droplet Z continue to emit their own backscattered radiation since they are still being energized by the rear half of the pulse.

Figure 50: Step Three

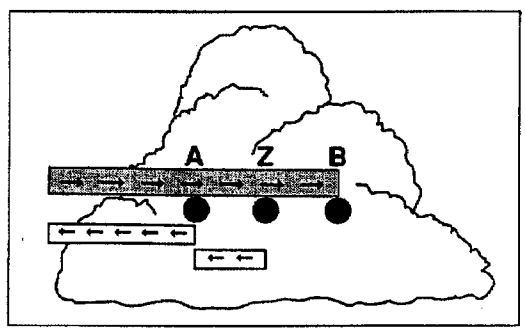


Figure 51: Energy from water droplet B is moving back to the antenna and somewhere along the way it passes the location of other water droplets-for instance, water droplet Z. Obviously, if the radar pulse is still energizing these water droplets, backscattered radiation from all these droplets continues back toward water droplet A in one mass or group.

Figure 51: Step Four

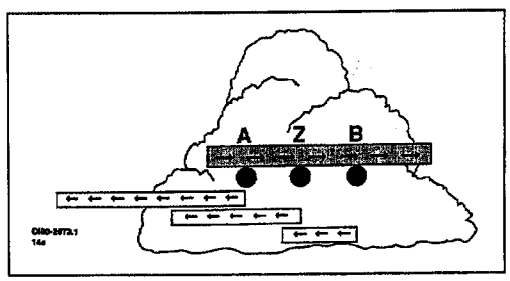
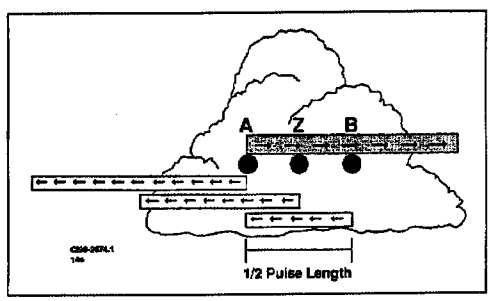


Figure 52: Eventually, backscattered radiation from water droplet B and all the other water droplets represented by Z reaches droplet A at the same time. Since water droplet A is still backscattering energy, we again have an example where electromagnetic energy has originated from many different locations, but is now occupying the same space.

Figure 52: Step Five



Once again, look at the area from which this backscattered energy has originated. All the energy from this area reaches the antenna simultaneously. So, at any one time, the radar samples energy which originated from anywhere within that distance. And, since our radar beam has both height and width, the radar 'samples" a volume of the atmosphere, which is one-half the size of the pulse length.

Now, more food for thought: Backscatter energy is received at the radar from millions of water droplets simultaneously. How can the radar tell which droplet is which?

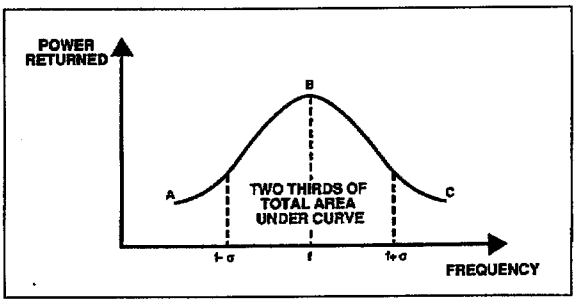
Since the sample volume is relatively large, individual targets are much smaller than the sample volume. This means that all targets within that volume contribute to the backscattered radiation received by the radar. In other words, the individual character of a target is averaged among the characteristics of other targets. If all the targets are similar to each other, this is not a problem. However, if a few targets are very different, their special characteristics can be lost among the total average.

The pulsed Doppler weather radar doesn't sense these motions individually. At any one instant, it receives a combination of the motions of the individual particles within the sample volume. Since this return consists of many different motions, it also consists of many different electromagnetic frequencies. The radar then processes these various frequencies and interprets them in terms of a Doppler Spectrum.

Doppler Spectrum

The Doppler Spectrum is the distribution of power received by the radar at each frequency within the sample volume. The radar electronically analyzes the spectra to determine the frequency returning the maximum power. If plotted visually on a graph, the typical return would look like figure 53.

Figure 53: Power Distribution



Notice the distribution of power plotted against frequency results in a bell curve. This curve shows the amount of power returned to the radar at any frequency. (Remember, we can translate these frequencies into velocities.) The top of this curve is the maximum power returned to the radar (figure 57, point E). You night then assume the frequency representing the greatest power return would also represent the motion of the greatest number of particles within the sample volume. However, this is not necessarily true.

Since the radar receives proportionally much more reflected power from large drops than from small ones, the frequency with the maximum power returned is usually that of the largest particles within a sample volume.

Mean Doppler Velocity

These larger particles tend to move with less effect from turbulent gusts and should be a pretty good representation of the mean airflow. Therefore, the frequency of the maximum power returned is used to estimate the mean Doppler velocity. This velocity approximates the average airflow within the sample volume as indicated by the motion of the largest particles, thus the term "mean[1] Doppler velocity.

Spectrum Width

Motion of smaller particles within the sample volume can be determined from portions of the spectrum right or left of the center of the curve. (Figure 53, points A and C). In other words, information on the most variable short—term gusts or turbulence within the sample volume are in the two extremes of the spectrum.

Spectral Shape

Variance

The variance is used as a mathematical description of spectral shape. The VHDD uses the variance so it can describe the range of frequencies received by the radar. The radar derives this variance by normal statistical rules, and then translates these statistical data into spectral shape information as a product you can view graphically.

Spectral shape information can be described in terms of the standard deviation of a distribution. If the frequency (f) in figure 53 corresponds to the mean Doppler velocity, then half of the total area under the curve falls both right and left of "f". The standard deviation is that distance right and left of the "V' which includes about 2/3 of the area of the curve.

The square of the standard deviation is called the variance, and it changes as spectrum width varies.

Recall that wider spectra generally indicate more turbulent targets. Since we said that the variance changes with the spectrum width, larger values of the variance also correspond to more turbulent targets.

We use this variance as an indication of spectral shape.

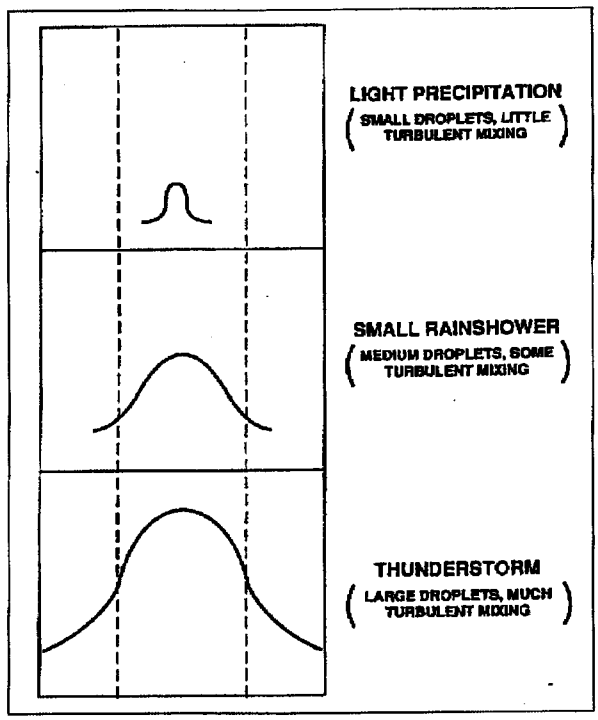
The variance is displayed as a graphic product in a similar way it displays reflectivity or velocity. During interrogation, you can simultaneously examine patterns of mean Doppler velocity, reflectivity, and variance (spectrum width). From this you can determine whether you should have confidence in your mean airflow and turbulence evaluations for various portions of a precipitation target.

For example, the most reliable estimates of mean motion within or near a precipitation target are obtained from spectra with narrow widths (small variance) and relatively sharp peaks (high reflectivity). Let's see why this is true.

Target Characteristics and Spectral Shape

The actual shape of the Doppler spectrum varies with the character of the target being sampled. For example, precipitation echoes with very large particles and large internal wind shears (thunderstorms) result in a flatter appearing spectrum. However, the spectrum for these targets have substantially more area under the curve than other targets since the particles are larger and reflect more power back to the radar. Targets with smaller particles and weaker wind shears produce a sharper spectral shape with much less area under the curve. In general, wider spectra denote a more turbulent atmosphere in condition. Figure 54 represents spectral shapes for various precipitation characters.

Figure 54: Spectral Shape



Radar Characteristics and Spectral Shape

The Doppler spectral 'shape is determined by the nature of both the target and the radar. In the generalized discussion of spectral shape that follows, keep in mind that characteristics of precipitation targets vary widely, and thus, their Doppler spectra vary widely. Effects of target characteristics upon spectral shape were summarized in figure 54.

We noted earlier that spectra, which are narrower and sharper, produce more reliable estimates of mean velocity of the sample volume. However, some of the variance seen in a spectra may be caused by the radar itself and shouldn't be interpreted as turbulence. For example, stabilizing the Doppler velocity estimate (a narrower spectrum width) can also be achieved by increasing the antenna size. This reduces the beam width, which in turn reduces the sample volume and amount of variability. Also, slowing the antenna's rotation stabilizes the velocity estimates by allowing repeated sampling of a given atmospheric volume. This produces a better estimate of velocity since a slower rotation allows for more sequential samples, and therefore, a more reliable estimate of mean velocity. Slower rotation is also used for sampling in clear air.

You must also realize that a high spectrum width does not always equate to turbulence and or wind shear. Always keep in mind that a high spectrum width may be due to weak reflectivity causing a poor signal-to-noise ratio. Also, we tend to see higher spectrum widths along the edges of echoes where power return drops off rapidly.

Review Question Chapter 10

Instructions

From memory, answer the following questions. Check your answers against the text.

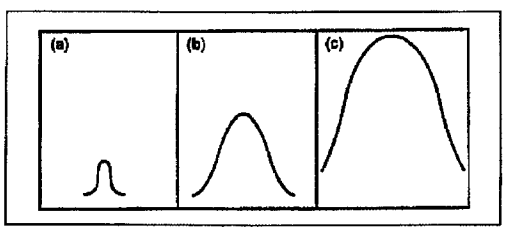
1. (T / F) The radar can determine which portion of the pulse is returning at any given instant.

2. The square of the standard deviation of the distribution is known as:

   a. Variance
   b. Spectrum width
   c. Mean Doppler velocity
   d. Doppler spectrum

3. Which of the diagrams in figure 55 best illustrates a precipitation echo with large particles and high internal shear? _____

Figure 55: for question #3



4. The sample volume represents the smallest amount of the atmosphere, which can be instantaneously sampled by the radar. This is because:

   a. Energy returned from particles separated by more than a sample volume's dimensions is averaged together as a single return.

   b. Particles must be separated by less than one pulse length to be detected and measured separately.

   c. Energy returned from particles separated by less than the sample volume's dimensions is averaged together as a single return.

5. Velocity measurements derived from a sample volume consist of:

   a. The maximum frequency shift of the smallest detected particles.

   b. The average frequency shift of all particles but heavily influenced by the largest.

   c. The average of every fifth sample volume along a radial.

Chapter 11

The VHDD350C Radar

Understanding The Radar Range Equation

Objective

Given the characteristics of a radar system, determine the detection range for a given rainfall rate at a specific range and determine the excess signal margin.

Introduction

To help you further understand the VHDD-350C radar system, a block diagram discussion precedes the radar range equation for meteorological targets. To determine the radar system's detection range we must change the calculation from a pulse volume measurement (mean value) of the pulse volume in the atmosphere to a point source target using a full beam.

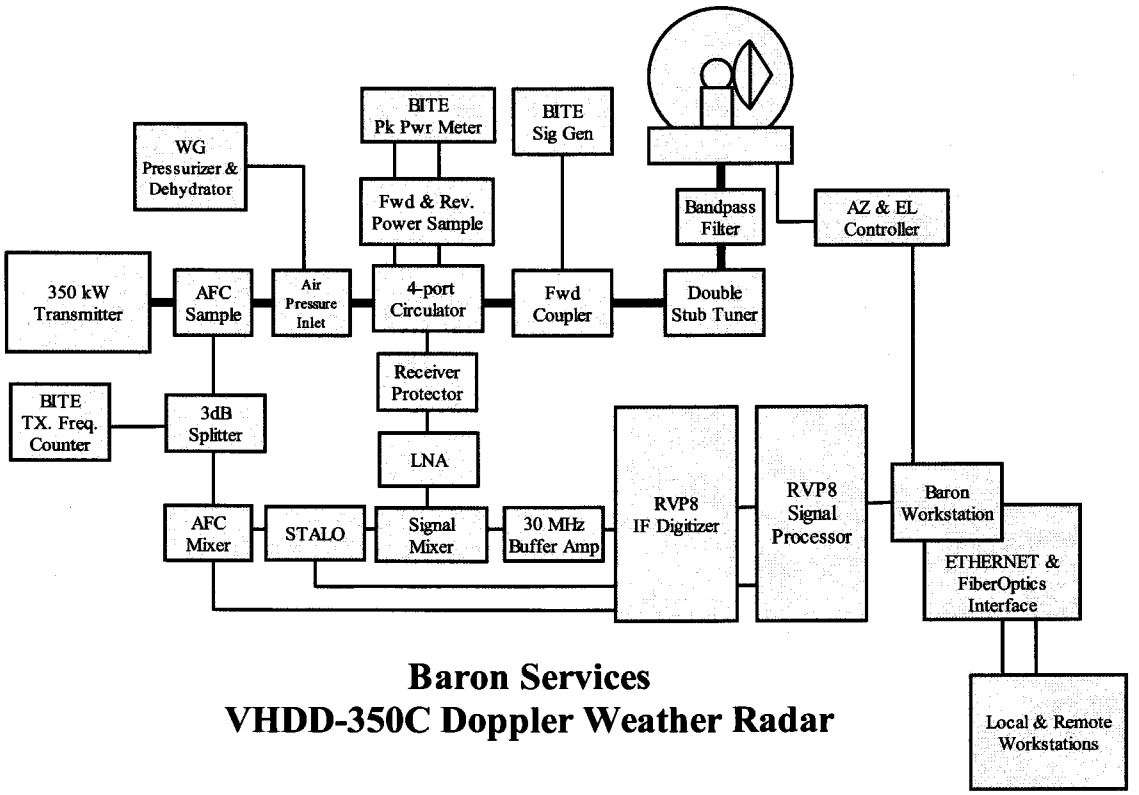
We will now look at the signal being received by the radar at any one instant in time, using the diameter of the hydrometeors and the reflectivity constant for water or ice. Recall from our discussion of conventional radar principles that a sample volume (echo volume) is the volume of the atmosphere, equals to 1/2 the pulse length times I beam width. In this section, we will add to our understanding of a sample volume, see what is contained within this volume, and then, see what the radar does with this information.

After completing this section, you will:

- Be able to understand the radar equation,
- Understand the major subsystems of the radar a how they operate,
- Be able to determine that by changing specific radar parameters, what the result will be in radar performance, and
- Understand calibration of the radar.

Radar Functional Block Diagram Discussion

A functional diagram of the DWR is shown in the figure below and discussed as follows:



Baron Services
VHDD-350C Doppler Weather Radar

Please refer to the diagram above for the following discussion regarding signal flow within the radar system.

RF Transmission:

Transmitter - Consists of a powerful 350-kilowatt tunable coaxial magnetron driven by an all solid-state modulator. The transmitter is controlled by the RVP8 signal processor, which controls the PRF and RF pulse widths generated by the transmitter. The PRF is controlled over a range of 250 pps to 1250 pps, depending on the mode and display range selected by the operator. Three pre-settable pulse widths are provided within the range of 0.8 to 2.0 microseconds.

The transmitter RF output pulse is coupled to the antenna via a pressurized WR187 waveguide assembly.

AFC Sample - Consists of a forward RF power coupler that couples a -75dB sample of the 350-kilowatt pulse (+85.4dBm) to a 3dB power Divider. The +10dBm output signal to the AFC Mixer.

Digital AFC - The AFC Mixer input signal is heterodyned with a Stable Local Oscillator (STALO) signal to produce a ~30 MHz IF signal that is phase coherence with the transmitter (COHO). The COHO signal is then coupled to the RVP8 IF digitizer and converted to a digital word containing the COHO frequency and phase information (digital COHO).

Air Pressure Inlet - A waveguide section is installed to allow pressurized dry air to enter the waveguide. The pressurized dry air is produced by a "Pressurizer/Dehydrator" that is provided as part of the radar system.

4-port Circulator - functions as a duplexer, which allows the radar system to transmit and receive RF energy using a single antenna. The duplexer provides ~25db of isolation between the transmitted and received RF signals. Transmitted energy enters the 4-port circulator at port 1, and exits at port 2. Received energy enters the 4-port circulator at port 2 and is fed to the receiver via port 3. VSWR mismatch in the waveguide transmission line is fed to a dummy load on port 4.

Port 1 is equipped with a Forward Power Coupler, which is used to measure Forward Power. Port 4 is equipped with a Reflected Power Coupler and used to measure Reflected Power (VSWR).

BITE Forward Coupler - is located on the output, port 2, of the 4-port circulator. This coupler is used to inject test signals from an RF Signal Generator. The BITE signal is used for auto-calibration, linearity range measurement and Minimum Discernable (MDS) tests of the Digital Receiver.

Double Stub Tuner - is provided to tune out any mismatch in the waveguide transmission line coupling the transmitter to the antenna, thus yielding a VSWR of <1.1:1.

Bandpass Filter - a 5.4GHz to 5.7GHz bandpass filter is installed in the output waveguide assembly to attenuate out of band signals to prevent interference with communications equipment.

Pedestal - The pedestal consists of an Elevation over Azimuth assembly that is used to point the antenna and direct the RF emissions at the desired point in the atmosphere.

Antenna – This antenna is a precision, 16-panel 3.7 meter painted aluminum reflector with a 57.6-inch focal length. The C-band signals are fed to the anttna via an optimized scalar feed that is horizontally polarized. This front fed parabolic reflector is designed for high gain (~45dB) and low side lobe (-27dB) operation.

18 ft. Diameter Radome - consists of a sectioned fiberglass assembly that is equipped with a lightning rod and ICAO lighting.

RF Reception:

Received Energy - backscatter RF captured by the antenna is coupled down the waveguide to the 4-port circulator, port 3.

Solid-State Receiver Protector - protects the sensitive Low Noise Amplifier (LNA) during the transmit pulse. Within a couple of microseconds after the transmitter pulse, the receiver protector has fully recovered and couples the returned (backscatter) RF signals to the Low Noise Amplifier (LNA).

Solid-State LNA - The LNA Noise Figure (NF) is 1.3dB and is the major

contributor to the receiver NF of 1.5dB maximum. The minimum pass band of the LNA is 5.4GHz to 5.7GHz. The saturated output power (1dB compression) of the LNA is +13 dBm.

Signal Mixer - heterodynes the received RF signals from the LNA with the STALO to produce a 30MHz Intermediate Frequency (IF) signal. The signal mixer is linear from MDS to +16dBm.

30MHz Buffer Amplifier - is used in combination with attenuator pads to set the range of the receiver from approximately -14dBm to -114dBm.

RVP8 IF Digitizer - converts the received 30MHz signals from weather and the COHO signal, into a serial digital data stream. These data are coupled to the RVP8 Digital Signal Processor via a Fiber-Optic cable.

RVP8 Digital Signal Processor - performs all of the meteorological receiver/signal processor functions in addition to generating the master timing signals for the radar system. The RVP8 serial output meteorological data contains Ray Data. Ray Data consists of the antenna pointing angles and the processed raw "moments" (T, Z, V & W). The RVP8 **BITEX** system provides full diagnostics and Go/No-Go indications for the digital receiver and signal processor. In addition, the RVP8 has a built-in test signal generator (some have built-in noise diode, or otherwise use and external generator) and "A-Scope" capability and built-in digital signal simulation, which allows the operator to inject signals and view these signals real-time within the system for diagnostic purposes.

Workstations - The RDACS workstation performs two functions. First, it functions as a local maintenance workstation and controller for the radar. Secondly, it forwards the Data Ray information to the Radar Product Generator (RPG) workstation.

Radar Performance:

Detection Range

The Meteorological detection capability of the VHDD-350C Doppler Radar System is demonstrated by solving the "Radar Range Equation". As an example, we will demonstrate the "excess margin or Signal to Noise Ratio" of theVHDD-350C detecting a 0dBZ target at a range of 100 kilometers as follows:

Radar Parameters	Value & Units
Tx Power	85.5 dBm or 350 kW
Pulse Width	2 microseconds
Wavelength	5.4 cm
Antenna gain (1 – way)	45 dB
Azimuth Beam Width	1.0 deg
Elevation Beam Width	1.0 deg
Rx NF	1.3dB

Tx Losses		Value	Units
Radome		0.5	dB
Rotary Joints (2)		0.2	dB
WG .015dB/ft	10	0.15	dB
DS Tuner		0.1	dB
Low Pass Filter		0.1	dB
Bandpass Filter		0.3	dB
Dir Coupler (2)		0.2	dB
4-Port Circulator		0.35	dB
Loss on Transmit		**1.9**	**dB**

Rx Losses		Value	Units
Radome		0.5	dB
Rotary Joints (2)		0.2	dB
WG .015dB/ft	10	0.15	dB
DS Tuner		0.1	dB
Low Pass Filter		0.1	dB
Bandpass Filter		0.3	dB
Dir Coupler (2)		0.2	dB
4-Port Circulator		0.35	dB
TR Switch		1	dB
Loss on Receive (Lr)		**2.9**	**dB**

Assuming a "full beam or pulse volume" solve for the power received (P_r) from a 0dBZ return @ 100km, using the linear equation:

$$P_r = \pi^3 P_t g^2 \theta_{az} \theta_{el} h |K|^2 Z / 2^{10} (\ln 2) \lambda^2 r^2 \qquad \textbf{(1)}$$

Where:

P_r = received power is in milliWatts

P_t = transmit power in kiloWatts

g = antenna gain in dB

θ = antenna beam width

$h = (c\,\tau)/\,2$

Where:

$c = 3 \times 10^8$

τ = pulse width in μsec (2×10^{-6})

2 = two way path of signal

$|K|^2 = |(m^2 - 1)/(m^2 + 2)|^2$ where m is the complex index of refraction. Then:

Water, $|K_w|^2 = 0.93$ and Ice, $|K_i|^2 = 0.197$

Z = the reflectivity factor dBZ

λ = wavelength cm,

r = range to the target in km.

All units in **(1)** are in the meters/kilograms/seconds system.

Combining constants and converting to conventional meteorological units:

$$P_r = \left[\pi^3 P_t h g^2 \theta^2 / 2^{10} (\ln 2) \lambda^2 r^2\right] \left[[kw]^2 z_e\right] \qquad \textbf{(2)}$$

The units in **(2)** are:

$Z = dBZ = mm^6/m^3$

Where:

$dBZ = 10_{log}\ 200\ r^{1.6}$

where: r = rainfall rate in mm/h

$P_r = (mW)$

$P_t = (kW)$

$\theta = (degrees)$

$r = 100\ km$

$\lambda = 5.4cm$

Now:

$$P_r = \left[(31)\ (350)\ (31622)^2\ (1)^2\ (300) \Big/ (1024)\ (.693)\ (29.16)\ (100)^2\right] \mathbf{X}$$

$$\left[(.93)\ (1000mm^6)\right] \qquad \textbf{(3)}$$

$$P_r = (-78.35dBm) \qquad \textbf{(4)}$$

In **(4)**, we see that 0dBZ at 100 km results in a received signal level of -78.35dBm at the receiver input.

Minimum Discernable Signal (MDS)

The MDS is described as the minimum viewable signal or discernable signal by the

operator, on the radar display, before the signal disappears into the noise. The noise on the display is determined as follows:

$$P_n = k\,T_s\,B_n \qquad \textbf{(5)}$$

Where:

P_n = Noise Power
K = Boltzmann's constant (1.38 x 10-23 watt-sec/degrees Kelvin)
T_s = System temperature in degrees Kelvin
B_n = bandwidth in Hertz

Then:

$P_{received}$ = (S/N_{power}) or Signal to Noise Ratio (SNR) **(6)**

As one can readily see in **(5)**, the noise floor varies in the radar system based on the system noise temperature. Therefore keeping the ambient temperature low in the receiver cabinet, improves the MDS, by lowering the system noise power (level).

Noise Figure (NF) is a "figure of merit" for the receiver. In other words, a lower NF yields a better MDS or better radar detection. The NF is, in the most part, determined by the front end of the receiver. Items that have more loss than gain add directly to the NF and items that have more gain than noise contribution act to lower the NF. For instance any loss, such as the loss in the connection between the T/R switch and the LNA contributes directly to the NF, because it has no gain, just loss.

The IEEE settled on a standard of 290 degrees Kelvin temperature (D.O. North, 1942) as a baseline to provide a standard for comparisons between, and expectations for receiver performance measurements.

Calculate MDS

Using logarithms and 290 degrees Kelvin as the IEEE standard:

$$MDS = -174db + NF + SNR + 10\log bw/Hertz \quad \textbf{(7)}$$

Where:

-174dB = the Noise Floor in a 1 Hz bandwidth

10log bw/Hertz = correction for bandwidths that differ from 1 Hertz, and

a Pulsed receiver matched filter = 1/Pulsewidth or $1/\tau$

Converting to a more often used term for 1MHz bandwidth:

$$MDS = -114db + NF + SNR + 10\log bw/MHz \quad \textbf{(8)}$$

Where:

The bandwidth is corrected for a 1μsec pulse (-174dB + 60dB = -114dB)

Then, using the radar parameters in this example above and solving for a 2μsec pulse:

$$MDS = -114dB + 1.3dB + 0 + -3dB = -115.7dBm, \text{ with } 0dB\ SNR \quad \textbf{(9)}$$

Solving for I_0

The minimum signal detectable in the system **(I_0)** includes the losses in the system. These losses are: Tx circuit loss, Rx circuit loss and Gaseous attenuation of the intervening atmosphere between the radar and the weather target of interest.

Then:

$$I_0 = MDS + l_g^2 + l_t + l_r \quad \textbf{(10)}$$

Where:

$MDS = -115.7$

l_g = loss due to atmospheric gases (C-band 2 way = .014dB/km) or 1.4dB

l_t = transmit loss 1.9dB

l_r = receive loss 2.9dB

Then:

$$I_0 = -115.7 + 1.4 + 1.9 + 2.9 = -109.5\text{dB} \quad \textbf{(11)}$$

Signal to Noise Ratio (SNR)

The signal to noise ratio is the received signal, $P_r - I_0$ from solutions **(4)** & **(11)** above.

Then:

$$SNR = (-78.35\text{dBm}) - (-109.5\text{dB}) \quad \textbf{(12)}$$

$$SNR = 31\text{dB}$$

Range Normalization:

Using the above analysis, one can readily determine that two problems exist when using the radar to make actual measurements, or estimations, of rainfall rate:

- Even small to moderate rainfall rates begin to have strong returns (Pr) in practice, where rainfall rates may be 60dBZ – 75dBz
- Without compensation for loss due to the difference in intervening range

difference between two identical targets, the display would make the closer target appear significantly larger, since the *Pr* varies at a rate of 1/range^2.

The solution to this dilemma is to apply a range normalization factor to *Pr* which acts to compensate for the deficiencies above. Range normalization acts similar to a Sensitivity Time Constant (STC) receiver bias circuit in conventional radar, but based on a $1/r^2$ curve. The Range Normalization Curve begins as an attenuator a 0 kilometers range and decreases attenuation at the $1/r^2$ rate out to maximum range.

By adding the amplitude of the curve to *Pr,* close in range targets are attenuated and long range targets are not attenuated. The result is that a *normalized* target of certain intensity, use 0dBz as an example, becomes the same amplitude at any range. Thus with a color display representing amplitude, 0dBz precipitation radar reflectivity remains the same color at all ranges, as long as the radar beam (pulse volume) is filled.

Oral Review