A MODERNIZATION PLAN FOR UGANDA'S METEOROLOGICAL SERVICES

Submitted as the Final Report of the Feasibility Study for the Uganda Department of Meteorology Modernization, funded by the United States Trade and Development Agency.

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EXECUTIVE SUMMARY

INTRODUCTION

MDA Information Systems LLC (hereinafter MDA) has prepared this Modernization Plan for the Uganda Department of Meteorology and incorporated extensive coordination with Department staff including site visits to key weather system stations located throughout the country. The study was funded entirely by a grant from the United States Trade and Development Agency in keeping with its mission to support and promote priority development projects in emerging economies, create sustainable infrastructure and economic growth in these partner countries, and foster trade between them.

The ability to monitor, report and forecast weather conditions and to issue warnings is critical to Uganda's social and economic development. Extreme weather events such as severe thunderstorms, hail, damaging winds, flash floods and drought cause substantial losses of life and property that could be mitigated with improved monitoring and forecasting capabilities.

Uganda has international responsibilities and obligations to provide weather data to member states of the World Meteorological Organization and the International Civil Aviation Organization. Timely data provided to their centers is made available worldwide to support national and international weather services and the operations of international airlines. Uganda, in turn, receives similar data from these organizations for its internal use.

It is incumbent on the Department of Meteorology (DoM) to modernize its meteorological observing, forecasting and warning technology and expands its services in order to more effectively achieve its mission. The reorganization of the DoM into the Uganda National Meteorological Authority (UNMA) will serve to enhance the ability to meet this challenge, including access to higher levels of funding for capital investment, maintenance and staff training. In this report, DoM will refer to the Uganda national weather service in the period up to September 2012, while UNMA will refer to the Uganda national weather service in the period from October 2012 onward.

PRESENT OPERATIONAL STATUS

The Department of Meteorology will face many technical and management challenges in its transition to an Authority. Among these are:

- Uganda's meteorological system does not adequately meet the needs of its citizens for simple access to past weather and climate data, present conditions and hazards, or detailed and accurate forecasts of future weather.
- Weather observing equipment is in a state of disrepair with many sensors nonfunctional, thereby limiting its utility.
- There is no operational lightning detection network or weather radar, which are essential means of identifying and predicting thunderstorm activity.
- Communication between weather station locations and the National Meteorological Center in Entebbe is inadequate; in many communications can only be initiated from Entebbe.
- Without lighting detection, weather radar or an adequate communications system, it is impossible to provide timely hazardous weather warnings.
- Essential and preventive maintenance of weather sensors and other equipment is lacking. Spare parts and supplies are often unavailable. The result is that many observing systems do not function, and those that do suffer compromised accuracy and reduced measurement frequency.
- Field and headquarters staffs have the required basic technical skills and demonstrate a desire to carry out their responsibilities, but are frustrated with the inadequacy of the equipment and facilities provided, and the lack of advanced and recurrent training.
- Uganda is not fully meeting its responsibilities for weather reporting to the World Meteorological Organization.
- By failing to meet its responsibilities to the International Civil Aviation Organization, Uganda is risking the safety, reliability and efficiency of international and domestic flight operations.

- Continual under-funding of operating budgets has contributed to many of the deficiencies above.

The existing weather data collection and dissemination program in Uganda is not meeting the expectations and needs of its citizens and the international community. The challenge for the modernization process will be for the Uganda National Meteorological Authority to invest in the equipment, resources and personnel that can deliver a dramatically improved weather programs and information services at a cost that is commensurate with the financial resources available.

A ROADMAP TO MODERNIZATION

The task ahead of the Uganda National Meteorological Authority (UNMA) may seem daunting, but it is doable by implementing a strategically balanced approach to educating and training personnel, updating equipment and providing improved communications.

MDA recommends that the implementation plan proceed concurrently on several key fronts during the first five-year period:

- The first step should be identification of a program manager, preferably a meteorologist, with experience managing the implementation of a large capital and human investment program. This individual will report directly to the Executive Director of the UNMA and have authority over all personnel.
- The next priority is the establishment of robust, high-bandwidth internet connections at all UNMA facilities. This will involve hard-wired Internet connections at Headquarters and Entebbe with a minimum speed of 2 Mbps, and at least mobile 3G+ Internet connections at all field offices, with routers allowing connection of all staff computers to a Local Area Network (LAN). This will allow rapid transmission of weather data and imagery to all UNMA staff.
- A continuous training program for UNMA staff must be developed by the National Meteorological Training School, which should be incorporated into the UNMA. The program should include the use of the Internet for distance learning, periodic training sessions run by the school with guest lecturers drawn from fully modernized national weather services, and formal education leading to advanced degrees for qualified staff.
- The accounting and inventory management program must be improved so that an up-to-date record of the condition of all UNMA equipment is maintained, and a workable schedule for maintenance and repairs is established.
- An outside contractor should be retained to provide regular and preventive maintenance including spare parts and supplies depot to all equipment. The contract should include an option to transfer to maintenance capabilities to UNMA staff over time.
- As a first step toward developing a capacity for detailed real-time monitoring of weather conditions, a total lightning detection system covering at least the region within a 200 km radius of Entebbe should be acquired as soon as possible. By 2014 this should be expanded to the entire country. Data from this system should be available in real time to all UNMA forecast staff, and should be the basis of a watch and warning program for severe weather.
- Additional radiosondes should be acquired to support twice-daily upper air soundings.
- UNMA should develop a secure, continuously updated archive of all automated sensor data using computer resources currently available to the department at NOAA. Observations should be available in this database within 10 minutes of measurement. Global numerical weather prediction (NWP) model forecasts interpolated to automated station locations should be placed in the same database, and model output statistics should be continuously calculated. These model output statistics should form the basis of a high-resolution comprehensive five-day forecast for all of Uganda, that should be presented in graphical form on the UNMA website. The functions can be transferred to UNMA computer resources as they become available.
- To support modern weather forecast operations, the National Meteorological Center (NMC) at Entebbe should move to a modern, air conditioned facility (purchased or built to order), with space for the National Meteorological Training School, a Quality Data Center, a Radar Operations Center, a Calibration Laboratory and headquarters office space. Included in this component is the installation of modern computer workstations and servers, adequate to generate calibrated weather forecasts based on numerical weather forecast models, to generate forecast graphical imagery, and maintain and provide access to the UNMA website.

- Installation of an S-band Doppler weather radar near the new UNMA Headquarters and, for operational purposes, not to be closer than 30 kilometers from the Entebbe Airport. Radar data should be made available on the UNMA website for access by all UNMA staff and the interested public.
- Field offices should be improved to allow secure 24 hour operations, and provide a stable environment for personnel and equipment.
- Installation of nine new automated weather systems and additional scientific sensors for synoptic observations. Together with the upgrade of the twenty-three existing automated weather systems, this will form a Mesonet that will ultimately expand to include 50 sites. As synoptic stations transition to automated weather observations, personnel currently performing observations should be transitioned to communication and calibration functions. Some assigned to communications should be embedded in District government offices to assure effective communication of weather and climate risks to responsible authorities.
- Installation of automated weather observing systems (AWOS-3PT) meeting International Civil Aviation Organization standards at 12 airports.

The period between years 6 and 15 broadens the reach of the modernization program. Key components are:

- Installation of an S-band radar near Lira some 120 km from both Gulu and Soroti.
- Installation of an S-band radar positioned some 30 km west of Mbarara, perhaps near Kabwohe.
- Installation of two AWOS-3PT units at Kidepo and Pakuba.
- Installation of 18 automated weather systems to replace the aging agrometeorological stations and complete the Mesonet.
- Upgrades to the newly deployed information and communication technology at all operational sites are desirable to ensure such capabilities as backup power, fire prevention and suppression, and redundant communications linkages.
- Advanced staff training for development, operation and interpretation of a Uganda-focused mesoscale numerical weather prediction model.
- Assumption of equipment maintenance functions or continuation of the contractual arrangement, including a mobile calibration facility to maintain calibration of AWS and ASOS stations.

FINANCING

A key factor that has inhibited the Uganda Department of Meteorology from improving its weather system was a lack of adequate funding, which in turn led to less than desirable strategic implementation practices. The formation of the Uganda National Meteorological Authority is intended to help overcome this limitation as it may now carry out its operations with a certain level of autonomy, including a higher level of involvement with the Ministry of Finance.

The MDA Team has identified options to obtain the necessary funding to bring the recommended modernization plan to fruition. These options will primarily emanate from multilateral institutions and bilateral donors, whose funding will complement funding from the Government of Uganda through direct investments and cost recovery. Specifically, for the short-term (first five years) of the modernization program, the UNMA should focus funding sources such as multilateral institutions such as the World Bank Group through its International Development Agency, the African Development Bank, United Nations Development Program, The Arab Bank for Economic Development in Africa, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, and the United States Agency for International Development are key potentials for the UNMA. Uganda has a proven track record with several of these organizations, which should facilitate their further engagement in the UNMA modernization program. In this regard, it is important to recognize that each of these institutions has specific goals and objectives associated with the types of projects that they fund. Accordingly, for the purposes of developing a sound funding strategy, it is essential that the UNMA, in concert with the Ministry of Finance, engage in face-to-face discussions with these institutions, and that they begin as early as practical. These meetings serve the primary purposes of conveying Uganda's priority to enhance its meteorological capability, increase and diversify the UNMA client base and revenue streams, and detail its goals, objectives and strategy for implementation. Concurrently, the institutions can suggest those types of projects that best fit its funding priorities.

Only through such discussions and other engagement with these institutions will the UNMA be positioned to maximize the benefit these institutions can provide in significant funding levels.

As the modernization program transitions to the medium- and long-term periods (years 6 through 15), UNMA should begin to diversify its funding sources to include:

- Export credit agencies such as the United States Export Import Bank of the United States and other institutions that promote exports from their respective countries.
- Regional development institutions including the Eastern and Southern Africa Trade and Development Bank (PTA Bank) and the East African Development Bank
- Commercial banking institutions that are active in Uganda such as Stanbic Uganda, Citibank, and the Development Finance Company of Uganda Bank Limited (DFCU Bank)
- Suppliers credits, particularly those experienced with foreign transactions involving any of the abovementioned funding sources

The experience and track record gained from the multilateral institutions will be especially relevant to these other sources of funding in the latter years of the modernization program.

Overall, funding for the implementation of the modernization program appears favorable. Uganda has an established track record with some of the institutions identified above and many are inclined to favor projects that support agriculture, transportation and human capacity development. It is worth repeating that having knowledge of each institutions goals and priorities will be a key element in securing funding in the amounts necessary. The UNMA with the active participation of the Ministry of Finance should begin discussions as soon as practical with those institutions that are best suited to meet the short-term needs of the modernization program. They should be prepared to review and highlight these factors of the UNMA modernization program:

- Project concept and market outlook
- Management and staff capacity
- Technical viability
- Financial viability
- Governance principles

CAPITAL AND OPERATING BUDGETS

The 15-year modernization program envisions a capital investment of about US$32 million, of which nearly one-half is required in the initial five years. This capital requirement can be met through the financing options identified above, provided that the UNMA can demonstrate a revenue stream and management of operating expenses to generate an annual positive balance. The major revenue sources are government direct billing, the private sector and government reimbursements. Operating expenses, particularly in the initial years, focus on personnel and training, and equipment maintenance. Operating revenues are not anticipated to exceed operating costs and the shortfall is in the range of US$5 million to US$9 million annually. Consequently, it will be necessary for the government to subsidize the UNMA in this amount in order to achieve at least a breakeven operation. Government subsidy of national meteorological services is not uncommon. It occurs in the United States, Canada and other countries. To assist with this makeup of the shortfall, the UNMA, through the government (Ministry of Finance), should seek other sources that include grant and loan funding from multilateral institutions and bilateral donors.

Modification to the capital investment program can also result in improved financial performance. For example, there may be merit in delaying the installation of the second and/or third weather radars that carry relatively high establishment and operating costs. In this regard, the UNMA should explore the joint implementation and maintenance of weather radars with Kenya and other Eastern African Community members. Weather radar data is not fixed by national boundaries and strategically located weather radars can provide coverage to serve multiple users.

Irrespective of modifications to the capital investment program, it is incumbent on the UNMA to find means to enhance operating revenues and control expenses. Revenue enhancement can be realized by demonstrating the value of improved meteorological services and products to the Civil Aviation Authority, which is a primary user of the data. Opportunities also exist in certain key economic sectors such as banking, insurance, oil and gas exploration and recovery, agriculture and tourism. This will require the UNMA to develop and implement a marketing program targeted to each sector. Actively

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engaging the customer and determining user-specific needs in terms of product/service, frequency of update and form of delivery generates a higher value of service (revenue.)

ECONOMIC RETURN

Any government investment needs to demonstrate that it can, aside from meeting essential requirements for public health, safety and welfare, provide an economic return. This begs the question whether the necessary expenditure of capital and operating costs for the modernization program is justified. The World Meteorological Organization has addressed this matter through the conduct of benefit/cost studies and found the ratio to be between five- and ten-fold. Even at the 5:1 level, this is an impressive benefit/cost ratio to demonstrate that funds spent on weather, climate and water-preparedness can prevent much larger sums from being spent on disaster-related economic costs.

An investment in the meteorological services provided by the UNMA through implementation of the modernization program translates into more added value to the various sectors of the Ugandan economy and the social framework of the country, particularly because of its susceptibility to weather and climate impacts.

FINDINGS AND RECOMMENDATIONS

There is an immediate and continuing need to modernize the conduct and delivery of meteorological services in Uganda and the recent formation of the Uganda National Meteorological Authority is a major first step toward realizing that objective. The present level of meteorological services and products is lacking in terms of international standards, and the deployment and funding of staff, equipment and facility resources has deteriorated to account for this status.

A rational and staged modernization program has been identified to bring the modernization program on line. This implementation process considers the availability of funding from a variety of sources, each of which is considered viable. Operating revenues are available through the fair administration of fees for the services and products provided to the public and private sectors. Operating expenses can be managed to yield efficiencies and take advantage of economies of scale, and certain functional activities can build on the experience of the private sector in meeting short-term operating requirements. The initial years of the implementation program will rely on government funding support and that from multilateral/bilateral donor support. The required level of such financial support is highest in these initial years given the major capital investment required to offset the lack of previous outlays. Future revenue streams should lessen the dependence on these funding sources, provided that the UNMA implements an aggressive marketing program to raise the levels of incremental income that can be accrued from the Civil Aviation Authority and the private sector. This takes advantage of anticipated increases in aircraft activity and the enhanced levels of meteorological services and products offered to this and other government agencies and the private sector.

The Uganda National Meteorological Authority should obtain strategic management assistance during its initial years. Seasoned, experienced advisors can best aid the Authority in the implementation of the modernization program. This assistance will prove to save time and resources as the Authority steps forward to meet the challenges ahead. There is much to do and the learning curve is steep, but the outcomes will demonstrate that implementation of the meteorological services modernization program is worth it all.

ACKNOWLEDGEMENTS

The MDA Team takes this opportunity to recognize those staff from the UNMA that contributed their knowledge, experience and guidance during the preparation of the modernization program. The candid interaction that was demonstrated during the time spent together served to make this a successful and professionally rewarding assignment. We were pleased to have been a part of the process and stand ready to further support the UNMA in its implementation of the modernization program. In particularly, we would like to thank the following individuals:

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At the Ministry of Finance: Ms. Jennifer Muwuliza, Ms. Joyce Ruhweeza,

At the Ministry of Agriculture: Ms. Annunciata Hakuza

At the NARO: Director General Dr. Emily Kabushenga Twinamasiko; Senior Research Officer Dr. Everline Komutunga

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At the Uganda Air Force: Brig. Gen. Samuel Turyagyenda

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1 INTRODUCTION

This is the final report of the Feasibility Study for the Uganda Department of Meteorological Service Modernization, undertaken by MDA Information Systems LLC (MDA) at the behest of the Uganda Department of Meteorology (DoM), with funding the United States Trade and Development Agency. Its goal is to lay out a clear path by which the DoM, soon to be the Uganda National Meteorological Authority (UNMA), can provide superior weather forecasting services, watches and warnings of dangerous weather, accurate and comprehensive flight information for civil aviation, and quality data services to all interested parties, in a financially sustainable way, for the benefit of Uganda's citizens.

It begins with a review of Uganda's climate in Section 2, followed by a discussion of Uganda's socioeconomic conditions as they relate to weather and climate in Section 3. Section 4 reviews the current status of Uganda's meteorological infrastructure and personnel, including observing stations, forecast offices and the central office, and the present state of communications between the Department of Meteorology and the various consumers of weather and climate information in Uganda.

The report then turns to MDA's recommendations for improvement and modernization of meteorological infrastructure, operations and services. Section 5 describes the meteorological sensor equipment MDA believes necessary for delivery of improved forecasts and climate data. Section 6 provides a list of United States companies that can supply this equipment. Section 7 describes in detail the organizational elements of modernization: how tasks including observation, data management, computation, forecasting and communications should be distributed among UNMA personnel and facilities. Section 8 details the procedures that should be followed to deliver quality data, watches, warnings, and forecasts to a range of clients including the general public, the aviation community and agricultural interests, and to maintain the good working order of UNMA equipment. Section 9 presents a financial model, including a comprehensive Capital Improvement Program, of the revenue streams and expenses of a modernized UNMA, with reference to the financial history of the DoM. Section 10 details the resources available for credit and financial assistance from local and regional banks, bilateral and multilateral lender and international development aid organization, and includes recommendations on which organizations should be approached to meet which needs. Section 11 synthesizes all recommendations into a step-by-step implementation plan. Sections 12 and 13 discuss the environmental and developmental impacts of the meteorological modernization process. Section 14 contains a tabular summary of recommendations, and Section 15 contains the capital investment program, a tabular summary of major equipment needs and their costs, organized by proposed date of purchase. Finally, Section 16 contains a brief conclusion, and Section 17 contains references.

MDA is convinced that these recommendations, assimilated and adjusted as conditions in Uganda evolve, will result in dramatic improvements in the quality, accessibility and timeliness of meteorological services in Uganda.

2 CLIMATE OF UGANDA

2.1 PRECIPITATION VARIABILITY

Gridded precipitation data is available throughout the tropics at 0.25º latitude and longitude resolution from the NASA TRMM satellite. All calculations reported here derive from NASA's 3B43 data set. For the years 1998-2011, annual mean precipitation averages about 1.3 m over Uganda (Figure 3.1). Some precipitation generally falls in all months (Figures 3.2, 3.3), with rare exceptions, but averaged over the whole country, 53% of each year's precipitation usually falls in the five months of April, May, August, September and October, while only 14% falls in January, February and December. Interannual variability is significant (Figures 3.4 and 3.5). Individual years may have precipitation amounts from 12% below to 12% above the long-term mean. Precipitation tends to occur in short, intense convection events. Average daily rainfall on days when more than a trace of rain fell, in the limited synoptic station data archived at MDA Information System (21382 daily reports from eight stations), was 9.7 mm. Ten percent (10 %) of daily reports on days with more than a trace of rain had more than 25 mm of rain, with only 2% above 50 mm.

It is of interest to compare rainfall retrieved by a range of sensing techniques. Figure 3.6 shows the interannual variability of precipitation as presented in NASA's 3B43 product and in the monthly station gage records. Monthly variations at individual stations agree very well between the two time series (not shown, correlation coefficients are typically above 0.80), but this is to be expected, since the 3B43 product includes station data. However, the annual mean numbers averaged over all stations diverge very substantially, especially after the year 2008. This divergence is puzzling, since the TRMM sensor is known to have very little secular trend in sensitivity. Close analysis of the correlations between the 3B43 and station records indicate a fall-off of correlations in the last two years, which indicates that the 3B43 product may have lost access to the station data at those times. This suggests that the fall-off in annual mean precipitation in the last two years of the 3B43 data is an artifact of the calibration change. On the whole, the trend in precipitation in Uganda is upward, but the disagreement between the two observing systems and the lack of a comprehensive high resolution rain gauge network make it difficult to assess the significance of the trend. A positive precipitation trend in Uganda is consistent with model predictions of the impact of human greenhouse gas emissions on precipitation (IPCC, 2007).

Figure 3.7 compares the climatology (average of the ten years 2003-2012) of lightning flash rate from NASA's Optical Transient Detector with the climatology of rain fall from the 3B43 data set, using 0.5° latitude-longitude grid boxes over the Uganda region. The data point cluster in a fairly compact form around a single curve. This suggests that total lightning detectors may prove able to provide an adequate high resolution retrieval of precipitation over Uganda. The OTD captures only a small fraction of lightning flashes, so the noisy curve found here does not preclude a much better fit using a sensitive in situ total lightning detection network, if that is installed in Uganda.

2.2 TEMPERATURE VARIABILITY

Uganda's climate is, over much of its area, classified as Aw in the Koeppen-Geiger system: Tropical Savannah, with the coldest month's temperature warmer than 18 °C, and the driest month's precipitation less than 60 mm (Peel et al., 2007). Daily maximum temperatures have a slight seasonal cycle, averaging about 25.4 ºC in April, and 27.3 ºC in February in Entebbe. Day to day variations are somewhat larger, with a standard deviation of daily mean temperature over all days of 1.5 ºC. Similarly, daily minimum temperature range from 18.1 ºC in August to 19.1 ºC in February, with a standard deviation over all days of 1.3 ºC. 12 ºC and 36 ºC represent record low and high temperatures for Kampala. In select locations, temperature can be a little more extreme. Temperatures are typically right around the freezing temperature in the high peaks of the Ruwenzori mountains, and daily high temperatures average around 30.5 ºC in February in the Albert Nile valley, which is at lower elevation than the rest of the country.

Gridded temperature data can be obtained from the U.S. National Weather Service Climate Forecast System Reanalysis, version 2, which provides 6 hourly data for the years 1981 through the present, again at 0.5º latitude and longitude resolution. Annual mean temperatures are correlated with altitude, with the highest values in the north and west, and the lowest in the south and west (Figure 3.8).

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Seasonal maps show that this pattern is fairly consistent through the year (Figure 3.9). The reanalysis data shows somewhat larger annual cycles in temperature (about 3ºC) for the country as a whole than those observed at Entebbe (Figure 3.10). Figure 3.9, shows the annual cycle of temperature averaged over all of Uganda: it varies from a high of 24.7 °C to a low of 21.2 °C. A map of the March-August temperature difference is shown in Figure 3.11. The largest values, around 5ºC, are in the vicinity of Kitgum, while values are near zero around Mbarara and Bushenyi. The alternation of rainy and dry weather produces an annual variation in the size of the diurnal temperature cycle, shown in Figure 3.12. Largest values (11 °C) are in the January-February dry season, while lowest values are in the April rainy season (9 °C).

Long term temperature trends in all of East Africa are unambiguously positive. Figure 3.13 shows that temperatures around Uganda have risen by about 0.8 °C since the 1950's, consistent with the global trend forced by human carbon dioxide emissions.

2.3 AIR POLLUTION

Air pollution is poorly observed *in situ* in Uganda. No station outside of Entebbe includes even automated visibility monitoring equipment, let alone observations of particulate mass or commonly measured pollutants such as carbon monoxide or ozone. Yet overwhelming dependence on charcoal for cooking fuel yields visible haze and a noticeable scent of wood smoke throughout Uganda. This level of particulate pollution is typically associated with strong negative health impacts (e.g. Pope et al., 2009), so improved observation of air pollution will be a highly important component of Meteorological modernization.

Satellite observations of *column* carbon monoxide are available from the NASA MOPITT instrument, and observations of aerosol optical depth are available from the NASA MODIS instrument, although these lack specificity to boundary layer conditions. Optical depth variations from the MODIS instrument on the TERRA satellite are presented in Figure 3.14. They show a regular variation from values between 0.2 and 0.3 in July, to values near 0.1 in the rainy seasons in spring and fall. These values are comparable to, though on average a little higher than, typical values in the U.S. Northeast. Similarly, column integrated carbon monoxide levels (available here: http://www.acd.ucar.edu/mopitt/MOPITT/data/plots5n/maps_mon.html) are typically on par with levels in the Eastern United States, though fortunately not nearly as high as in neighboring Congo.

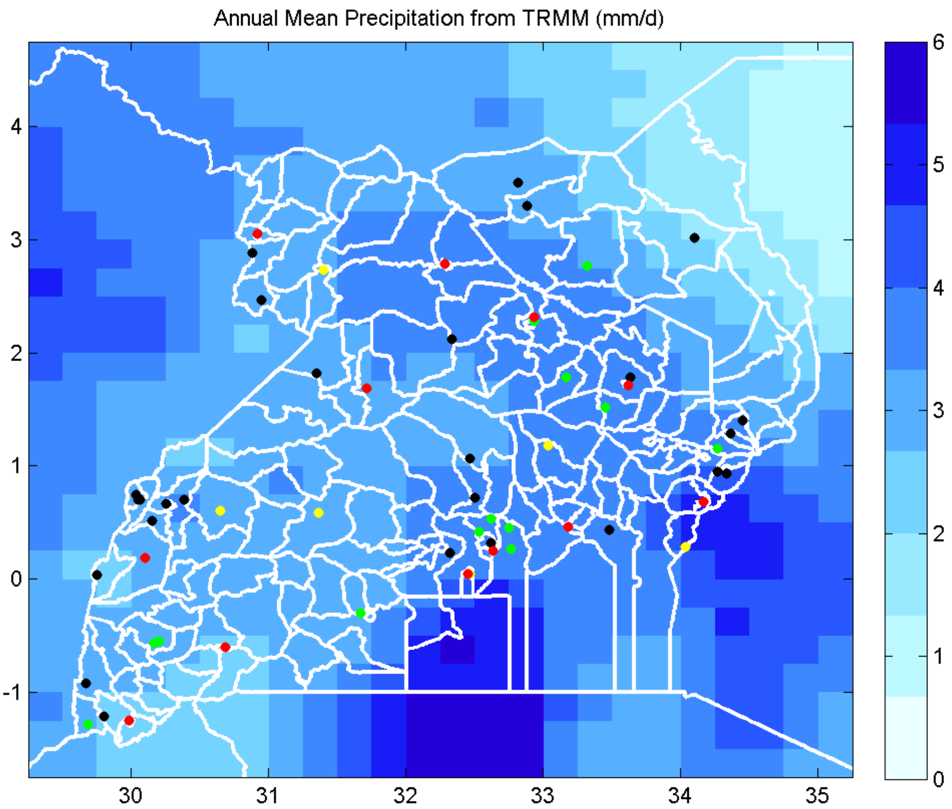

Figure 2.1: Annual mean precipitation for the years 1998-2011 over Uganda, calculated using NASA's 3B43 calibrated TRMM monthly rainfall product, at 0.25º resolution. Uganda's administrative district boundaries are shown in white, and observations stations are marked: red points are synoptic stations, green points are agromet stations, yellow points are hydromet stations, and black points are rainfall stations. Mean value for Uganda is 3.6 mm/d or 1.3 m/yr.

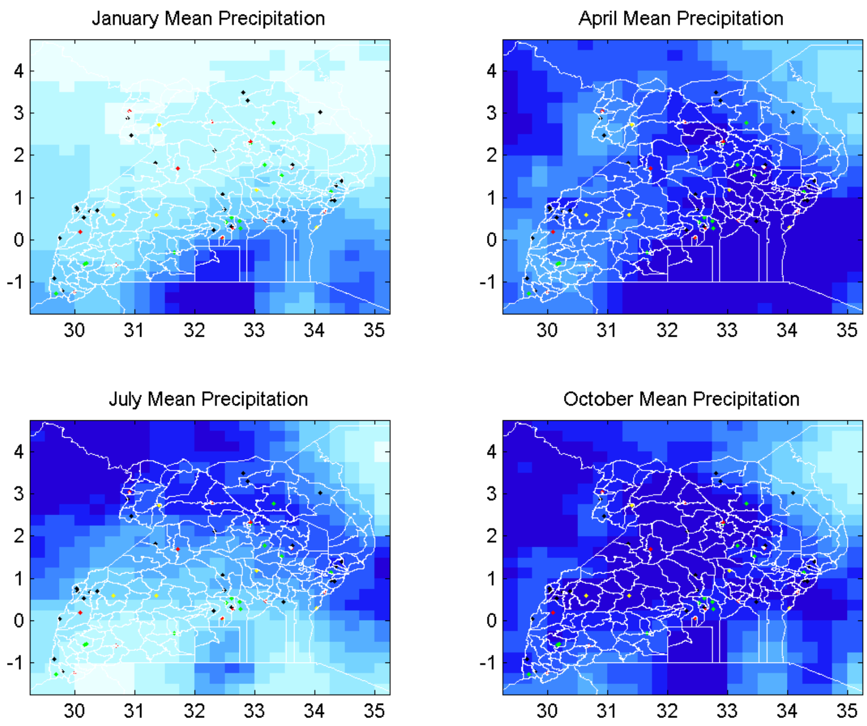

Figure 2.2: Monthly mean precipitation for the years 1998-2011 from the NASA TRMM precipitation product. Color scale same as in Figure 1.

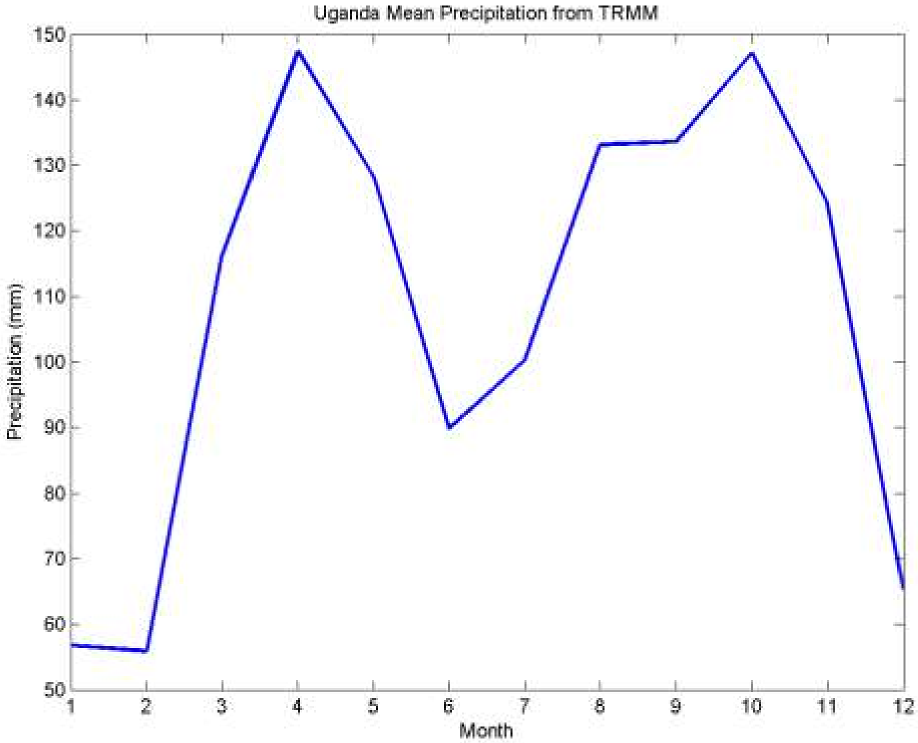

Figure 2.3: Monthly mean, Uganda mean precipitation for the years 1998-2011 from the NASA TRMM precipitation product.

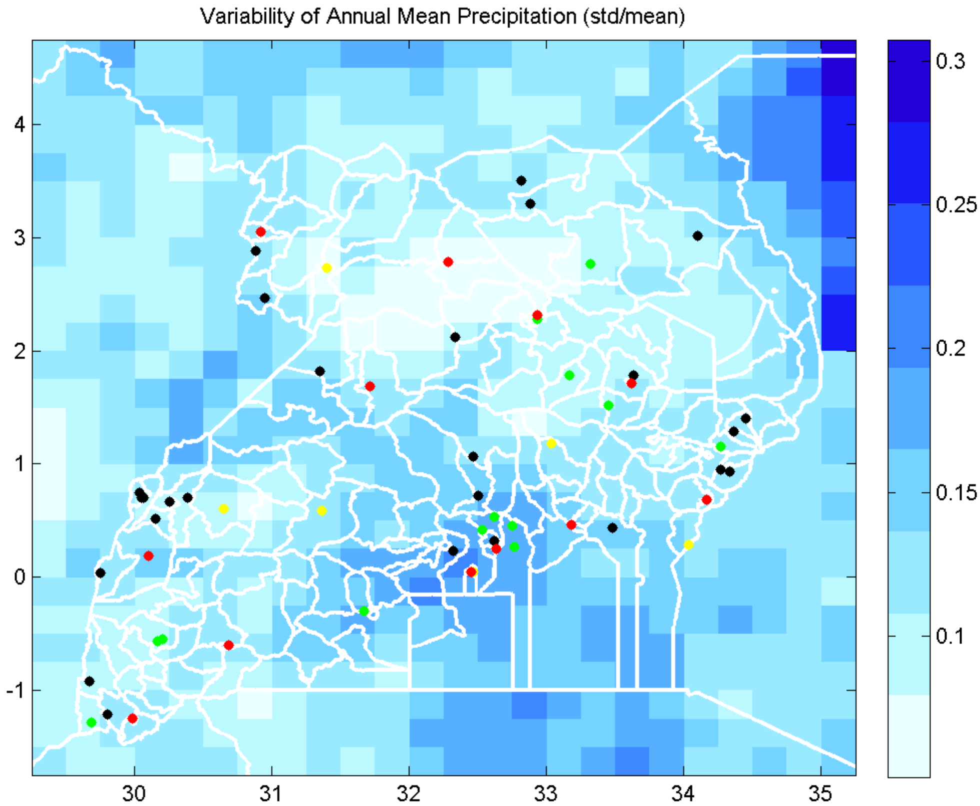

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Figure 2.4: Standard deviation of annual mean precipitation divided by mean precipitation to give fractional interannual variability of precipitation.

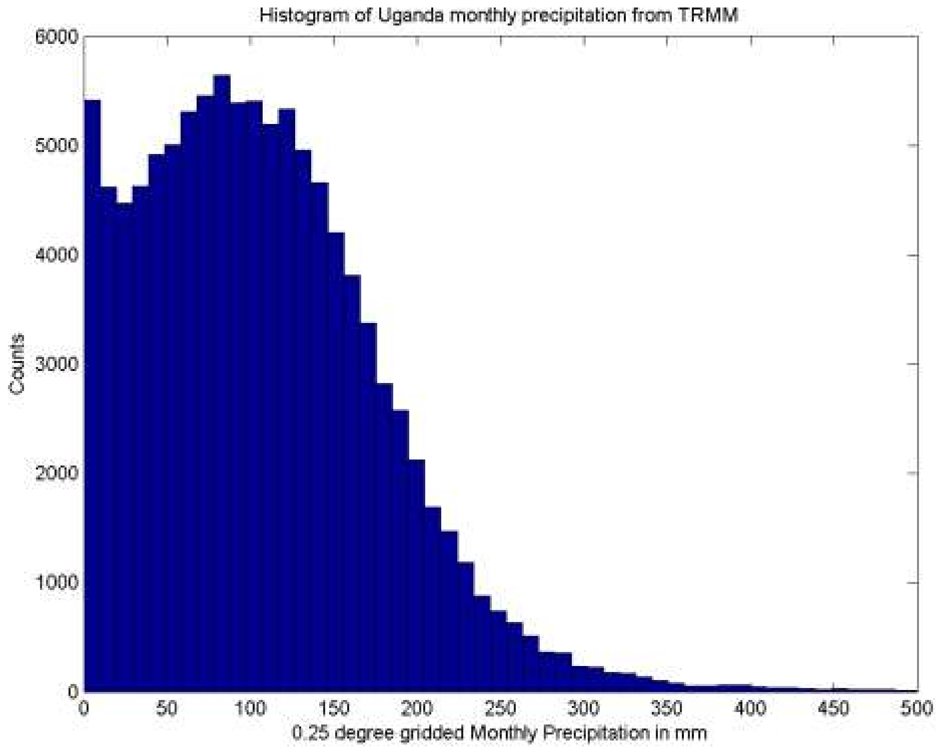

Figure 2.5: Histogram of monthly mean TRMM 0.25º gridded precipitation over Uganda.

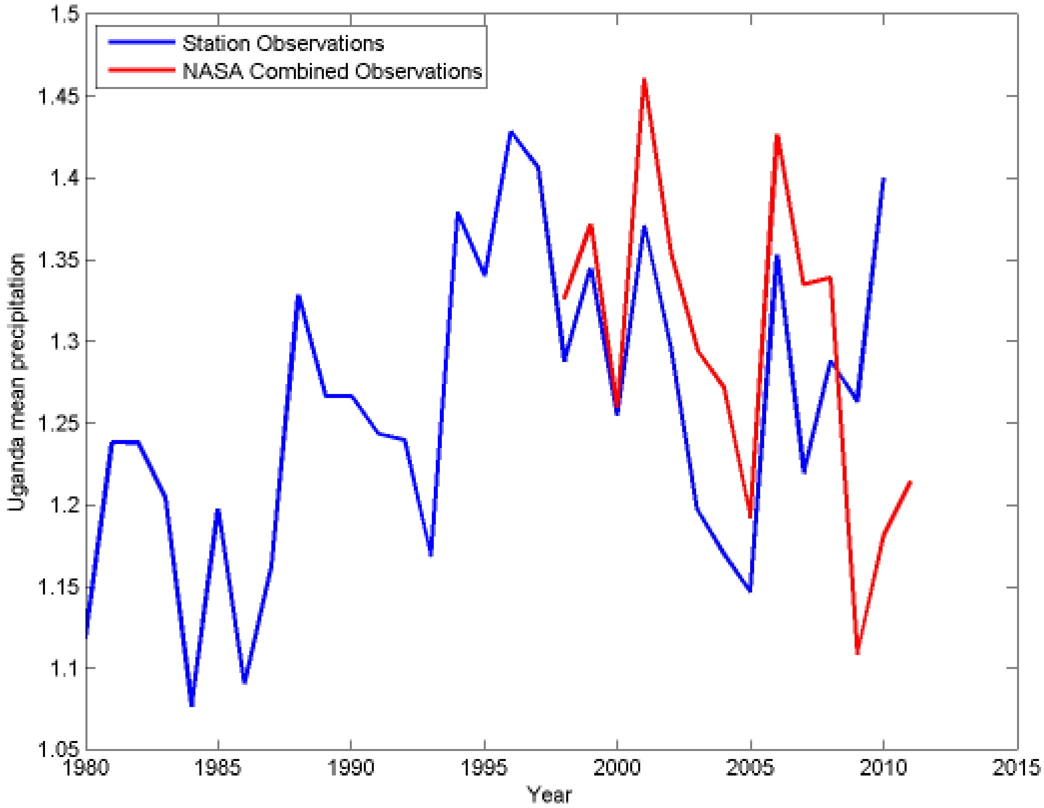

Figure 2.6: Annual mean precipitation averaged over all Ugandan synoptic stations, compared with annual mean precipitation in m from the NASA TRMM-based data set, interpolated to Ugandan synoptic station locations.

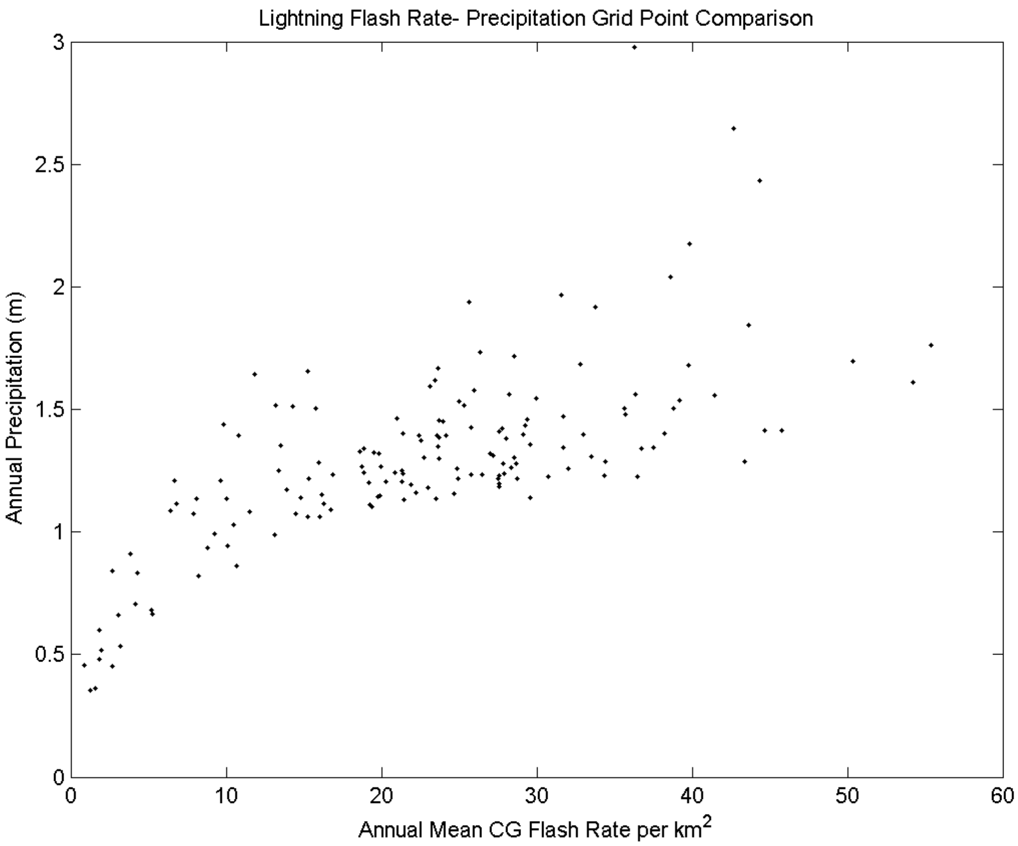

Figure 2.7: Climatological Comparison of 15 years of lightning data versus 10 years of Precipitation data, using 0.5 degree grid squares.

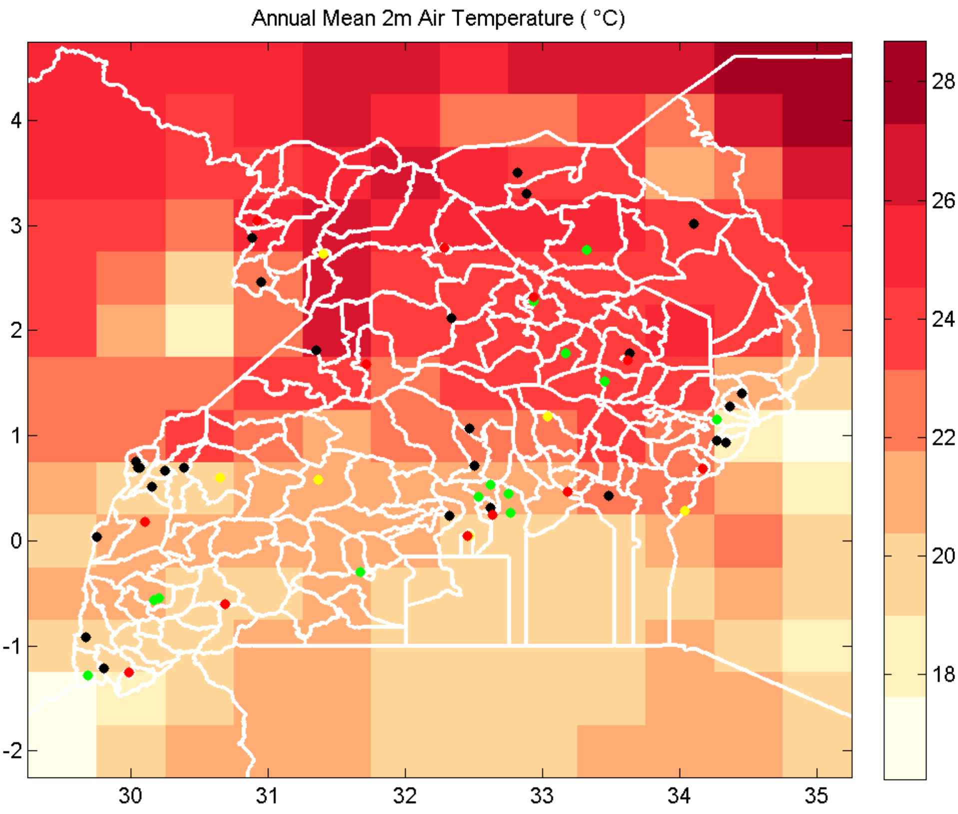

Figure 2.8: Annual mean 2m air Temperature from the U.S. National Weather Service Climate Forecast System Reanalysis, version 2, for the years 1981-2010. Station markings are as in Figure 1.

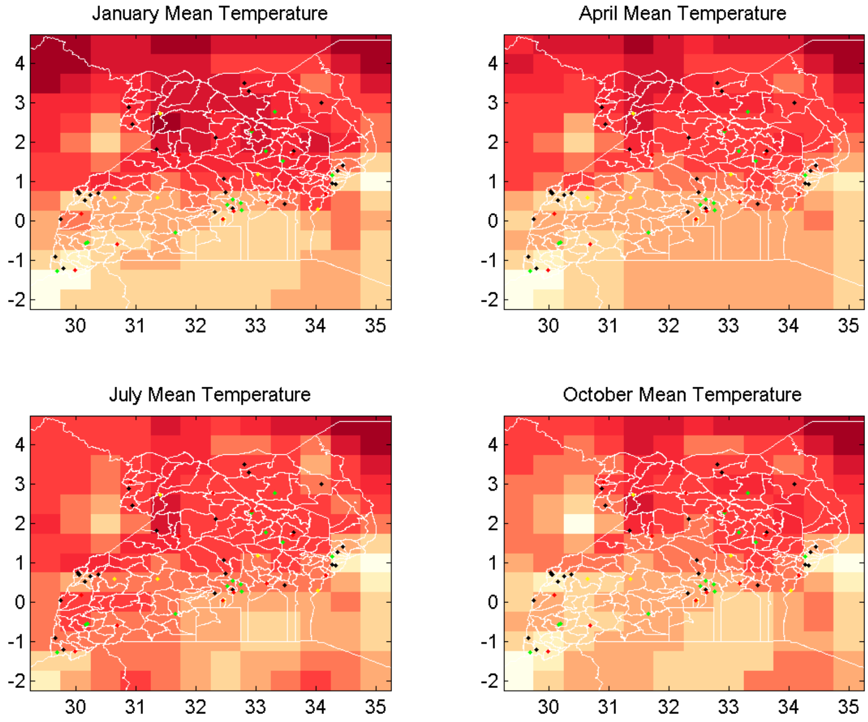

Figure 2.9: Monthly mean temperature from the CFSR for the years 1981-2010. Color scale same as in Figure 8.

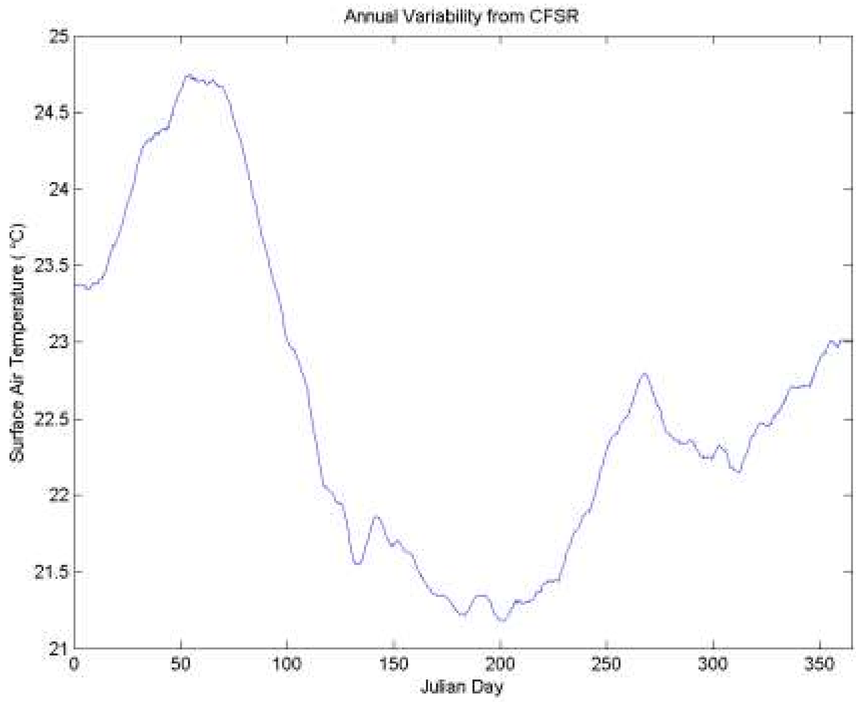

Figure 2.10: Uganda seasonal temperature cycle averaged over the years 1981-2010 from the CRSR.

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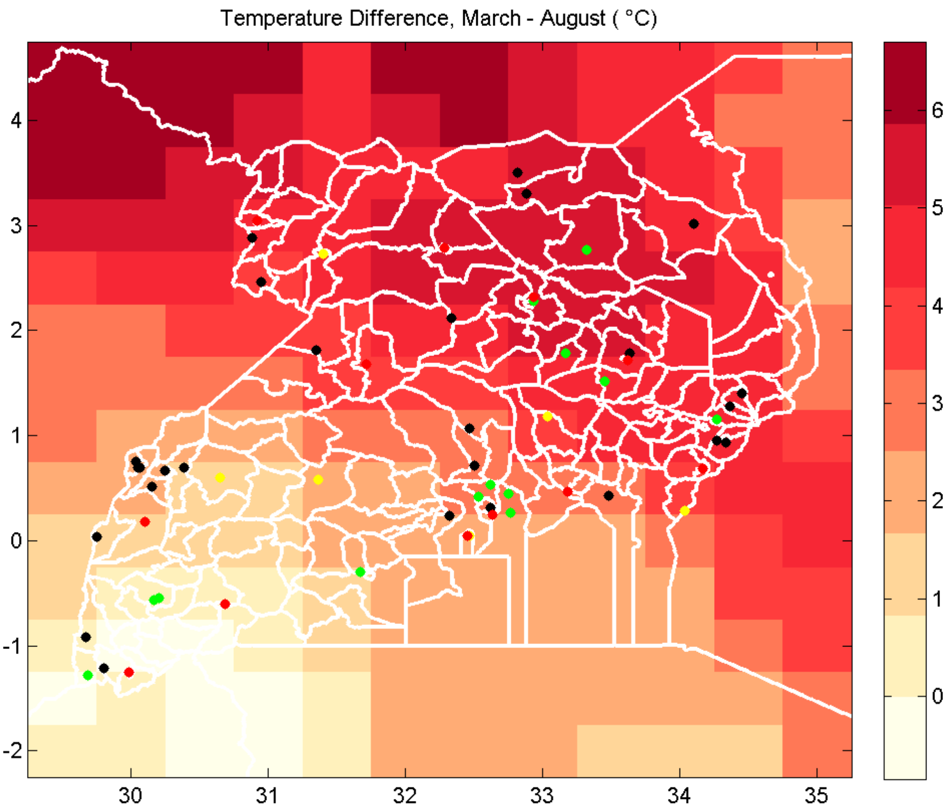

Figure 2.11: Temperature difference between March and August from the CFSR.

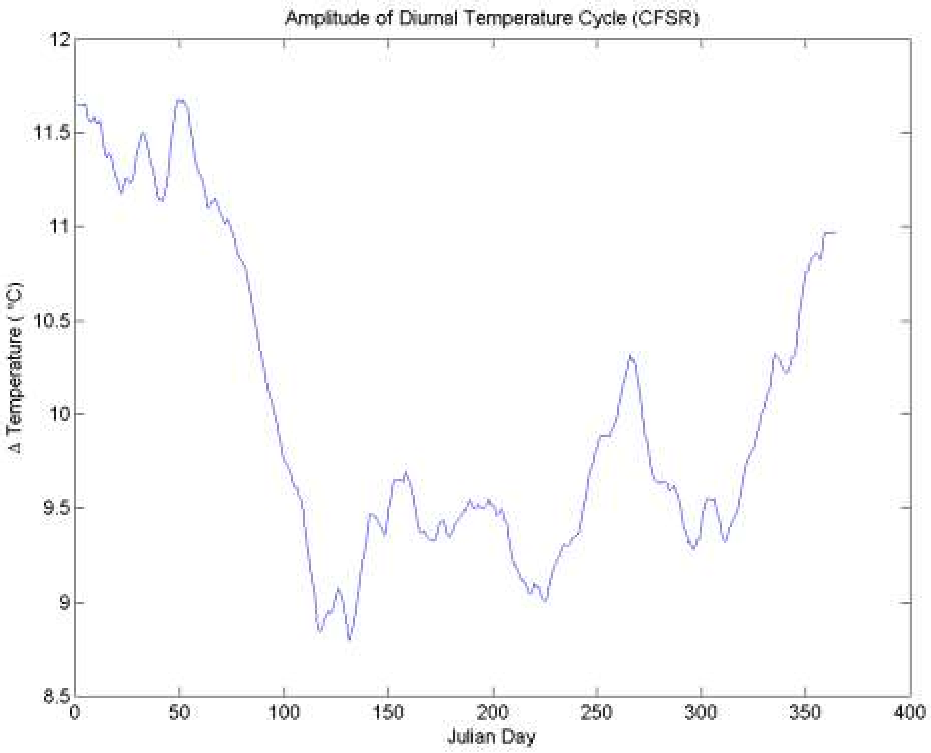

Figure 2.12: Seasonal cycle of the amplitude of the diurnal cycle (12 UTC-0 UTC). Diurnal cycle is largest in the dry season, smallest in the spring rainy season.

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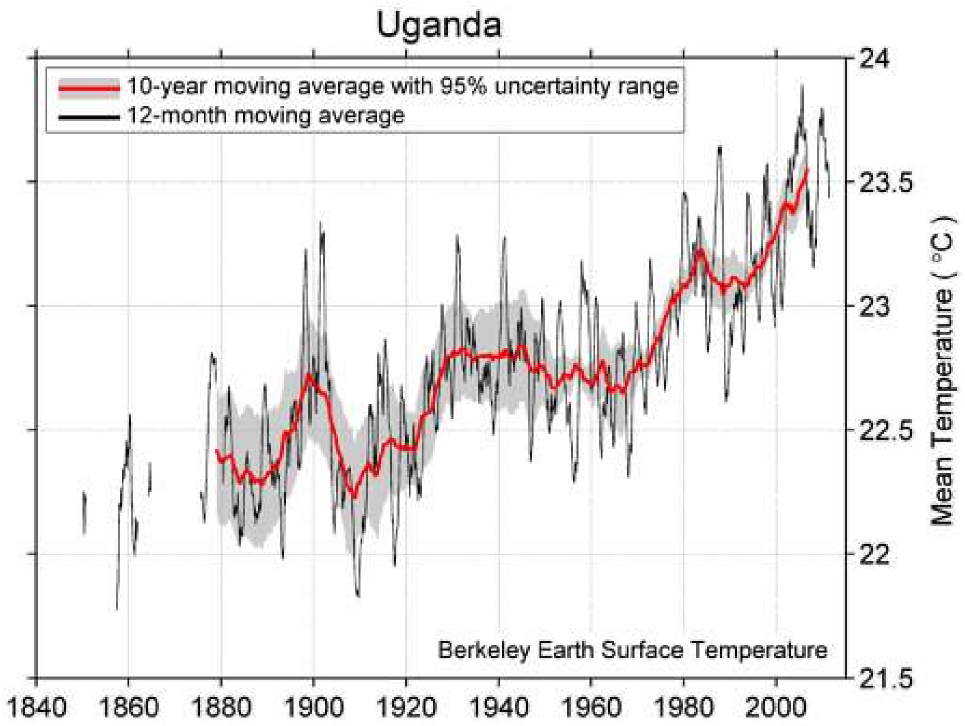

Figure 2.13: Surface temperature trends in Uganda (partially derived from surrounding stations), from the Berkeley Earth Surface Temperature project: http://berkeleyearth.lbl.gov/regions/uganda

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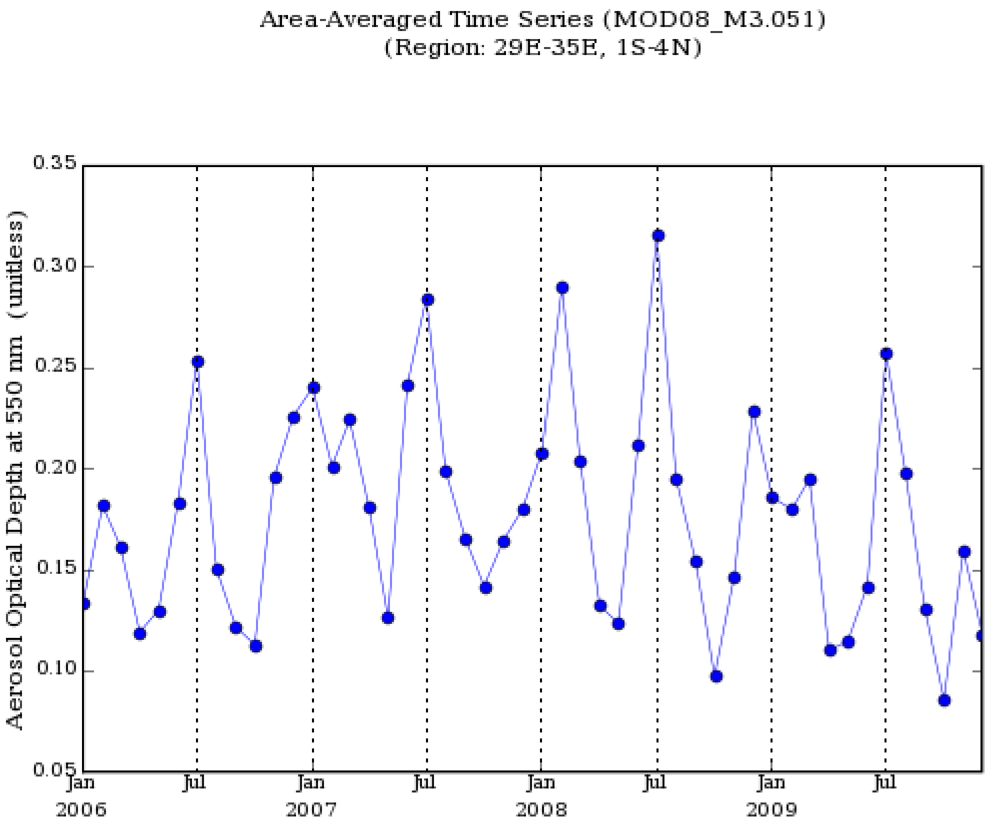

Figure 2.14: NASA MODIS retrieval of aerosol optical depth over Uganda. Seasonal variations are largely due to agricultural burning in the dry season. Figure produced using the Giovanni online data system, developed and maintained by the NASA GES DISC (Acker and Leptoukh, 2007).

3 ECONOMIC AND SOCIOECONOMIC ANALYSIS

Because of its geographic location, Uganda experiences many types of extreme weather events such as severe thunderstorms, floods and drought. The economy is very sensitive to these extreme weather events because among other things, agriculture is one of its main sectors. Furthermore, these events, particularly the severe thunderstorms, impact the safety of air travel in the country. Because of these extreme events and the high probability of future events, it is incumbent on the DoM to modernize their meteorological observing forecasting and warning technology and expand their services in order to continue effectively achieving their mission.

Thunderstorms are one of the most serious weather threats to Uganda society and economic well-being. The impacts on the agricultural and aviation sectors of the economy are especially significant and can have serious ripple effects through the socio-economic fiber of the country (Shively and Hao, 2012). Thunderstorm development, motion, and strength very much depends on wind information at all levels of the atmosphere, but Uganda lacks the ability to monitor and utilize such data with any degree of certainty. Upper air wind data is simply not available and its absence adversely affects the development of forecasts of weather patterns upon which the public and industry may rely.

Convective development is very much controlled by flow aloft and environmental shear that play a prominent role in determining its character and severity. Because equatorial Africa most often experiences light winds aloft and as such vertical shear is weak and plays a minor role in storm strength and severity. However, upper air disturbances occasionally do develop and drift through the Ugandan troposphere. These events can bring about more organized multicellular storms and with those, an increased threat of hail, turbulence and sudden wind shifts, all of which have been experienced throughout Uganda. Moreover, deep cloud bearing layer wind shear, if sufficiently strong, can even produce supercell storms and storm structures. For the climate of Uganda, this situation may be very infrequent, but when materialized the resultant thunderstorm severity will be at its peak. The only way to confidently identify that environment is with the twice daily release of the radiosonde.

The Ministry of Agriculture, Animal Industry and Fisheries, in its Development Strategy and Investment Plan (DSIP) 2010 – 2015, states that at the macro level, the agricultural sector faces a daunting set of output-level challenges that include low levels of productivity across most enterprises, high losses due to pests, vectors and diseases, and negative consequences of climate change. It should be noted that these challenges can be addressed by effective utilization of weather and climate information.

The Ugandan population largely depends on the growth, harvesting and sale of agricultural products, all of which are weather dependent. The Ugandan agriculture sector employs some 80 percent of the population and accounts for about 20 percent of the country's gross domestic product. Planting and harvesting schedules are extremely vulnerable to the beginning and ending of the rainy and dry seasons. To generate the most productive output, the sector requires better indicators for the timing to plant and harvest. This information is best utilized when forecasts of the start and duration of the rainy season can be optimally determined. Equally important is predictions of dry spells that can hinder crop yield and management, heat waves and inadequate grass growth for cattle grazers in the dry season are another major concern, especially in the middle section of Uganda. In northern regions of Uganda, well water is used to supplement surface water for agriculture and for watering of livestock. In extended dry seasons, wells may run dry (Martine Nyeko, pers. communication). Improved ground water monitoring and forecasting would provide significant benefits to well-water dependent agriculture.

Other critical weather phenomena in Uganda that bear monitoring and prediction include, but are not limited to:

- Pest outbreaks, which are significantly governed by above normal rainfall and humidity.
- Lightning is a hazard to those engaged in outdoor activities, especially those working in the agricultural sector. Lightning injures about 200 people each year in Uganda, and kills about 50 (NEMA, 2011, Mary and Gomes, 2012), with very large variations from one year to the next. Lightning strikes can also damage the power grid.
- Flash flooding, especially in the mountainous east and west regions of Uganda causes deaths. Most recently, a mudslide in the mountainous east of the country caused by flooding and above normal rainfall resulted in the death of some 18 people (Edyegu and Watala, 2012). Although the

potential for this hazard was known to exist, the ability to predict the storm that triggered the slides, and to warn the local population of the imminent threat were absent.

- Heavy rains in the eastern part of Uganda, north of Lake Kyoga, can lead to persistent flooding in the marshlands, blocking roads and impeding rice cultivation (Odong and Osujo, 2012).
- Hail is a major hazard to crops especially at the beginning of the rainy season and to aircraft flight safety (Shively and Hao, 2012).
- Wind storms do occur, but not as frequently as hail and flash flooding, and blowing dust generated from the Sudan and Chad to the north have caused day-long closures of the Gulu airport (pers. comm., J. Edattu, O.C., Gulu Synoptic Station).
- Low level windshear has been reported by pilots as they approach to land at the Entebbe Airport apparently associated with downdrafts and microbursts, at times when inadequate on-site weather observing systems report safe conditions.
- High winds and waves on Lake Victoria claim the lives of fishermen when boats capsize (Luganda, 2012).
- Drought conditions leading to low flow in the Nile River can have a negative impact on Uganda’s hydro-power generation capability, which in turn can have adverse economic effects.

The weather hazards described above strongly support the need to collect weather data on a near real-time basis, analyze that information and disseminate it together with user-specific forecasts and warnings in a timely and useful format. In addition to the agriculture and aviation sectors, information and data could affect the general public and other vital sectors including power generation, water resource management, and banking, insurance, and industrial. These deficiencies and their solutions will be addressed in subsequent chapters of this report.

4 Inventory of Current Systems and Facilities

There are four main types of meteorological stations in the Uganda hydro-climatic network – synoptic, climatological, agro-meteorological and hydro-meteorological. There are other specialized weather stations located throughout the country, principally research sites established by local universities with grants from worldwide food and agricultural production interests.

As of May 2012, the World Meteorological Organization recognized 10 synoptic stations in Uganda, although the DoM listing includes a total of 12 stations as shown in Table 3.1 (Lira and Makerere are not recognized by the WMO). Site visits to most of these stations led to the conclusion that the installed equipment and sensors are nonfunctional and in varying state of disrepair. A number of sensor systems are not fully capable of reporting required climate data. The lack of maintenance, annual or preventive, and communications resources severely limit the utility of these stations and the skills resident in the local DoM staff.

Besides the synoptic stations the Government of Uganda maintains a number of other meteorological stations for specialized agricultural or hydrological purposes. These are listed in Tables 3.2-3.4 below. The geographic distribution of all these stations is presented in Figure 3.15.

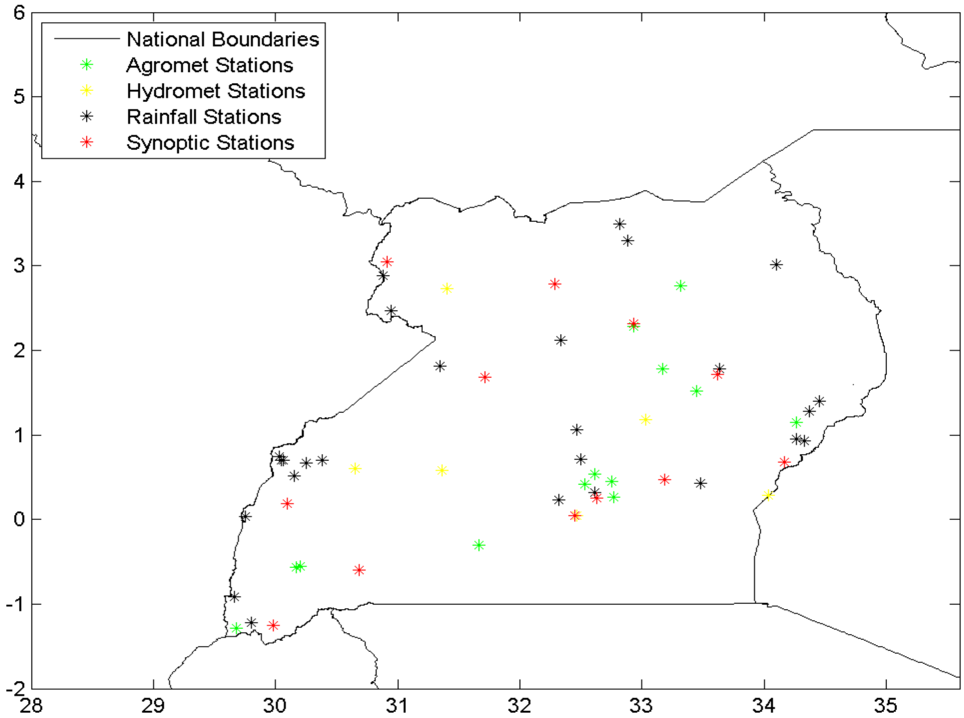

Figure 4.1: Map of DoM Observation Stations.

Table 4.1: Synoptic Stations

					Latitude			Longitude			
	Name	WMO ID	Opened	District	deg	min		deg	min		Height (m)
1	Arua	HURA	4/1/1911	Arua	3	3	N	030	55	E	1211
2	Gulu	HUGU	6/1/1911	Gulu	2	47	N	032	17	E	1105
3	Masindi	HUMI	9/1/1906	Masindi	1	41	N	031	43	E	1147
4	Soroti	HUSO	4/1/1914	Soroti	1	43	N	033	37	E	1123
5	Kasese	HUKS	1/1/1964	Kasese	0	11	N	030	06	E	961
6	Entebbe	HUEN	7/17/1946	Mpigi	0	3	N	032	27	E	1155
7	Jinja	HUJI	4/16/1954	Jinja	0	28	N	33	11	E	1173
8	Tororo	HUTO	5/1/1923	Tororo	0	41	N	034	10	E	1171
9	Mbarara	HUMA	3/1/1902	Mbarara	0	36	S	030	41	E	1413
10	Kabale	HUKB	7/1/1911	Kabale	1	15	S	029	59	E	1869
11	Lira	HULI	1992	Lira	2	15	N	032	55	E	1091
12	Makerere	HUMK	1992	Kampala	0	20	N	032	34	E	1240

Table 4.2: Agro-meteorological Stations

				Latitude			Longitude		
	Name	District	Opened	deg	min		deg	min	
1	Lira Ngetta	Lira	7/1/1964	2	17	N	032	56	E
2	Patongo	Kitgum	5/25/1939	2	46	N	033	19	E
3	Serere	Soroti	7/1/1920	1	31	N	033	27	E
4	Kaberamaido	Kaberamaido	1/1/1932	1	47	N	033	10	E
5	Bugusege Coffee Research	Mbale	12/1/1930	1	9	N	034	16	E
6	Mukono DFI	Mukono	9/1/1934	0	27	N	032	45	E
7	Kawanda Research	Mpigi	12/1/1938	0	25	N	032	32	E
8	Namulonge Research	Mpigi	1/1/1947	0	32	N	032	37	E
9	Kituza Coffee Research	Mukono	1/1/1963	0	16	N	032	46	E
10	Bushenyi	Bushenyi	4/1/1929	0	33	S	30	12	E
11	Bushenyi Agromet	Bushenyi	1/1/1963	0	34	S	030	10	E
12	Kamenyamigo	Masaka	1/1/1952	0	18	S	031	40	E
13	Ruhengere	Kisoro	8/1/1938	1	17	S	29	41	E

Table 4.3: Hydro-meteorological Stations

				Latitude			Longitude		
	Name	District	Opened	deg	Min		deg	min	
1	Wadelai W.D.D.	Nebbi	1/1/1962	2	44	N	031	24	E
2	Kiige Water Dev. Dept.	Kamuli	6/26/1969	1	11	N	033	02	E
3	Kyenjojo	Kabarole	7/1/1943	0	36	N	030	39	E
4	Mubende Hydromet	Mubende	10/22/1968	0	35	N	031	22	E
5	Entebbe Water Dev. Dept.	Mpigi	1/1/1954	0	3	N	032	28	E
6	Lumuli Hydromet	Tororo	11/13/1969	0	17	N	34	02	E

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Table 4.4: Rainfall Stations

				Latitude			Longitude		
	Name	District	Opened	deg	min		deg	min	
1	Padibe	Kitgum	5/14/1939	3	30	N	032	49	E
2	Vurra Customs	Arua	8/31/1938	2	53	N	030	53	E
3	Nyapea St. Aloysius	Nebbi	2/1/1941	2	28	N	030	57	E
4	Atura Port K.U.R.	Lira	1/1/1934	2	7	N	032	20	E
5	Kakoge Gombolola	Luwero	9/1/1942	1	4	N	032	28	E
6	Mpondwe Customs Post	Kabarole	10/1/1938	0	2	N	029	45	E
7	Bundibugyo	Bundibugyo	1/1/1928	0	42	N	030	04	E
8	Butiti	Bundibugyo	8/1/1909	0	42	N	030	04	E
9	Kahangi Estate	Kabarole	6/1/1928	0	42	N	030	23	E
10	Nyakasura School	Kabarole	1/1/1930	0	40	N	030	15	E
11	Kisomoro	Kabarole	12/1/1938	0	31	N	030	09	E
12	Nyaruru	Bundibugyo	11/1/1938	0	45	N	030	02	E
13	Bundibugyo Cocoa Dev.	Bundibugyo	1/1/1969	0	42	N	030	03	E
14	Mpigi Agric. Station	Mpigi	8/1/1938	0	14	N	032	19	E
15	Kampala Sewerage Works	Kampala	1/1/1958	0	19	N	032	37	E
16	Bubulo School	Mbale	6/26/1969	0	57	N	34	16	E
17	Bukwabusi C.O.U School	Mbale	6/26/1969	0	56	N	34	20	E
18	Kayonza	Kabale	8/20/1966	0	55	S	29	40	E
19	Kitgum VTC	Kitgum	4/1/1914	3	18	N	032	53	E
20	Kotido	Kotido	9/1/1946	3	1	N	034	06	E
21	Butiaba H.M.	Hoima	1/1/1904	1	49	N	031	21	E
22	Arapai Agric. College	Soroti	5/1/1965	1	47	N	033	38	E
23	Buginyanya Coffee Research	Mbale	10/23/1964	1	17	N	034	22	E
24	Kapchorwa Agric. Station	Kapchorwa	1/1/1965	1	24	N	034	27	E
25	Bukalasa Agric. Station	Luwero	7/1/1920	0	43	N	032	30	E
26	Ikulwe Farm Inst.	Iganga	9/1/1950	0	26	N	033	29	E
27	Karengyere Pyrethrum Plant	Kabale	4/8/1940	1	13	S	29	48	E

4.1 REVIEW OF UGANDA'S METEOROLOGY STATION NETWORK.

During the period June 20-July 1 the MDA team visited 18 meteorological observing stations: Entebbe, Makerere University, Kampala, Kawanda NARL, Jinja, Tororo, Soroti, Gulu, Gulu University, Masindi, Kakoge, Mbarara, Bushenyi Agromet, Kabale, The Institute for Tropical Forest Conservation, Bwindi Impenetrable Forest,(Mbarara University), Kalyengere Agromet, Ntungamo hydromet, Kasese, and Kichwamba Sub-County. Our path through Uganda is shown in Figure 4.1. At all of these stations we encountered a consistent pattern. Staffs were well trained to make observations, and were equipped with thermometers and manual rain gauges. However, more sophisticated equipment was generally in poor state of disrepair or inoperable due to a lack of supplies, telephone communications were poorly funded, many radios were inoperable, and no stations outside of Entebbe had access to internet, or any other means of obtaining information on conditions beyond their immediate view. Radiosondes have not been launched in Uganda for 5 years, and the radar at Entebbe has not functioned in a similar period.

Photographs of individual stations are shown in Figures 4.13-4.30. High resolution images may be found on the internet at:
https://plus.google.com/photos/111905219535616756030/albums/5756190614218816769.

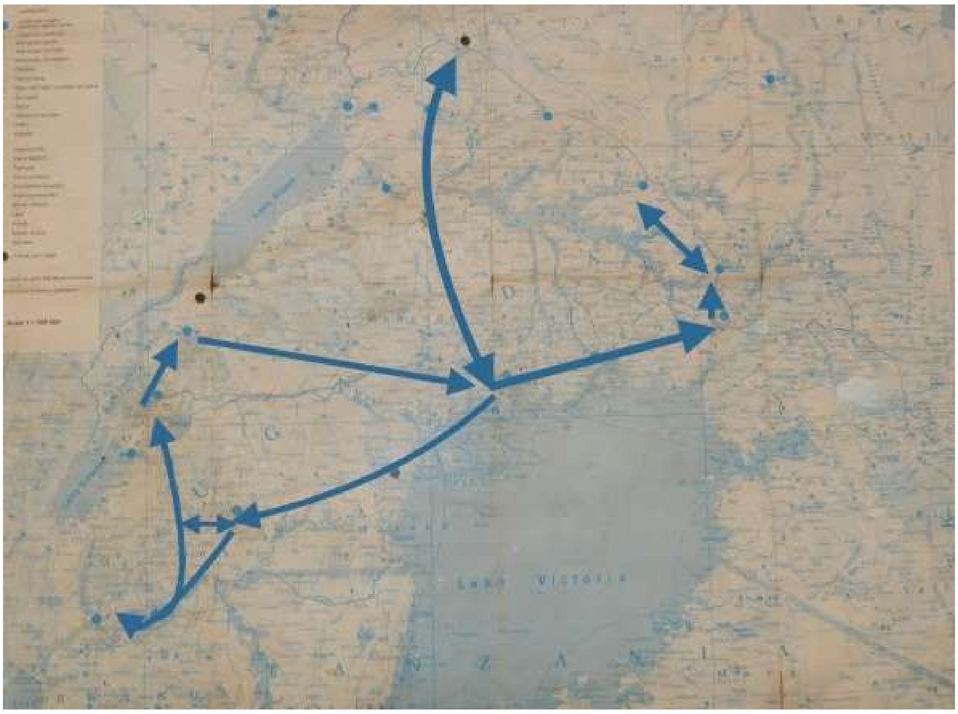

Figure 4.1: We visited 18 meteorological observation stations in Uganda, including 10 of the 12 active synoptic stations (excluding only Lira and Arua).

On the positive side, we found many conscientious and diligent staff with high expectations for continuing career advancement. Most stations have appropriate siting (representative of regional land patterns, removed from immediate obstacles to air flow) for their mission, and some have adequate land and buildings to provide farm income and on-site lodging for staff. However, the Gulu and Mbarara stations are being encroached upon by urban development, and will likely need to be moved -- Gulu immediately, and Mbarara eventually. Stephenson screens, daily rain gauges, counting anemometers, and wind vanes are generally operational, though the latter are often in poor working condition. Historical data is maintained on site, and provided to interested local parties. There are staffed observatories at principal airport locations (Entebbe, Soroti, Kasese, and Gulu pending), though in most cases the Department staff are unable to provide adequate advice on weather aloft, due to a lack of internet services.

However, there are many weaknesses in the station network. No sites have a full complement of mission-required equipment. In particular, pibal balloon soundings, sun-hour paper, continuous rain gauges, 10-meter wind speed and direction towers, and barometers are missing or non-functioning. There are no operative radiosonde stations (hydrogen supply), radar or lightning detection equipment. Computers are present, but in some cases non-functioning. They lack sufficient speed and memory for basic modern meteorological tasks such as satellite image presentation and model data analysis and presentation.

Despite the investment in computer equipment, no software for training has been provided for the staff. Staff were not knowledgeable of the availability of such free resources (such as the online tropical meteorology textbook at www.meted.ucar.edu, which can be downloaded, burned on CD-ROM and installed on each computer.

Telephone communications are underfunded and radio communications are unreliable or non-existent, which often means that stations can only wait for a call from Entebbe to report their data. Internet access is not provided and there was a general lack of awareness of available international data and forecasting resources, both at meteorological stations and more generally among people engaged at the agricultural offices with available access to the internet.

Beyond the level of station performance, our discussions revealed a number of organizational difficulties. Maintenance is poorly coordinated across the department. There is an absolute dependence on the National Meteorological Center in Entebbe for all forecast and synoptic data, when internet access would make individual stations much more able to provide forecast and data services to their local communities.

Equipment purchase, maintenance, repair and status logs were not made available to the MDA team. Equipment such as automated rain gauges, anemometers and wind vanes appeared to be poorly maintained; in many cases anemometers and vanes had not been greased in years, likely resulting in poor performance. No repair tools and few repair manuals are available, especially for automated equipment. Several AWS stations had not been operating for months or years because of simple wiring problems. There appears to be an under-emphasis on equipment repair and maintenance in the meteorological training provided at Entebbe.

We observed a lack of autonomy in the station staff. They lack training and permission to improvise solutions to equipment problems under their own initiative. For instance, none of the stations had sun hour cards for their globes and no one had attempted or felt empowered to improvise a solution. The lack of training opportunities and static job placement over long periods appeared to lead to staff burnout and a sense that no positive change could be expected. The Department relies heavily on staff to supplement their salaries with farming and other endeavors, which essentially requires field staff to subsidize department operations.

Many station facilities and offices are provided by other government organs and tenure is not assured. Perhaps because local governments get little in the way of forecast services from the local stations, working relations are not sufficiently close to allow for support of Department goals. For example, in Gulu the local government wants the meteorology department to vacate their offices in town and move out to the airport. The Civil Aviation Authority would also like to arrange this move. But the logistical support to move the equipment and installing protective fencing have not been secured by the Department.

We found that the general population or in the Agricultural or Civil Aviation authorities have little confidence in the weather forecasting skill of the Department. The coarse spatial resolution of forecasts (issued only for particular cities and not for distinct regions on a map), the daily-only issuance of forecasts in a climate dominated by fast-evolving convective systems, and the limited (thrice yearly) issuance of long-range (seasonal) forecasts has given the public little opportunity to gain confidence in the Department's forecast skills.

Overall, the observational system is in very bad condition, barely capable of reporting ~~any useful~~ adequate climate data, and capable of providing only a very partial instantaneous view of atmospheric conditions in Uganda. This represents a waste of human resources comprised of talented meteorological staff who are unable to use their skills due to a lack of capital investment that should otherwise provide them with the requisite physical and information tools and resources. The Department will need to implement rapid improvements in maintenance, repair, material supplies,

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security and record-keeping of its current system and a capital investment program for the future if it is to earn the confidence required to obtain the financial support of potential lending institutions.

Figure 4.2: Makerere University, Kampala Synoptic Station. This station was one of the better equipped, but was missing recording cards for its sunshine recorder. It has a functioning AWS station and internet and telephone access is available to the observer, who sits in the offices of the Geography department, where Prof. Charles Basalirwa runs the graduate and undergraduate Meteorology program.

Figure 4.3: Entebbe Synoptic Station / National Meteorological Center. Also well-equipped, although no evaporation pan was present. The NMC is the operational center for meteorology in Uganda, the source of all forecasts issued by the DoM. Its responsibilities at Entebbe also involve briefings to pilots. Entebbe operations are discussed in more detail in Section 8.

Figure 4.4: Kawanda Research Agromet Station. The station lacks 10 m wind speed or direction, but is otherwise relatively well equipped, including a functioning automated weather system (AWS). Dr. Komutunga Everline of the National Agricultural Research Laboratory detailed the need to more accurate and more frequent precipitation forecasts for Uganda's agricultural sector.

Figure 4.5: Jinja Synoptic Station. Jinja's station provides occasional guidance to pilots (mostly trainees for the school at Soroti), and to local agricultural interests. They are hampered in their ability to do this by a lack of telephone service and transportation (many staff do not own bicycles or any other means of transportation). The AWS on-site was off-axis, and its precipitation meter was not functioning due to a broken wire. Precipitation pan lacks an adjacent water source. Like all other field stations outside of Kampala and Entebbe, they have no internet access.

Figure 4.6: Tororo Synoptic Station. Located away from the airport due to security concerns, this station answers occasional data requests from local road crews and construction companies. They have not installed their precipitation pan. They have a functional AWS, but have no way to measure wind speed on their own and must estimate it using the Beaufort scale for their synoptic reports.

Figure 4.7: Soroti Synoptic Station. This station provides frequent meteorological guidance to flight students from the nearby flight school. They have a number of concerns about security, due to the proximity of their enclosure to the barracks of a local army base. The AWS is not functioning due to a broken modem, and they have neither evaporation pan nor a functioning anemometer.

Figure 4.8: Gulu Synoptic Station. The Gulu station is located in town, and the enclosure is subject to encroachment by surrounding buildings. They have no outgoing phone service, nor a functioning radio. They are slated to move to the Gulu airport, but this has been held up due to a lack of funds to rent a truck to move their equipment, and to build a fenced enclosure at the airport.

Figure 4.9: Gulu University Hydrology Research Station. Dr. Martine Nyeko of the faculty of Agriculture and the Environment has set up a state-of-the art AWS, including an automated evaporation pan here, to support his research on groundwater depletion.

Figure 4.10: Masindi Synoptic Station. This stations AWS was stolen some time ago. They lack 10 m wind speed, or 2 m speed or direction, and do not currently make evaporation measurements. They have no functioning telephone, but do have a radio connection to Entebbe.

Figure 4.11: Kakoge Agromet Station. We did not speak to staff here, but observed that their small complement of instruments (screen, evaporation pan, counting anemometer) appeared to be functional.

Figure 4.12: Mbarara Synoptic Station. Work on a new building to replace the temporary shed appeared to be stalled. A set of solar radiation instruments here were set up by a researcher at Makerere University, but their readings are not available to the observing staff. They do not have a barometer, or a functioning anemometer. There is some development pressure on the property from the town of Mbarara.

Figure 4.13: Bushenyi Agromet Station. Work conditions are poor here: fly-ridden banana chips are stored in the observer's office. The station lacks any means of communication- observations are collected monthly by staff from DoM. The Stephenson screen was in poor condition, and there is no functioning anemometer.

Figure 4.14: Kabale Synoptic Station. This station has good office space, and what was at one time a very impressive AWS, now out of service. Staff have not received training to operate their evaporation pan, and have no functioning anemometer.

Figure 4.15: Bwindi Tropical Ecology Assessment and Monitoring Network Station (Institute for Tropical Forest Conservation, Mbarara University). Graduate student Badru Mugerwa has established this state-of-the-art AWS as part of the TEAM network (www.teamnetwork.org), with funding from Conservation International and other NGOs. Data is read only once a month, due to a lack of available cellular data transmission.

Figure 4.16: Kalyengere Agromet Station. One of the highest observation stations in the country, at 2450 m. The station lacks functioning anemometers, and the Stephenson screen needs to be replaced. No radio or telephone connection available to the observer.

Figure 4.17: Ntungamo Hydromet Station. Not currently active, but a volunteer observer has been identified.

Figure 4.18: Kasese Synoptic Station. The airport receives only a few flights per week, and pilots do not generally rely on data or forecasts from the meteorology staff. Anemometers are not functioning. Incoming phone calls (from Entebbe NMC) are the only means of communication.

Figure 4.19: Kichwamba Sub-County AWS Station. A recently installed modern AWS and Stephenson screen. The AWS is not currently functional, because the computer to which it is attached has had the software for communicating with the AWS removed.

4.2 STAFFING AT METEOROLOGICAL STATIONS

The staffing and skill levels at the meteorological stations are, for the most part, inadequate and/or underutilized. The DoM has seen a major reduction in its workforce over the past many years, from some 750 in 1977 to about 126 in data presented to the team as of May 15, 2012. There are many reasons for this decrease, including the long awaited organizational change to an Authority. Nonetheless, the current staffing levels do not support the mission of the DoM. For proper functioning on a 24/7 basis, each synoptic station should be staffed with a five-person complement. Shift work is a requisite, as is the provision of adequate resources to conduct their responsibilities – housing, transportation, security, communications and modernized working facilities – each of which will be evaluated in subsequent chapters of this report.

The current deployment of full time DoM staff breaks down as follows:

Table 4.1

Entebbe	43
Kampala	26
Soroti	12
Tororo, Kabale	4 each
Jinja, Arua, Gulu, Mbarara, Masindi, Kitgum, Kotido, Lira, Namulonge	2 each
Serere, Kasese, Namalu, Ntuusi, Kiige, Kabanyolo, Kawanda, Kibanda	1 each

In some cases (e.g. Kasese, Jinja) the permanent staff is supplemented by contractors, who are typically recently trained, younger people hoping to be moved to the permanent staff.

The breakdown in staffing does not include any vacancies or C4 Meteorologist Assistants. The Team encountered C4 employees on its travels in Uganda. All meteorologists/meteorologist assistants working for DoM in Uganda appear not to have been reclassified according to the new WMO guidelines published in 2001. Further, the MDA team will need to ascertain the complete number of employees available for a modernized UNMA as it prepares to propose a new organizational structure.

In addition to the lack of adequate working facilities, training and advancement opportunities are extremely limited, which lends to an observed low morale among the staff. Position descriptions and performance standards are in place, but serve no meaningful purpose unless the staff is motivated to achieve higher personal goals and objectives, and receive commensurate consideration. The shifting of training responsibility from the DoM to the Ministry of Education and Sports has adversely affected career development of the DoM staff, and a means to transfer that function back to the UNMA is one of the objectives to be addressed in this report.

4.3 KEY OBSERVATIONAL DEFICIENCIES

Uganda lacks a number of observational facilities that are crucial to a modern meteorological service. These include radiosonde launch capability, radar, lightning detection, and low-level shear detection. We review the status of each of these technologies and their relevance to Ugandan meteorology.

4.3.1 AUTOMATED OBSERVATIONS AND NETWORKING

Automated weather stations have been installed periodically throughout the synoptic station network, and at a number of other locations in Uganda over the past 40 years. Many of these stations have broken down over the years, and not replaced. Others are partially functioning. Only a few include an elevated wind observation (6 m or higher), and aside from a few scientific installations none include solar radiation measurements or soil moisture or temperature measurements.

Entebbe Airport has installed three automated weather observing system (AWOS) units on the primary Runway 17-35. There is one system at each runway end and one located at the midway point. The AWOS reports wind speed and direction, temperature, dew point, barometric pressure, ceiling and visibility. The data is transmitted to the displays at the air traffic control tower and relayed by the controllers to the pilots. Visibility is not measured at the runway midpoint. Pilot reports of winds measured by sensors on the aircraft have been inconsistent with the AWOS wind speed and direction sensor data, which may be an indication of the need for maintenance and/or calibration.

Modern weather forecasting depends heavily on the development of Model Output Statistics, which allow for the removal of biases in translating numerical weather prediction model output at grid points to forecasts for particular locations. Global numerical weather prediction models are now quite skillful at the prediction of temperature, humidity and precipitation throughout the tropics (Chakraborty and Arindam, 2010). Development of model output statistics requires reliable and consistent hourly observations of temperature and precipitations at all locations for which forecasts are issued. Thus, the absence of functioning automated stations and the absence of functioning data transmission from these stations to the NMC is a key stumbling block to the development of modern weather forecasting in Uganda. If Uganda's territory were thoroughly sampled with automated weather stations in each administrative district that reported directly to NMC, it would be a simple matter to set up calibrated forecasts based on model output statistics for each administrative unit, to display this forecast in on the UNMA website, and to make SMS text message forecasts available to cell-phone subscribers, tailored to their locations. This would represent a tremendous improvement in forecast services for Uganda.

4.3.2 RADIOSONDES CAPABILITY AND STATUS

A key resource in all of weather forecasting is the radiosonde. Without this invaluable tool, atmospheric stability cannot be evaluated along with the threat of strong winds, downbursts, windshear, rain, heavy rain, hail and other adverse and hazardous phenomena. As an example, windshear issues can only be identified through an analysis of the vertical structure of the atmosphere. When weak shear is present throughout the depth of the atmosphere and the environment is moist through deep layers, tropical convection with very heavy rain can organize. In fact, "warm rain processes" very often are the culprits in flooding and flash flooding situations. These processes and the potential for these processes are uniquely identifiable through the radiosonde and the kinematic and thermodynamic atmospheric structure, all of which are of immense applicability to weather patterns in Uganda.

Radiosonde observations are also needed for numerical weather prediction. Although satellites can now retrieve temperature and humidity from clear sky regions, they do not adequately observe humidity in regions with cloud layers, and they cannot estimate winds with much vertical resolution. Faccani et al. (2009), using results from the AMMA observation and forecasting experiment of 2006, show that numerical prediction of West African rainfall is significantly improved by additional radiosonde observation in that region. These results strongly suggest that Uganda would gain a noticeable improvement in forecast accuracy from the international modeling centers if it could provide regular radiosonde data. They further suggest that a region revival of radiosonde launches (from Kenya, Tanzania, Congo, Sudan and Ethiopia, none of which were regularly launching radiosondes in June 2012) would greatly improve regional forecasting.

Owing to the lack of a hydrogen generator, the Entebbe NMC has been unable to launch any Radiosondes as required by the WMO. Some movement to supply the generator and 400 Radiosondes may be nearing conclusion, although this would yield one sounding per day as opposed to the required two daily events. Further, no observing station in Uganda is able launch pibals. The re-establishment of a pibal network would permit forecasters to perform a streamline analysis over topical areas of Uganda. Confluence and diffluence patterns revealed by the pibal network will help the forecasters and supplement their knowledge of the wind patterns between the radiosonde launches. This would also greatly improve recognition of the likelihood of thunderstorms and their attendant threats.

4.3.3 LIGHTNING DETECTION CAPABILITY AND STATUS

Unique to the thunderstorm is lightning. Lightning detection permits the unambiguous identification of the thunderstorm. And, as discussed earlier, lightning is a multifaceted threat to weather equipment, aircraft on the ground and in flight, livestock, commerce of all kinds, and especially to people of all ages and occupations.

Tropical Africa is also known for Mesoscale Convective Systems (MCS) that are particularly lighting active. The MCSs over tropical Africa generate intense lightning activity with tropical Africa being the hotspot of lightning activity on a global basis.

In the summer of 2011 in Kampala Uganda, according to various news sources, lightning strikes killed approximately 15 people and injured 52 people per week. Runyana Elementary school, one of the major schools, located 225 km NW of Kampala, was reported to have sustained the most injuries and deaths.

Currently Uganda lacks a lightning detection network (LDN) of any kind and there is a general lack of any knowledge of real-time cloud-to-ground lightning information. Without this knowledge, no users including agricultural, civil and commercial aviation and the military can be alerted to this potentially fatal threat. Worldwide lightning detection networks exist and a representative output is depicted below (Figure 4.20) and illustrates the lightning activity over tropical Africa for the July through September 2005 period. A means to access this data and utilize it as part of the NMC will be addressed in a subsequent chapter of this report.

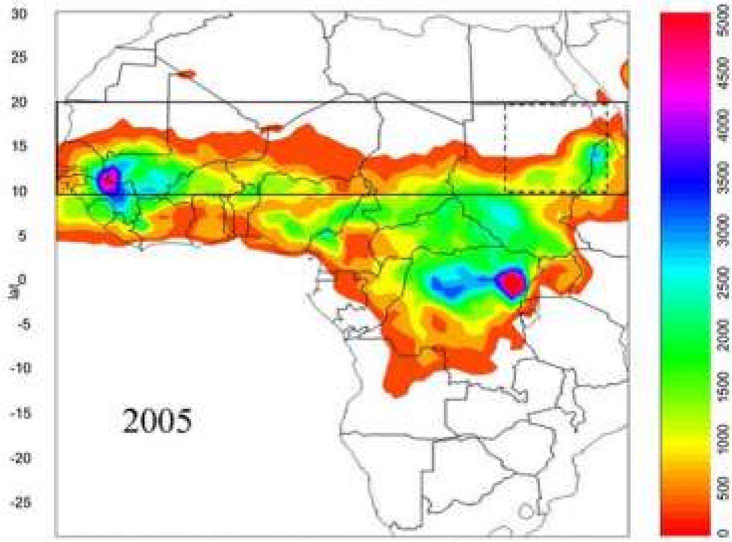

Figure 4.20: July, August, and September (top) lightning activity over Africa (flashes/2.5_ 2.5_g rid box) as detected by the WWLLN VLF array.

4.3.4 RADAR CAPABILITY AND STATUS – WEATHER AND AIRCRAFT SURVEILLANCE

In past years, Uganda had a single functioning radar, located at the Entebbe Airport. However, this C-band radar has not functioned for over five years. Maintenance for the radar is not feasible and spare parts are nonexistent. This serves to explain why only remnants of the radar remain. The manufacturer, Thompson, is out of business, and spare parts are hard to find as well. No staff presently employed at NMC are trained and experienced in the interpretation of weather radar imagery.

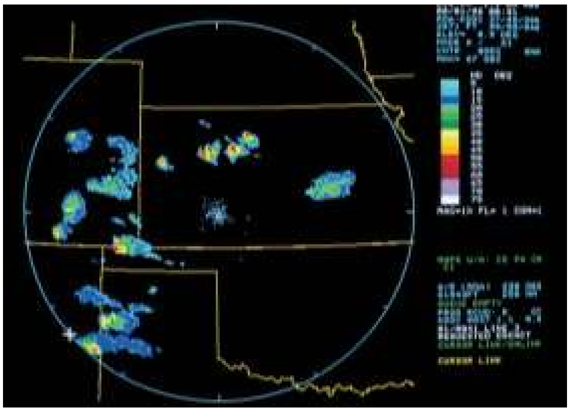

Figure 4.21: A radar reflectivity display with intensity color code on right. The blue circle has a radius of 480 km. The precipitation echoes shown here are thunderstorms.

Radar is uniquely equipped to identify rain and rainstorms, and those thunderstorms associated with hail. Hail, which is produced by thunderstorms, is common across Uganda and this threat is often closely associated with strong winds and windshear. Hail is produced by better organized thunderstorms of the multicellular and supercell variety. By far, the best tool for evaluating thunderstorm severity and the hail threat from a thunderstorm is radar and especially when coupled with the thermodynamic stratification of the environment revealed by recent radiosonde launches. It is a real-time, long range (and near range) remote sensing tool. Figure 4.21 depicts an image of a common plan position indicator display. The storm seen in the first three panels of Figures 4.22 exhibits a structure often associated with large hail in a sheared environment, whereas that presented in the lower right panel is a storm in a weakly sheared tropical air mass similar to Uganda and likely associated with smaller hail. Storms similar to this are also sometimes found to be associated with downbursts creating strong localized windshear capable of bringing down large commercial and military aircraft.

The lack of radar capability in Uganda prevents DoM from issuing severe weather watches and warnings of existing or future dangerous weather. The absence of radiosondes and radar prevents any short-fused severe weather watch and warning system for Uganda. Lin et al. (2005) show that simple extrapolation of radar-detected storm features allows much more skilled prediction of storms than numerical weather prediction in the first six to nine hours. This improvement is shown in Figure 4.23 below. Deaths and trauma from landslides in the Mt. Elgon area might have been reduced in 2012, if people had been alerted a few hours in advance that a strong storm was developing in the area, with rainfall sufficient to trigger dangerous landslides.

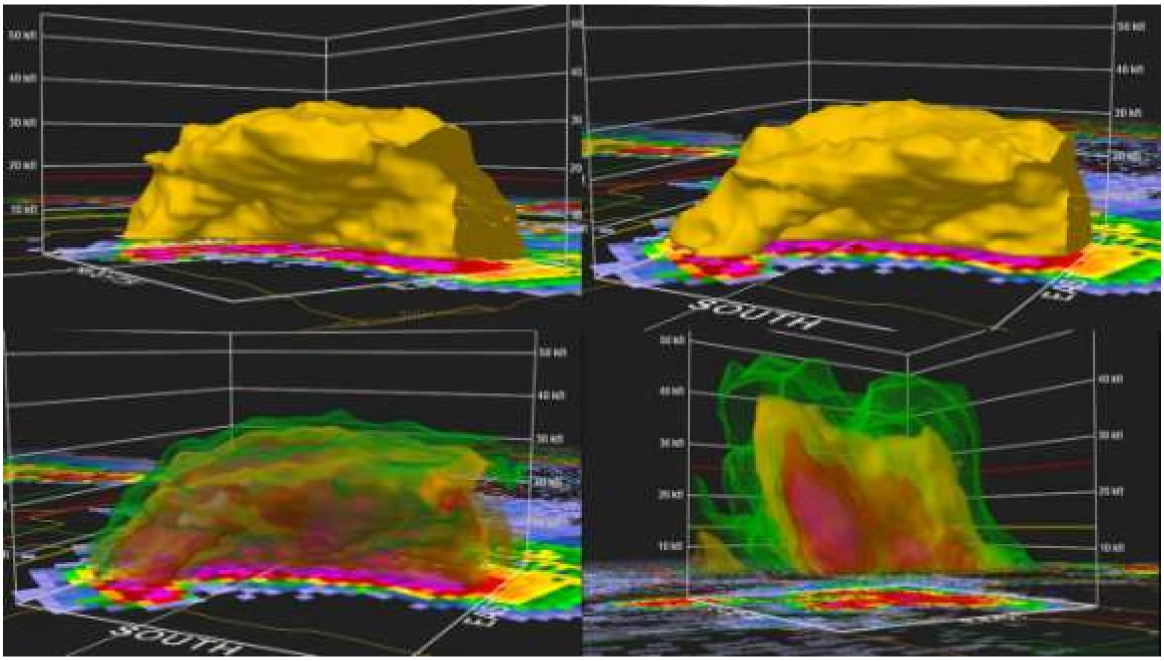

Figure 4.22: Upper left: A volume rendering of 3D, 45 dBZ isosurface display generated from the base Level II reflectivity data. Note thin yellow line near an altitude of 9 kft (0 degrees C) and the red line near 18 kft (-20 degrees C) obtained from the nearest and latest radiosonde. Upper right: same storm from a different angle. Lower left: same as upper right, using a volume 3-D rendering of a set of reflectivity isosurfaces (30, 45, 50, 55, 60, 65 and 70 dBZ). Lower right: as in lower left, for a different radar and storm.

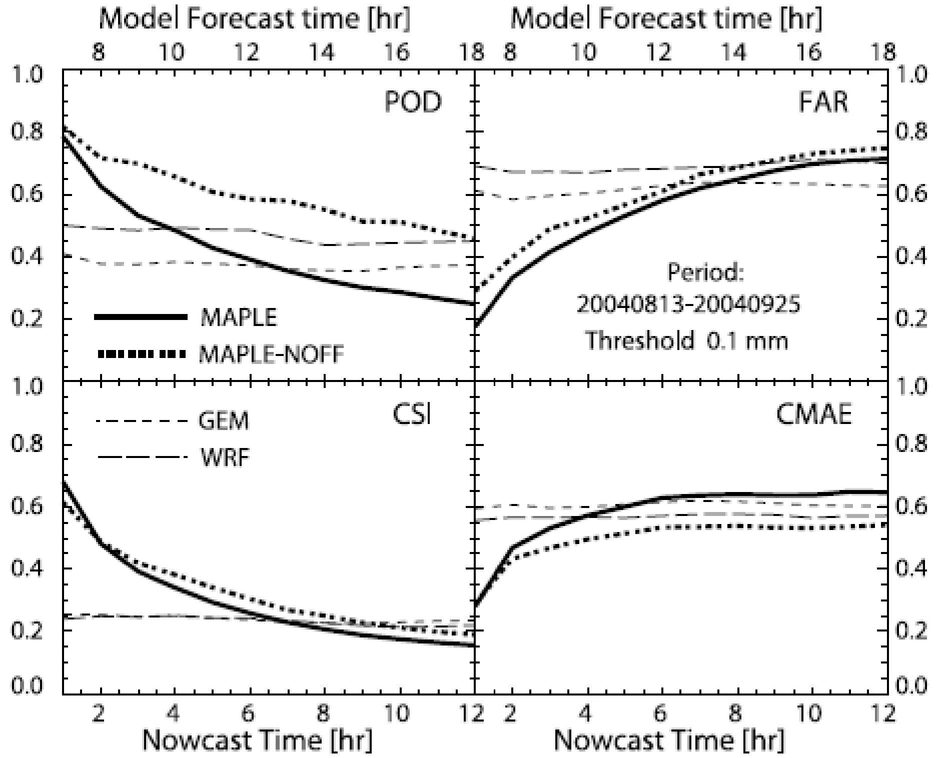

Figure 4.23: A figure from Lin et al. (2005), demonstrating that forecasts based on extrapolation of observed features in radar returns ("MAPLE" and "MAPLE-NOFF") are more skillful in the first 12 hours than numerical weather prediction forecasts ("GEM" and "WRF"). Each box represents a different skill score system- POD is probability of detection, FAR is the false alarm rate, CSI is the critical success index, and CMAE is conditional mean absolute error in the logarithm of reflectivity.

4.3.5 WINDSHEAR DETECTION CAPABILITY AND STATUS

Windshear can be created in a number of ways within the environment and within the convective storm itself. One of those ways is simply the "gust front" or downdraft outflow from the cool downdraft of ordinary convective storms.

Although the Entebbe Airport does not appear to have the topographical issues associated with other airports in Uganda, its proximity to Lake Victoria and the resulting effects of land/lake breezes promotes a high number of thunderstorm days. Turbulence and shear in and near thunderstorms can be associated with downbursts, microbursts and gust fronts generated by the thunderstorms. As illustrated in Figure 4.24, the microburst and resulting low-level windshear can be deadly and is therefore a high priority aviation threat for the modernized UNMA. Its detection is heavily dependent on radar and a network of surface based anemometers.

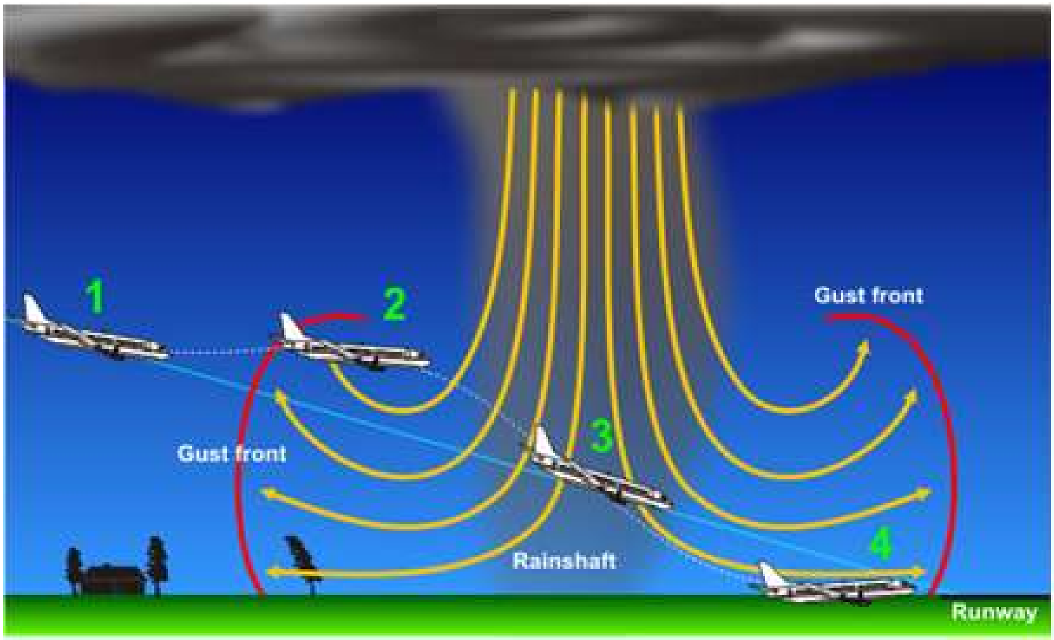

Figure 4.24: A microburst and associated gust front is illustrated here causing the crash of a commercial aircraft.

In recent years, operational windshear detection systems such as the Low-Level Windshear Alert Systems (LLWAS) have been introduced at most major airports in the U.S. and at an increasing number of airports internationally. This warning system combines dedicated sensor systems (radar and/or networked anemometers) with automatic processing software to produce real-time hazard alerts and alarms for air traffic controllers and supervisors. Lake/land breeze can be dry and yet have a profound effect on windshear and the LLWAS can detect this. The Entebbe Airport is scheduled to install a LLWAS in 2012-2013. The addition of nearby weather radar can assist in this Entebbe system.

4.4 ROLE OF THE NATIONAL WEATHER CENTER

The DoM National Meteorological Center (NMC) for Uganda is located at the Entebbe Airport. The role of a national meteorological weather center as defined by the World Meteorological Organization is to:

> Deliver national weather, water, and climate weather guidance, forecasts, warnings and analyses to its Partners and External User Communities. These products and services are based on a service-science legacy and respond to user needs to protect life and property, enhance Uganda's economy and support Uganda's growing need for environmental information.

Terms in this statement are defined as follows:

- Partners – Those with whom the NMC works to develop improve and deliver products and services, including DoM offices and the private sector.
- Guidance – Products used by NMC forecasters in making forecasts (e.g. numerical model output, national scale basic weather prognoses, and others.)
- Users – Those who apply DoM products and services to meet specific needs. These may include DoM's partners.
- Environmental Information Database – The collection and analyses of all data that can be used to assess the impact of the environment on the nation.
- Service and Science Legacy – Improving services through science, especially in improving guidance to user community.

The Uganda NMC is not fully meeting these international standards of practice. Weather forecasts for public use are prepared daily without updates with only limited regional specificity and released to an e-mail list. Although radio stations do broadcast the forecasts generated by the NMC, the mindset of the print and television industry is that communications of weather products for public consumption is not a service demanded by the public, but rather a service performed for the DoM, from which they expect to derive revenue. This has restricted the flow of such information, since DoM lacks funds to pay for newspaper space and television time.

Part of the role of the NMC is to be the Meteorological Watch Office (MWO) for Uganda. This is an International Civil Aviation Organization (ICAO)/World Meteorological Organization (WMO) requirement that is not being fully met by the NMC. The requirements are as follows: The NMC shall maintain watch over meteorological conditions affecting flight operations within its area of responsibility; Prepare SIGMET and other information relating to its area of responsibility; Supply SIGMET information and, as required, other meteorological information to associated air traffic services units; Disseminate SIGMET information; AIRMET responsibility if required: and Volcanic information as required. A means to address this shortfall in functionality will be addressed in subsequent chapters of this report. Modernization of the NMC will allow Uganda to have a true national center and fulfill their national and international requirements.

Data access at NMC is limited. There is a direct link to Meteosat, in order to receive satellite and guidance information. A software package is utilized to display satellite data along with ingested model data from the UKMO and ECMWF and a wide range of weather data variables. In addition, the staff hand-plot contours of 300 hPa height charts to get a sense of positions of the semi-permanent highs in the Indian and South Atlantic Oceans for purposes of extended forecasts.

Part of the operations at NMC Entebbe is the data communication center. There are two people on duty at a time. One communicator receives the data from Ugandan weather stations and the other communicator sends the reports to Nairobi using the Internet. Nairobi relays the data to the International networks. The briefing office also receives data via the Internet. A new modern link Global Telecommunications System (GTS) through fiber optic has been installed between NMC Entebbe and the Regional Telecommunication Hub (RTH) at Nairobi, Kenya. However, this GTS link is not operational as negotiations continue between Entebbe and Nairobi. Once this link is operational and observational and forecast/warning systems are improved, Ugandan warnings, advisories, forecasts and data will be received worldwide and important data sets not readily available the NMC meteorological staff will become available.

An additional operational component of the NMC Entebbe is the flight folder briefing office on the flight line at Entebbe Airport. Flight folders are provided to each aircraft crew or ground handler departing Entebbe, typically 30 to 60 minutes prior to scheduled departure time, and contain significant weather charts, satellite imagery printouts, terminal area forecasts and METARS along the planned route of flight and at alternate airports and winds aloft. The information is obtained from the Internet. General aviation pilots upon request are provided with a briefing and a flight folder. Most scheduled airline operators also obtain weather data from their base location, which supplements that offered by the briefing office. The data is printed in black-and-white. The relatively small briefing office suffers from a slow Internet connection and lack of modernized computer/printer equipment. All the meteorologists at the NMC rotate through the flight briefing office, which operates on a 24/7 basis.

Uganda is meeting its ICAO flight folder obligations, which is but one component of the international aviation weather data reporting standards. However, the briefing office needs to be modernized with new communications, computers and facilities. There are automated procedures that can be put in place that allow the flight folder requirements to be met with automation and the Internet. This would allow better use of the personnel in a reorganized meteorological service.

As far as the MDA team was able to determine, there is no agreement between CAA and the DoM concerning what services DoM will provide, how observations will be taken to support airport operations, and what information will be passed to the CAA Air Traffic Services.

4.5 CIVIL AVIATION IN UGANDA

Civil Aviation in Uganda operates under the Civil Aviation Authority (CAA), which was created by an Act of Parliament in 1994 as a state agency of the Ministry of Transport, Housing and

Communication. The mandate of the CAA is to coordinate and oversee Uganda's aviation industry, including licensing; regulation; air search and rescue; air traffic control; ownership of airports and aerodromes; Ugandan and international aviation law; representation of Uganda in an international capacity to the aviation community; and to all other aviation matters. The head offices are at Entebbe Airport.

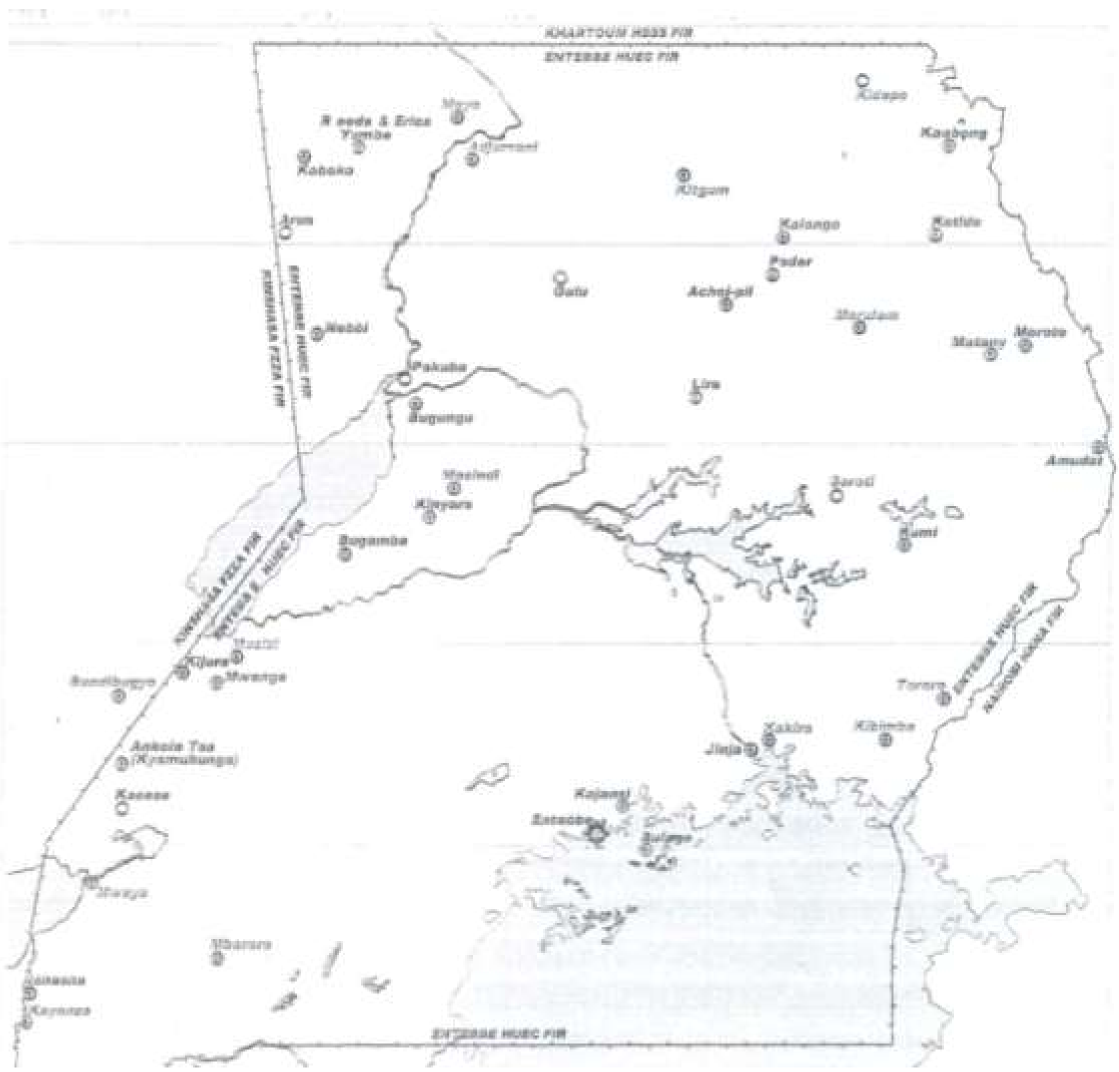

Figure 4.25: Aerodromes of Uganda. Figure courtesy of the Uganda Civil Aviation Administration.

The distribution of airports within Uganda is presented in the Figure 4.25.

The primary/major international aerodrome in Uganda is Entebbe. Entebbe is an aerodrome of entry and departure for international air traffic, where all formalities concerning customs, immigration, health, animal and plant quarantine and similar procedures are carried out and where air traffic services are available on a regular basis.

Secondary/other international (Category A) aerodromes in Uganda are Arua, Gulu, Kidepo, Kasese, Soroti, and Pakuba. These aerodromes are available for the entry or departure of international air traffic, where the formalities concerning customs, immigration, health, and similar procedures are made available by Directorate of Safety, Security and Economic Regulation on a restricted basis to flights with prior approval only not less than two days prior to the proposed date of operation. National aerodromes available only for domestic air traffic including those military aerodromes where civil air traffic is allowed under certain conditions are Category B, i.e. Adjumani, Achol Pii, Ankole tea, Bugungu, Bugambe, Bundibugyo, etc.

Police aerodromes or strips are Agoro, Loyor, Masaka, Nabilatuk, Kaabong, Amudat, etc.

Uganda is a landlocked country and air transport is of strategic importance to the nation. Air transport guarantees an alternative and one of the most efficient and quickest gateways to the rest of the world. The country's perishable high value commodities, notably flowers, are primarily exported by air. The development of a safe, efficient and reliable air transport industry is among government's priority programs, and the requisite meteorological support is an essential component. We have generated several tables to illustrate the operational capability at the airports.

Table 4.2: Total international passengers at Entebbe Airport.

	2007	2008	2009	2010	2011	2012
Jan	58271	75199	75707	82086	86657	107929
Feb	51612	65615	65298	70932	69904	89415
Mar	65501	85851	71561	76967	79098	97203
Apr	57601	65700	70717	72640	83452	95838
May	61745	74290	72738	82405	83649	93189
Jun	64421	79511	73520	82807	90417	
Jul	73865	85195	87299	100068	107083	
Aug	75181	86165	88340	100582	97476	
Sep	74375	81155	77459	81777	89772	
Oct	67872	78650	87319	92298	99558	
Nov	64151	77609	75788	87878	95034	
Dec	66863	81244	84306	92997	103779	
Total	781428	936184	929042	1023427	1085609	483574

In Table 4.2 above, the number of international passengers arriving and departing at Entebbe Airport has shown an increase in the five-year period passing the one million mark in 2010. The number of passengers has increased about 28 percent over the five-year period. Comparison of the first five months of 2012 against the same period in 2011 indicates another 17 % increase for the year, suggesting that 2012 will continue the trend of increased passenger traffic.

However, Table 4.3 paints a different picture for domestic passenger traffic in Uganda. Over the past five years, domestic traffic arriving and departing passengers from the Entebbe Airport shows a 73% decrease in activity. There are indications of some increases in 2012.

Table 4.4 presents the number of overflights of Ugandan airspace in the past five years. The trend is definitely upward with an increase of over 110% in the five-year period. The numbers for the first five months of 2012 indicate this trend will continue.

Table 4.3: Total domestic passengers at Entebbe Airport.

	2007	2008	2009	2010	2011	2012
Jan	2060	1695	1289	799	715	708
Feb	2343	2306	1476	1028	620	702
Mar	2264	2009	1666	869	789	951
Apr	1833	2035	1458	802	889	904
May	2423	2015	1392	934	773	1014

Jun	2152	1822	1642	1136	821	
Jul	2139	2149	1820		978	
Aug	2287	2023	1347	1198	972	
Sep	2149	1948	1378	922	704	
Oct	2557	1803	2169	1104	703	
Nov	1772	1549	1266	1171	776	
Dec	1920	1718	1006	844	768	
Total	25899	23072	17909	11879	9508	4269

Table 4.4: Total over-flights of Ugandan airspace

	2007	**2008**	**2009**	**2010**	**2011**	**2012**
Jan	520	664	744	787	957	1154
Feb	477	680	641	674	795	1103
Mar	526	675	714	687	904	1127
Apr	537	647	726	634	865	1181
May	552	668	661	702	868	1155
Jun	513	667	680	813	959	
Jul	552	740	747	901	1178	
Aug	589	773	756	872	1153	
Sep	565	668	740	802	1085	
Oct	597	693	741	838	1076	
Nov	639	754	740	932	1169	
Dec	646	762	804	932	1133	
Total	6713	8391	8694	9574	12142	5720

4.6 UGANDA'S INTERNATIONAL RESPONSIBILITIES/OBLIGATIONS WITH RESPECT TO WEATHER DATA

4.6.1 WORLD METEOROLOGICAL ORGANIZATION

The DoM is not currently fully meeting its requirements for providing weather data consistent with the standards established by the WMO. One deficiency is that the deployment of weather stations be representative of individual climate zones to show the spatial variability of the weather elements, especially rainfall.

Broken equipment, inadequate communications, and generally poor infrastructure have negated the ability of the DoM to describe a detailed climatological regime over Uganda. The current station network is incomplete with most stations clustered at sites where institutions or other interested organizations are located. Most of the stations located outside any institutions' jurisdiction are often incomplete because of vandalism or nonoperational equipment. For areas that have no stations, the weather and climate information has to be generalized only using satellite data. WMO data indicate that only 50% or less of Ugandan synoptic reports reach the international communications network.

4.6.2 INTERNATIONAL CIVIL AVIATION ORGANIZATION

The DoM is meeting part of the requirements established by the ICAO. A flight folder/briefing office is preparing appropriate flight documentation for departing international aircraft and a briefing is available for pilots upon request. However, the NMC is not preparing adequate forecasts of local meteorological conditions, nor does it maintain a continuous watch over meteorological conditions affecting flight operations over all the airports in Uganda. It does not exchange meteorological information with other meteorological offices in the country. NMC does not generate SIGMETS of any kind and prepares a terminal area forecast once daily for Entebbe Airport. Similar data is not available for other airports in Uganda with domestic scheduled flight operations. Therefore, on the whole, Uganda is not contributing to the safety, regularity, and efficiency of domestic and international air navigation.

4.6.3 ACCESS TO SOURCES OF INTERNATIONAL WEATHER DATA AND MAPPING

As indicated previously, the NMC has a direct link to Meteosat Second Generation (MSG) Low Rate Information Transfer (LRIT) Direct Dissemination Service. This service allows the NMC to establish and operate a user station to receive a subset of MSG data and products. The linkage provides access to a software package that presents the satellite data along with ingested model data from the UKMO and ECMWF numerical models. The computer also plots up a wide range of variables. A lack of funding prevents the NMC from changing the Station Key Unit (SKU) to obtain additional satellite imagery or data. The SKU is a hardware device required to provide codes used in the decryption of the LRIT data files. The SKU contains a microprocessor that is pre-programmed with a Master Key which, when combined with the other keys within the LRIT allow decryption of the data. No other satellite data is available to the NMC

4.6.4 DATA COMMUNICATIONS

The internal DoM communication system in Uganda is grossly underfunded and not optimally utilized. Meteorological stations are without outgoing telephone service and rely on calls from the NMC to obtain hourly weather reports that are grouped into three-hour packages. Access to the Internet is not

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available and the computer hardware, where available on site, do not have the capacity to handle large volume data streams.

The communication facilities at the NMC are old, with slow operating speeds and are expensive to maintain. Communications among staff at the NMC is by word of mouth or through the passage of written materials. None of the workstations are linked and Internet service within the office is extremely slow. There is an urgent need to overhaul the telecommunication system in order to ensure a standardized exchange of data information with DoM stations and partner states, including meeting the ever dynamic technology challenges.

A new Global Telecommunication System (GTS) switch has been installed between the NMC at Entebbe and RTH Nairobi, Kenya. However, this new GTS switch is not working as negotiations continue between Entebbe and Nairobi to get the switch operational. Forecasters have to depend on a slow connecting Internet to get information from outside Uganda. Synoptic observations from within Uganda are transmitted to the WMO over the Internet.

Once this switch is operational it will permit observations, forecasts and warnings to be distributed to the International communication network and permit the forecasters at NMC Entebbe to receive like data from neighboring countries. The GTS is an integrated network of point-to-point circuits and multi-point circuits, via a combination of terrestrial and satellite telecommunication links, and data-communication network services, which interconnects telecommunication centers and operates with internationally agreed procedures. It consists of a core network, the Main Telecommunications Network (MTN), Regional Meteorological Telecommunication Networks (RMTNs) and National Meteorological Telecommunications Networks (NMTNs). The entire system is operated by national Meteorological Services, national or international satellite agencies or telecommunication service providers under contract.

4.7 SUMMARY AND IMPLICATIONS FOR FUTURE ANALYSIS AND RECOMMENDATIONS

Uganda's meteorological system is not adequate to meet the needs of its citizens for past weather and climate data, present conditions and hazards, or detailed and accurate forecasts of future weather. Many Ugandans have grown accustomed to this state of affairs and are skeptical of the possibility of accurate weather forecasts. The coarse spatial resolution of forecasts (issued only for particular cities and not for distinct regions on a map), the daily-only issuance of forecasts in a climate dominated by fast-evolving convective systems, and the limited (thrice yearly) issuance of long-range (seasonal) forecasts has given the public little opportunity to gain confidence in the Department's forecast skills.

However, a modernized weather service could readily deliver accurate, useful data and forecasts as well as an invaluable weather warning program. The challenge for the modernization process will be build confidence in the future potential of the Meteorological Authority by investing first in the equipment and personnel that can deliver the most dramatically improved information services at a cost that is commensurate with the financial resources available.

In this section we review the current state of Meteorological systems in Uganda, and indicate the broad shape that modernization will need to take. Later installments of our Feasibility Study will present detailed proposals and plans for this modernization.

4.7.1 ADEQUACY OF CURRENT EQUIPMENT

Daytime measurements of temperature and dew point, and daily measurements of precipitation are made at many stations across Uganda, and are made available (together with barometric pressure observations, and in some cases pan evaporation) at least every three hours from the twelve synoptic stations. However, higher time resolution precipitation measurements, precision wind observations at standard levels, observation of insolation and soil moisture and temperature, are generally lacking. Nighttime observations are available only from the automated stations, many of which are in disrepair. A well-calibrated and widely disseminated system of AWS's, including observations of air quality, insolation and soil quality will be a crucial component of Meteorological modernization.

Except for Entebbe, there is no instrumentation at any of the airports runway and landing thresholds. As the aviation program expands in Uganda, DoM should seek the help of the Uganda CAA to install airport instrumentation at proper locations. Ultimately all airports providing MET services should install automatic weather stations at locations along the runway boundaries. In the meantime, the control tower weather instruments will often be the only meteorological instruments available at many of Uganda's smaller airports. The basic tower MET systems, however, only include an altimeter, wind speed, and wind direction. There is also a need for at least an approximate measurement of the ambient air temperature to aid pilots in calculating aircraft maximum takeoff weights.

The current Agromet station network should be included within a new communication system that will be required to get all observations centralized and available for scrutiny spatial resolution of the forecasts are improved. As a start the Agromet stations should give daily reports to the synoptic stations who would then relay the information to the newly designed Forecast Center at Entebbe.

Until the Fall of 2012, Uganda's upper air sounding system at Entebbe ~~has~~ had been out of order for some time. ~~The Consulting cannot emphasize strongly enough the importance of getting the system up and running.~~ Upper air soundings are critical for forecasting convective activity and Uganda needs to have reliable 12 Z sounding available and should have a goal of also launching a regular 00 Z sounding from Entebbe. The Consulting team is aware of a current plan to put in a new system and get adequate hydrogen generation for the system. The pibal network is nonexistent due to lack of hydrogen and decay and theft of instrumentation. Data aloft is extremely important and as the modernized system becomes capable of ingesting real-time data, the monitoring of the winds aloft can only help improve the real time forecasts and warnings.

Neither lightning detection nor radar is operated by the DoM.

Communication between DoM facilities is woefully inadequate. No telephone service, inadequate minutes on cell phones, Internet unavailable or painfully slow was the normal operation that the consultants found in their office visits. Improved access to Internet connectivity is likely to become an important issue as additional data sets and large image files are broadcast in support of enhanced pilot briefing systems at airports other than Entebbe and enhanced DoM offices in the up country.

4.7.2 MAINTENANCE AND CALIBRATION

In our survey, we found that equipment maintenance, especially of electronic equipment such as AWS's, is poorly coordinated across the DoM. The most obvious problem with the meteorological sensors is the apparent lack of adequate routine maintenance and prompt repair after systems go out of warranty. In some cases, systems that have been installed only a few years ago have been abandoned, taken off the inventory lists, and left to rust in place.

As a critical aspect of any maintenance initiative, there is a need to establish a calibration facility to make periodic checks of sensor performance. This can be done through the acquisition of a number of portable reference quality sensors that can be used to check sensor performance in their operational environment. A routine schedule of calibration tests should be combined with preventative maintenance activities. Instruments with moving parts, like wind vanes and rotating cup anemometers, usually require the most maintenance, including regular replacement of their bearings on a schedule as recommended by the manufacturer.

In addition to the portable reference quality sensors, there should be a calibration laboratory with more sophisticated reference standards and controlled environment chambers for verifying the accuracy of the portable reference sensors and for extended testing of suspect sensors removed from operational use. This laboratory must be a dedicated facility run by UNMA.

Maintenance is a vital part of a meteorological observational system as with any other electrical or mechanical system. ICAO Annex 3 (paragraphs 2.2.2 to 2.2.4) emphasizes the need for accurate, reliable observations in the context of "quality assurance" and explicitly calls attention to the need for calibration and maintenance activities (paragraph 4.4).

As a part of a general effort for monitoring data quality, there should also be routine checks to ensure that data submissions are actually reaching their intended international destinations and are available through the GTS and AFTN international OPMET databases (see Annex 3, paragraph 2.2.5).

Observers with a special interest and talent for working directly with weather sensors may be good candidates for advanced training in maintenance and calibration leading up to being assigned to a calibration and maintenance group.

4.7.3 OPERATIONS AND PROCEDURES

Safe and efficient flight operations and accurate aviation and public forecasts and warnings require a good situational awareness of current weather conditions, and accurate nowcasts (0 to 2 hours) and forecasts (2 to 24 hours) of adverse weather. At present, the only attempt at situational awareness using the products received from the GMS combined with limited surface observations. Public forecasts are issued once a day to four cities. No routine agriculture forecasts are issued and no SIGMET or AIREP reports are issued. The issuance of SIGMET and AIREP reports should provide critical weather information.

UNMA will need to issue the required SIGMETs and AIREPs. AIREPs, in particular, should be relatively easy to implement since the formal reporting of written AIREPs is primarily a procedural and operational issue, not requiring any substantial reallocation of resources. Pilots already verbally report turbulence and other hazards to Air Traffic Control (ATC), and these warnings are often transmitted verbally to other planes in the area. The ATC in Uganda is located at Entebbe Airport in the same building as the DoM National Meteorological Center (NMC). There is no connectivity between the two sites even though they are only meters apart. One of the priority tasks should be to establish connectivity between the ATC and the NMC and use the communication staff at NMC to transcribe verbal reports hazards into written records that can be entered into the GTS and AFTN system. The generation of written AIREPs and SIGMETs can be facilitated through the use of computer-based templates for easy report preparation.

For operational efficiency, Uganda should expand the local networking of meteorological workstations so that there isn’t a need to manually retype METARs and other synoptic reports on multiple systems such as is done now. Manual retyping is slow and increases the likelihood of introducing errors into the reports. To the extent possible, use of computer templates and automatic checking of outgoing messages to ensure that they are machine readable should be incorporated into routine operations. These systems are needed to support the emerging generation of CNS/ATM systems that will be based on computer monitoring of submitted reports.

Within an expanded system of local networking and data sharing, there needs to be an increased use of meteorological workstations for data integration and forecasting. In particular, these workstations need to incorporate automatic plotting and analysis software suitable for processing Ugandan upper-air soundings and pibals.

As an important part of submitting METAR and upper air reports into the AFTN and GTS data communication systems, Ugandan MET staff should routinely confirm that submitted reports actually get into the international OPMET databanks. There should be a serious effort to ensure that current products, observations, reports and forecasts are successfully reaching their intended targets.

As discussed in Section 8, the NMC is not preparing adequate forecasts of local meteorological conditions, nor does it maintain a continuous watch over meteorological conditions affecting flight operations over all the airports in Uganda. It does not routinely exchange meteorological information with other meteorological offices in the country. NMC does not generate SIGMETS of any kind and only prepares a terminal forecast for Entebbe Airport. Similar data is not available for other airports in Uganda with domestic scheduled flight operations. Therefore, on the whole, Uganda is not contributing to the safety, regularity, and efficiency of domestic and international air navigation. An aerodrome forecast (TAF) is required for Uganda’s international airport Entebbe (AFI FASID, Table MET 1A), and is being issued.

As a goal, UNMA should work towards having tailored forecasts, updated several times daily and extending at least five days, for every administrative region. Long-term forecasts of precipitation, based on publically available climate forecast models (e.g. the U.S. NWS Climate Forecast System, http://www.cpc.ncep.noaa.gov/products/CFSv2/CFSv2seasonal.shtml) should be issued at least every two weeks, rather than three times yearly as at present. These agricultural forecasts should be issued collaboratively with trained Agrometeorologists at the Department of Agriculture. TAFs should be issued several times daily for every controlled airport. Such an expansion in the number of forecasts may require the decentralization of some forecasting functions to regional centers or to local airports where the experience of the airport meteorologists regarding local weather could be an advantage. This possibility of this decentralization is another key benefit of the provision of internet access to each field office of the UNMA.

As a key component of the forecast program, UNMA, CAA, and Department of Agriculture should initiate a comprehensive program of forecast verification as a tool for improving forecasts and as a way to increase confidence in the forecast products.

At present, Uganda has not established effective two-way communication with the Toulouse Volcanic Ash Advisory Center (VAAC). Because of the extreme time sensitivity for issuing notices of volcanic eruptions, communication with the Toulouse VAAC requires special procedures, including authorizations for direct long-distance and telephone calls and FAX transmissions. Yet, the Nyamuragira volcano is located very near Uganda's western border and has a history of eruptions. As soon as there is any evidence of an imminent eruption or early reports of an actual eruption the NMC Meteorological Watch Office (MWO) is required to issue a SIGMET announcing the potential danger. After issuing the SIGMET, the MWO should follow up with a direct phone call to the Toulouse VAAC, a FAX, or a direct e-mail message notifying them of the eruption or potential eruption. After being notified, the Toulouse VAAC will monitor the volcano and issue its own advisory with more specific information about the hazard. After receiving the volcanic ash advisory or other direct contacts from the Toulouse VAAC, the NMC MWO will issue a second, more detailed SIGMET, if required. Volcanic ash SIGMETs are always issued by the MWO and not by the VAAC. To ensure that the MWO is able to communicate with the Toulouse VAAC as required, NMC should confirm that the Toulouse VAAC has current contact information for the MWO (including voice phone and FAX numbers) and conduct yearly communication tests with the VAAC.

4.7.4 PERSONNEL AND TRAINING

There are staffed observatories at principal airport locations (Entebbe, Soroti, Kasese, and Gulu pending). The staffing and skill levels at the meteorological stations are, for the most part, inadequate and/or underutilized. The DoM has seen a major reduction in its workforce over the past many years, from some 750 in 1977 to about 126 presently. There are many reasons for this decrease, including the long awaited organizational change to an Authority. Nonetheless, the current staffing levels do not support the mission of the DoM. For proper functioning on a 24/7 basis, each synoptic station should be staffed with a five-person complement. Shift work is a requisite, as is the provision of adequate resources to conduct their responsibilities – housing, transportation, security, communications and modernized working facilities – each of which will be evaluated in subsequent chapters of this report.

In addition to the lack of adequate working facilities, training and advancement opportunities are extremely limited, which lends to an observed low morale among the staff. Position descriptions and performance standards are in place, but serve little purpose unless the staff is motivated to achieve higher personal goals and objectives, and receive commensurate consideration. The shifting of training responsibility from the DoM to the Ministry of Education and Sports appears to have adversely affected career development of the DoM staff, and a means to transfer that function back to the UNMA is one of the objectives to be addressed in our Feasibility Study. The vast majority of the meteorological staff working at Uganda meteorological offices and the NMC Meteorological Watch Office are classified as observers, many of whom have performed the same job for 15-20 years. These observers have shown great loyalty and dedication in staying with their jobs this long even without opportunities for training or professional advancement. The consultants feel that these staff members represent an untapped resource that could be used to increase the number of more highly trained MET staff. With the eventual introduction of advanced observational systems and improved meteorological briefing materials, it will become increasingly important to develop personnel to fill more high-level meteorologist positions. The most efficient way to fill these positions is through advanced training of existing staff members.

The introduction of automatic weather observing stations at Ugandan airports should eventually reduce the time required to prepare and distribute METARs and other routine observational chores that take up most of the observers' work day. With additional training, the observers could be able to provide enhanced briefing services and assist with the preparation of TAFs for additional airports and tailored forecasts for local radio stations and other specific interests, while limiting the need to hire more staff.

In additional to the standard courses for advancement to higher WMO classifications, there may be a particular need for special training in the areas of sounding analysis and prediction of convective activity. The airports with cloud ceiling and visibility problems suggests that special training in predicting the onset and clearing of fog and low cloud would be a great benefit to the Ugandan meteorological system. As new equipment and facilities become available, there will need to be special training courses for the users of the new resources, well beyond a cursory training of a limited number of designated staff.

An especially challenging training program is that for radar. Because there are no radar meteorologists within the DoM there is a need to use one or more outside experts to assist Uganda in designing a radar training program for all Ugandan meteorologists. Essentially every meteorologist in Uganda must be taught weather radar and especially in Doppler and dual polarization radar. Training in radar theory will be essential as will be the limitations of radar. (See Topic 3. http://www.wdtb.noaa.gov/courses/dloc/outline.html.) Then the design of the particular radars to be used by the UNMA must be covered (Topic 2, 3).

However, the operational meteorologist will not perform radar maintenance or calibration. These are strictly electrical engineering or electrical technician duties. Maintenance training should use hands on training on separate radar and not one used for applications to weather. This radar would be used to train maintenance personnel.

See http://www.wdtb.noaa.gov/courses/dloc/index.html for an operational weather radar training program. Note that much of that training can be accomplished using distance learning so staff does not have to leave their station to obtain most of the training. . In fact, a variety of training delivery techniques are used including, for example, those listed under Topic 7 of the above URL. Note that those methods listed are: on-line web module (prerequisites), asynchronous instructor-led web modules (Lessons 1-18), and tele-training (Lesson 19) However, the current program does require one week of residence training where half of that period is spent using the WES or the Warning Event Simulator. In fact, a variety of training techniques are mentioned below.

Another major aspect of radar training is that of actual applications to weather and storms and the related image and data interpretation. This will involve a study of the types of storms and the environments conducive to those storms. (See Topic 7 under the referenced URL). Then the Ugandan meteorologist must learn the conceptual models of these storms found in the “base data”, their environments, and radar recognition of these storms (e.g., Topic 7).. With that recognition will come an understanding of the storm threats such as hail, microbursts, and flooding rains which are often associated with those storms. Certain “signatures” will appear in radar images that involve the conceptual storm models and the production of these damaging threats. The forecaster is then able to assess the threat through storm interrogation and issue warnings a required. The goal to issue warnings with a “lead time”, before the threat is manifest. In other words, the warning forecaster attempts to issue the warning BEFORE the event actually occurs at the surface.

However, in addition to learning storm recognition through the base data interrogation, a number of derived products and related algorithms are used with modern weather radars (see the above referenced Topic 5). Each and all of these products and algorithms must be thoroughly understood by the operational meteorologists employing radar in their duties.

Finally, as mentioned above the use of a Weather Event Simulator is a very successful technique and is used extensively in the U.S. for hands-on training. This is very similar to the pilot simulators used by airlines in training. This training program also trains the meteorologist in the use of the Work stations. In time, hopefully a simulator can be added to the Ugandan training program. This is a major software development project, requiring something on the order of two person-years of effort by a well-trained programmer and an expert meteorological observer.

It is obvious that this specialized training program must be developed or begun development very early in the modernization program. For that reason it is recommended that a selected few training meteorologists be trained, perhaps in the U.S., very early in the program. A consultant can help with this. In this way the trainers are trained in the U.S, perhaps at the Warning Decision Training Branch in Norman, OK.

Please visit the Warning Decision Training Branch and the Distance Learning Operations Course (DLOC). http://www.wdtb.noaa.gov/courses/dloc/index.html and browse through the topics. See also the Student Guide for Topic 7: Convective Storm Structure and Evolution.

The remaining training program should make full use of AFI technical cooperation regional projects as well as taking advantage of the full range of WMO training opportunities. Additional specialized training may require an enhanced training budget within DoM to support customized training programs that would be offered to meteorologists. The radar training program is one of these.

At the highest level, senior meteorologists should be encouraged to seek advanced university degrees either in Ugandan or outside the country. Such training, perhaps assisted by government financial assistance, could be used to develop advanced capabilities in specialized applications such as radar meteorology, satellite meteorology, or numerical modeling.

One way to ensure that training is focused on actual day-to-day operational needs would be to bring in outside consultants, perhaps recently retired senior meteorologists from the AFI region or meteorologists from Europe or the US, to act as resident mentors, working alongside Ugandan forecasters and analysts as they do their normal daily activities.

4.7.5 ORGANIZATION

As discussed in Sections 1 and 5, the existing organizational structure of the meteorological system in Uganda is lacking clear lines of authority and interconnectivity. Presently DoM is centralized and does not cover all of Uganda. Our discussions revealed a number of organizational difficulties. Maintenance is poorly coordinated across the department. There is an absolute dependence on the National Meteorological Center in Entebbe for all forecast and synoptic data, when internet access would make individual stations much more able to provide forecast and data services to their local communities. While organizational issues will be addressed in a later phase of this study, it is clear that there needs to be a thorough examination of the options for streamlining the organizational structure and improving efficiency. In the end there needs to be a clear structure, with clear responsibilities. Centralized monitoring of maintenance schedules, capabilities and deficiencies, and prioritization and mobilization of repairs, is a particularly crucial pre-condition to the modernization project.

We also found a lack of legal and institutional framework for cost recovery, and provision of meteorological services. Additionally, there has been a diminishing government financial budgetary support; inability to train, recruit and retain qualified human resources.

Before entering into serious consideration of reorganization, it will be necessary for the UNMA to conduct a careful review of their respective responsibilities and obligations for airport meteorological stations, synoptic stations, Agromet, hydromet stations and rainfall stations. While there are obligations for meteorological support to aviation, many of the airport weather stations could be used as synoptic stations in support of the WMO's World Weather Watch and Regional Basic Synoptic Network (RBSN) as well as serving as climate stations as part of the WMO's Regional Basic Climate Network (RBCN) and Global Climate Observing System (GCOS).

As part of this review of national and international data reporting requirements, the UNMA should carefully review the relevant ICAO and WMO documents for consistency and accuracy. In reviewing these documents for this report we discovered a number of what appear to be unrealistic commitments, observing stations that may no longer be in service, and internal inconsistencies. Updating the formal ICAO and WMO publications, however, should wait until a clear plan for future Ugandan observations has been agreed upon.

Changing the organizational structure can't compensate for inadequate funding and limited resources, but may minimize duplicate efforts and remove some administrative obstacles to efficient operations. On the other hand, an investment program for human capacity building will enable the UNMA to improve its level of service to vital sectors as well as enhance a much needed public service capability.

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5 EQUIPMENT AND FACILITY REQUIREMENTS

This report is the second of a series to be prepared by MDA Information Systems, Inc (hereinafter MDA) under a grant to the Uganda Department of Meteorology funded by the United States Trade and Development Agency. The first report presented an assessment of the existing weather data collection, analysis and dissemination capabilities of the Uganda Department of Meteorology (DoM) based on representative site visits conducted by the MDA team members. This second report addresses equipment and facility requirements to meet existing deficiencies and establish a framework for the phased implementation of a modernized Ugandan meteorological system. Additionally, this report identifies the requisite Capital Investment Program and potential environmental impacts associated with the implementation of the equipment and facility improvement program. Each of these aspects will be influenced by the pending designation of the DoM as the Uganda National Meteorology Authority. Emphasis is placed on the identification of a modernization program that focuses on the aviation and agricultural sectors of the Ugandan economy, as well as on the provision of weather and climate information to Ugandans that enables them to protect life, health and property from weather hazards. Ugandan obligations to international organizations that establish standards for the quality and reporting of weather information are an integral component of the feasibility study. The obligations incurred by Uganda in this respect are to the International Civil Aviation Organization and the World Meteorological Organization.

Recommendations for a financial plan will be presented in a subsequent report, building on the findings and recommendations from the previous documents and the experience and judgment of the MDA Team. In addition, recommendation for staff training and for U.S. suppliers of major hardware and software items will also be provided in subsequent reports.

5.1 NATIONAL SENSOR NETWORK

5.1.1 INTRODUCTION

Weather sensors form an integral component of a modernized meteorological service. Equipment in common use worldwide allow for automated readings independent of human intervention, thereby affording individuals trained in the meteorological sciences to utilize the data and prepare user-specific forecasts, warnings and other value-added products and services to the wide range of industry sectors that are dependent on timely and reliable weather data. Automated weather observations should conform to international standards that vary depending on the type of sensor and the ultimate user of that information. The more exacting performance standards typically apply to those sensors serving the aviation sector.

Surface observations are critical for satisfying ICAO and WMO international requirements, short-term forecasting, issuance and verification of warnings, calibration of remotely sensed data, research, and for climate change studies. In addition, the data are used for decisions regarding natural catastrophes, human health, energy resources, water resources, ecosystems, agriculture, tourism, transportation, and construction.

For most measurements, well-maintained automated sensors provide the highest quality and consistent data for users, particularly if the data are quality assured through a systematic procedure that includes both manual and automated methods. Research-quality data made available in real-time to decision makers should be the goal of every UNMA surface observing system. In addition, for cost effectiveness, observing networks should be designed with multiple purposes, overarching objectives, and input from multiple stakeholders both within and outside the UNMA.

Manual observations need to be continued for observations that are difficult or cost-prohibitive to automate (e.g., cloud buildup not within sensor range, hail size, smoke plumes); sites located in remote locations and lacking of communication facilities or in difficult terrain; or to maintain data continuity at sites with historically long records. The UNMA should move quickly and decisively to transition to automated measurements with high temporal resolution, low data transmission latency, and appropriate spatial resolution, as required by DoM users and recommended by the WMO. During the transition, the UNMA should provide a period of overlap of manual and automated measurements that lasts for at least 12 months. Daily raingage measurements collocated with automated (tipping bucket) measurements should be continued indefinitely to maintain an accurate record. This transition would include improvements to the existing manual observational network to bring it back to good working order, and the establishment of detailed calibration procedures that guarantee that accuracy of the automated observational system by comparison of each instrument against internationally accepted standard measurements. In our Capital Investment Program, we have allocated $50,000 in the first year to bring the observational equipment of the synoptic and Agromet stations back up to fully operational status. This includes purchase of NIST-certified thermometers and barometers and wind vanes and anemometers, as well as repairs to Stevenson Screens.

Automated stations are those stations where instruments take observations automatically and transmit (or record) their data electronically. These stations should be located where a long period of record is desired; power supply (e.g., solar or electrical) is adequate to provide for 24 hours per day, 7 days per week, 52 weeks per year (24x7x52) operations; and two-way, real-time communications are ensured. Deployment of new automated stations should be conducted jointly with the upgrade or deletion of existing, older automated sites. Unless superseded by other needs, the UNMA should reduce or terminate the manned portion of 24x7x52 synoptic stations after automated stations demonstrate a record of reliably measured elements. The DoM should maintain at least five types of meteorological stations in the hydro-climatic network – aviation, synoptic, climatological, agro-meteorological, and hydro-meteorological.

The UNMA should establish standardized measurement protocols, procedures, siting, instrumentation, metadata, and elements measured. Observations should comply with ICAO and WMO standards as much as practicable, being mindful of the needs of the users. Elements measured should be categorized as required or desired. Required elements must be measured at all standardized observing stations (i.e., at airport stations, at surface synoptic stations for atmospheric observations, at agriculture stations, at main hydrological stations for hydrological observations). Desired elements may or may not be measured at every standardized observing station. In all cases, observations should be collected and transmitted in a manner consistent with their use in an operational environment -- regularly, accurately, and with notation of any reason to suspect data quality.

The final report (WMO-No. 1068) of the Fifteenth Session of Regional Association 1 (Africa), Regional Basic Synoptic Network (RBSN) prepared in November 2010 presented a listing of synoptic and climatological stations for Uganda as presented in Table 5.1.

Table 5.1

Synoptic and Climatological Network for Uganda

		Type of Station	
Index	**Station Name**	**Synoptic**	**Climatological**
63602	Arua	Yes	Yes
63630	Gulu	Yes	Yes
63654	Masindi	Yes	Yes
63658	Soroti	Yes	Yes
63674	Kasese	Yes	Yes
63682	Jinja	Yes	No
63684	Tororo	Yes	Yes
63702	Mbarara	Yes	Yes
63705	Entebbe Airport	Yes	Yes
63726	Kabale	Yes	No

In that same document, the WMO urges members to:

- Secure, at the earliest date possible, full implementation of the network of RBSN and RBCN stations and observational programs set forth in Annexes I and II to the present resolution.
- Comply fully with the standard times of observation, the global and regional coding procedures and data collection standards as laid down in the WMO Technical Regulations (WMO-No. 49), the Manual on the Global Observing System (WMO-No. 544), the Manual on Codes (WMO-No. 306) and the Manual on the Global Telecommunication System (WMO-No. 386.)

The criteria for inclusion of stations in the RBSN are classified in two groups. For the definition of criteria, two types of requirements are distinguished:

- Target requirements (TRQs) that refer to desired characteristics of network stations.
- Minimum requirements (MRQs) that refer to threshold characteristics which are decisive for inclusion or exclusion of a station.

The inclusion of a station in the network implies a clear commitment of the Member concerned to make fair efforts to achieve and maintain compliance with the TRQs.

Table 5.2

Target and Minimum Requirements

Requirement	**TRQ Surface**	**MRQ Surface**
Parameters (measured and recorded)	Pressure Temperature Wind Humidity Weather Visibility Cloud Cover Cloud Base	Pressure Temperature Wind; (not for buoys) Humidity. (Not for buoys)
Level	Surface	Surface
Observations at main hours	4	3
Observations at main and Intermediate hours (3 hourly)	8	5
Availability of data	100%	50%

The MDA Team further recommends that data quality assurance (QA) measures incorporate an integrated system of standardized sensor calibration and maintenance, site maintenance, accurate and up-to-date metadata, automated quality control (QC) routines, manual QC by trained and well-qualified professionals, and complete technical support. An appropriate upgrade or replacement cycle should be specified for each sensor and funded through the annual UNMA budget. Through careful attention to the QA process, research-quality surface data can and should be made available in real-time to users.

Detailed specifications for instrument requirements are presented in tabular form in Section 14.

5.1.2 RECOMMENDED DEPLOYMENT OF AUTOMATED WEATHER SYSTEMS

The use of automated weather stations at airports, surface synoptic sites, and agricultural and hydrological stations is recommended where feasible within Uganda. Of these automated weather stations, those serving the aviation community must comply with ICAO standards that address the technical specifications and performance of each of the weather sensors. Additionally, automated weather stations at airports serve a dual role by supplanting or complementing similar stations used for other meteorological purposes.

A plausible AWS network layout is shown in Figure 5.1. Locations are not precise- we used the centroid of the district in which the station would be located. In addition to the synoptic stations, we emphasized a relatively even spatial distribution, coverage for regions with especially low and high altitudes, and made sure to include a station on one of the Lake Victoria Islands (Bugala Island). The stations are located in the following districts: Kooki, Kabula, Buruli, Bbaale, Kiboga, Nakaseke, Buwekula, Kongasis, Manjiya, Bulamogi, Kasilo, Usuk, Okoro, Dodoth, Jonam, Obongi, Lamwo, Bokora, Nwoya, Chua, Jie, Kilak, Agago, Matheniko, East Moyo, Aruu, Bufumbira, Bunyangabu, Bwamba, Ntoroko, Nyabushozi, Mwenge, Bujenje, Kibale, Igara, Bujjumba. Buhaguzi, Kampala, Bukoto, Kampala, Jinja, Soroti, Tororo, Arua, Gulu, Lira, Kabale, Busongora, Kibanda, and Mbarara.

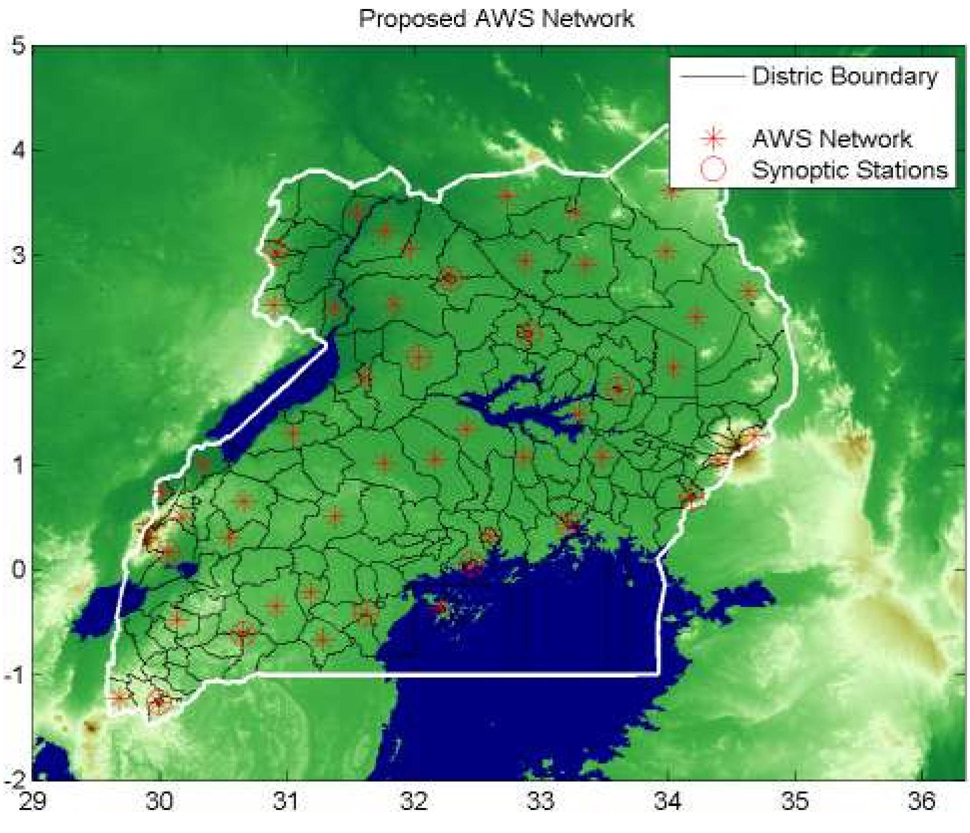


Figure 5.1: Proposed AWS nework. Approximate station locations are shown with *'s, and the synoptic stations (which will have AWS stations) are denoted with o's.

5.1.3 AVIATION

The automated weather stations at airports should provide real-time data on the following parameters:

- Wind speed
- Wind direction

- Temperature
- Dew point
- Barometric pressure (two systems for cross check and verification)
- Cloud Ceiling
- Visibility
- Present weather (type precipitation)
- Thunderstorm activity

Weather observations at airports should be updated on a minute-by-minute basis and the reports transmitted to either the air traffic control tower when operational for direct communication to the pilot upon request or as part of clearances, or broadcast over a discrete frequency for pilots in aircraft on the ground or en route. A typical voice-synthesized broadcast range is 45 km, which affords pilots in the area with ample time to make flight route decisions.

In Uganda, the automated weather stations should be located at the airports provided with scheduled domestic and international airline service. These would include Entebbe, Gulu, Kasese, and Soroti, Three automated weather stations are positioned along Runway 17-35 at the Entebbe International Airport; however, the MDA Team has not been able to confirm if these meet ICAO standards. Additionally, airports that are available for international operations should be equipped with an automated weather station. These include the airports serving Arua, Kidepo and Pakuba.

The availability of aviation weather to pilots while en route is especially valuable, particularly as weather boundaries move across the country. Pilots also need to know weather conditions at their destination and alternate airports prior to initiating their flight. When weather conditions deteriorate at the destination airport, these pilots need to be prepared to fly to their alternate airport. This strongly implies that weather information at the alternate airport be known as well. A distribution of automated weather stations deployed at airports across Uganda helps to provide area wide coverage of aviation weather data. As pilots navigate, they can tune into the automated weather station broadcast frequency and listen to the weather observation data in real-time. They can self-monitor if weather conditions are stable or deteriorating along their route of flight. As they approach their destination airport that is equipped with an automated weather station, pilots may continually monitor the automated weather station broadcast to ensure that weather conditions are favorable and not below authorized landing minima. When necessary, they may opt to discontinue the approach and fly direct to their alternate airport. This avoids the need to execute a missed approach procedure, saves time and fuel associated with the flight, and enhances flight safety.

Therefore, in addition to the seven airports indicated above, the UNMA should establish a network of automated weather facilities at airports positioned on the order of 100 km apart, which represents a flight time of about 30 minutes for light aircraft. Airports should be selected that are located along commonly flown visual and instrument flight routes, have reliable power sources, and are secured to prevent vandalism. It is noted that automated weather stations can be powered using solar panels. The UNMA should coordinate with the Civil Aviation Administration to identify those airports suitably sited to serve in the role of en route surface weather data.

5.1.4 UPPER AIR

Restoration of the upper air sounding capability at Entebbe should be a very high priority, since regular upper air wind observations will not only improve forecasts of convection for the day ahead, but via the assimilation of radiosonde winds into global models will likely result in significant improvements in the 1-5 day forecasts for Uganda and surrounding countries. Such improvements have been noted in East Africa, since the reestablishment of the sounding network there as part of the AMMA experiment. Ugandan forecasts would benefit significantly from additional soundings in Tanzania and Kenya.

The MDA Team has been advised that the UNMA has negotiated with Vaisala Oyj of Finland to purchase RS92-SGPD radiosondes and a hydrogen generator. Vaisala Oyj has included 400 radiosondes as part of the sale, which will enable one sounding per day. The MDA Team encourages the UNMA to acquire an additional 400 radiosondes in order to comply with WMO recommendations to conduct twice daily soundings.

Once the capacity for soundings exists, it will be possible to test the additional forecast skill benefit derived from an additional sounding station in Uganda, which could be located at Gulu or Soroti.

5.1.5 SURFACE SYNOPTIC

The WMO agreement with DoM has deemed that nine stations are sufficient to represent the major climate regions of Uganda. However, the present network does not include the high altitude regions where climate sensitivity (expected warming due to human greenhouse gas emissions) is expected to be largest, and where ecological sensitivity to climate change is also especially large. The ITFC/TEAM site at Bwindi could be added to the network with the addition of communication capability. Stations in the Rwenzori west of Kasese and on the slopes of Mount Elgon would also be excellent candidates for long-term climate monitoring capability. In addition, the addition of a synoptic station in the Masaka area would fill a gap in a highly populated region of Uganda.

5.1.6 AGRICULTURAL

The current network is sufficient to observe conditions in all agricultural regions of Uganda. However, reliable automated soil moisture, soil temperature and evaporation measurements are crucial, as is reliable archiving and public accessibility of data. Evaporation measurements using manually read evaporation pans are made only sporadically at synoptic stations at present. We recommend that these be replaced with simpler systems (such as the ETgage, for example), that have a smaller evaporative surface, designed to mimic evaporation from a particular plant type, and therefore require much less frequent and voluminous resupply with water. As many synoptic and agrometeorological stations have no convenient water supply, this will substantially improve the dependability of these measurements.

5.1.7 HYDRO-METEOROLOGICAL

The current hydro-meteorological network needs to be reevaluated to reflect the inclusion of the new stations that the Directorate of Water Resources Management has deployed or plans to deploy.

5.2 AIR POLLUTION

Air pollution is a serious concern in Uganda, due especially to heavy reliance on charcoal burning for cooking and heating, and on agricultural burning for disposal of crop residue. AERONET observations (available at http://aeronet.gsfc.nasa.gov) in the 2000's demonstrated that levels of aerosol pollution frequently exceed levels considered unhealthy by epidemiologists. In 2008, the government of Uganda joined with other East African states in signing the East African Air Pollution Agreement (http://www.sei-international.org/gapforum/regions/East_Africa/Eastern_Africa_Air_Pollution_Agreement.pdf), agreeing to "develop and maintain national emission inventories for main air pollutants and greenhouse gases, including trans-boundary air pollution and assess the impact of different policies and measures on these emissions" and to "establish air quality monitoring stations using harmonized regional instrumentation and protocols and link this to modeling and forecasting efforts globally."

Ideally, the UNMA would deploy a suite of sensors to detect the major air pollutants in a wide range of setting across Uganda - some in rural areas, some in urban and suburban areas, and some in important tourist areas where visibility would be a particular concern. Sensors in mountainous areas on the east and west boarders of Uganda would help to define background levels of air pollution imported from neighboring countries.

A sufficient sensor suite would include the following automated analyzers and sensors:

- ozone (O3),
- carbon monoxide (CO),
- nitrogen oxide (NO, NO2, and the suite of reactive nitrogen oxides referred to as NOy)
- sulfur dioxide (SO2)

- PM2.5
- PM10 fraction
- visibility

Such a suite would cost approximately US$100,000 at each location. A good starting point might be to install sensor suites measuring PM2.5 and ozone, which might cost $30,000, at the Makerere University (Kampala) and Kabale stations. Makerere would sample air affecting Uganda's largest population center, and Kabale lies in a narrow mountain valley, where particulate pollution is likely to be particularly unhealthy. Visibility sensors, carbon monoxide and ozone analyzers could be installed at the ITFC site in Bwindi Impenetrable, Kidepo and Queen Elizabeth National Parks, and at a site on Mt. Elgon. These locations are important tourist destinations, and are high altitude sites near Uganda's borders, well situated to observe imports of long-lived pollutants such as ozone and carbon monoxide from neighboring countries. When financially viable, the sensor suite can be upgraded to include the other pollutant measures listed.

5.3 REMOTE SENSING OF PRECIPITATION

5.3.1 METEOROLOGICAL RADARS

Most of the major weather threats to Uganda other than drought are directly caused by or related to thunderstorms. As stated earlier, the main tool used to nowcast or warn for these storms is radar. Uganda simply cannot implement a nowcasting and warning program without a network of S-band Polarimetric Doppler weather radars. Nor can they implement routine forecasting without weather radar.

5.3.1.1 WHY DUAL POLARIZATION RADAR?

Considering that most European countries use C-band Doppler weather radar and certainly not dual pol radars then why does MDA recommend dual pol radar? As far as S-band, all we will say here is that S-band is chosen to avoid the serious problem of attenuation at S-band. But we will consider more carefully the question of why dual polarization.

Briefly, a basic weather radar transmits a powerful microwave signal in the form of a “pencil beam”. After transmitting this pulse of energy the radar receiver “listens” for very weak backscattered power. The amplitude of this backscattered power, measured in dBZ, from a target is said to be *reflectivity* or in short sometimes it is referred to as *Z.* A Doppler weather radar continues to transmit these powerful pulses and to receive and measure Z but it also has the ability to measure additionally, both the *Mean Radial Velocity* of the target (measured in m/s or in knots) and called V for short and the velocity *Spectrum Width* or SW (again measured in m/s or knots). Thus a Doppler weather radar measures these 3 base “moments” (Z, V, and SW) or basic variables. With the upgrade of the radar to a dual-pol radar we add 3 more base moments. First, we add the *“differential reflectivity”* or the ratio of the reflected horizontal and vertical power returns. Among other things, it is a good indicator of drop shape which can assist the meteorologists in estimating the average drop size. This ratio is the magnitude between the vertical and horizontal polarized signals and is called *ZDR* (in dB). The second variable that is measured by the dual pol radar is the “*Correlation Coefficent” (CC)* which is a statistical correlation between the reflected horizontal and vertical power returns. It is a good indicator of regions where there is a mixture of precipitation types, such as rain and hail. It is also a good indicator of the target types other than weather targets such as birds, insects, smoke, etc. And the third dual pol variable is *Specific Differential Phase (KDP) and is* a very good estimator of rain rate. The specific differential phase is a comparison of the returned phase difference between the horizontal and vertical pulses in degrees per km. This phase difference is caused by the difference in the number of wave cycles (or wavelengths) along the propagation path for horizontal and vertically polarized waves. Unlike the differential reflectivity and CC and linear depolarization ratio, which are dependent on reflected power, the specific differential phase is a "propagation effect." The specific differential phase is a comparison of the returned phase difference between the horizontal and vertical pulses. This phase difference is caused by the difference in the number of wave cycles (or wavelengths) along the propagation path for horizontal and vertically polarized waves. It should not be confused with the Doppler frequency shift, which is caused by the motion of the cloud and precipitation particles.

The meteorologist must use all these moments or variables together in combination and he/she must watch closely to see which variables are high or increasing and which are low or decreasing. We now consider at an example.

As with many of the applications using dual-pol radar, active knowledge of the near-storm environment is crucial. For heavy rain, this is especially so because it keeps situational awareness of what variables to expect to be high. If a local or model sounding looks something like the sounding in Figure 5.2, with very thin CAPE, low LCL, a deep warm cloud layer, very high precipitable water, and deep moisture, highly efficient rain production and more of a tropical drop size distribution would be expected.

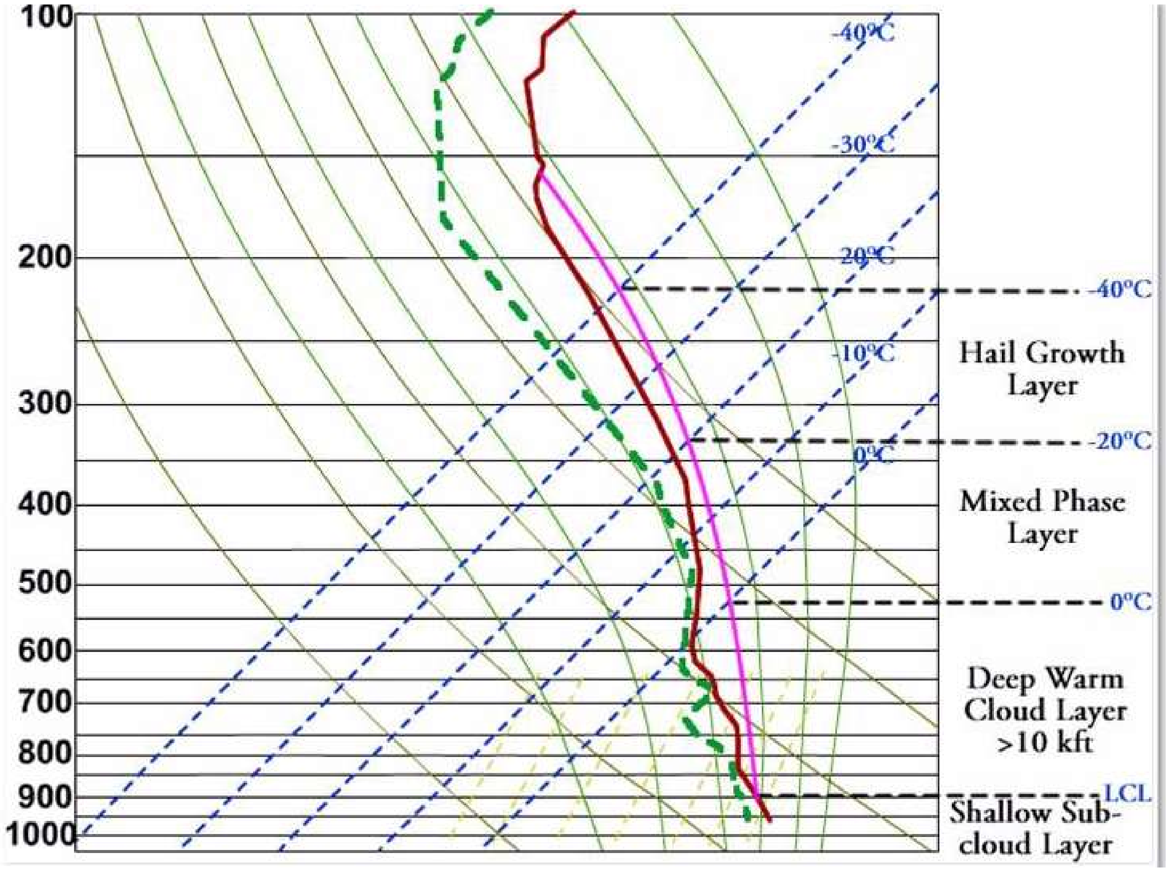


Figure 5.2: Sounding for environment favorable for producing heavy tropical rains.

Here we will introduce a method to differentiate between tropical (warm) rain, continental rain and rain mixed with hail using the dual-pol radar products. This will show ways to identify types of heavy rain as well.

We begin with an examination of heavy rain in a tropical environment similar to that often found in Uganda where the warm rain process dominates convection (see Figure 5.3). The following dual-pol characteristics are certainly not hard thresholds, but merely guidelines for how heavy tropical rainfall might look near Kampala. All the base data values shown here should overlap in order to say with a high degree of confidence that heavy rain is occurring. Reflectivity should be fairly high, but not in the realm associated with hail, anywhere from 40 to 55 dBZ. Warm rain processes involve very high numbers of smaller rain drops resulting in differential reflectivity values (ZDR) in the moderate range (between 0.5 and 3 dB). Pure rain will have very high correlation coefficient because it's all one precipitation type, and of roughly the same size. Expect to see CC values of 0.98 or 0.99 values for heavy rain associated with warm rain processes. Finally, KDP should be greater than 1.0 deg/km in order to be heavy rain. Keep in mind that instantaneous precipitation rate can always be examined for an estimation of how strong the rain rates are.

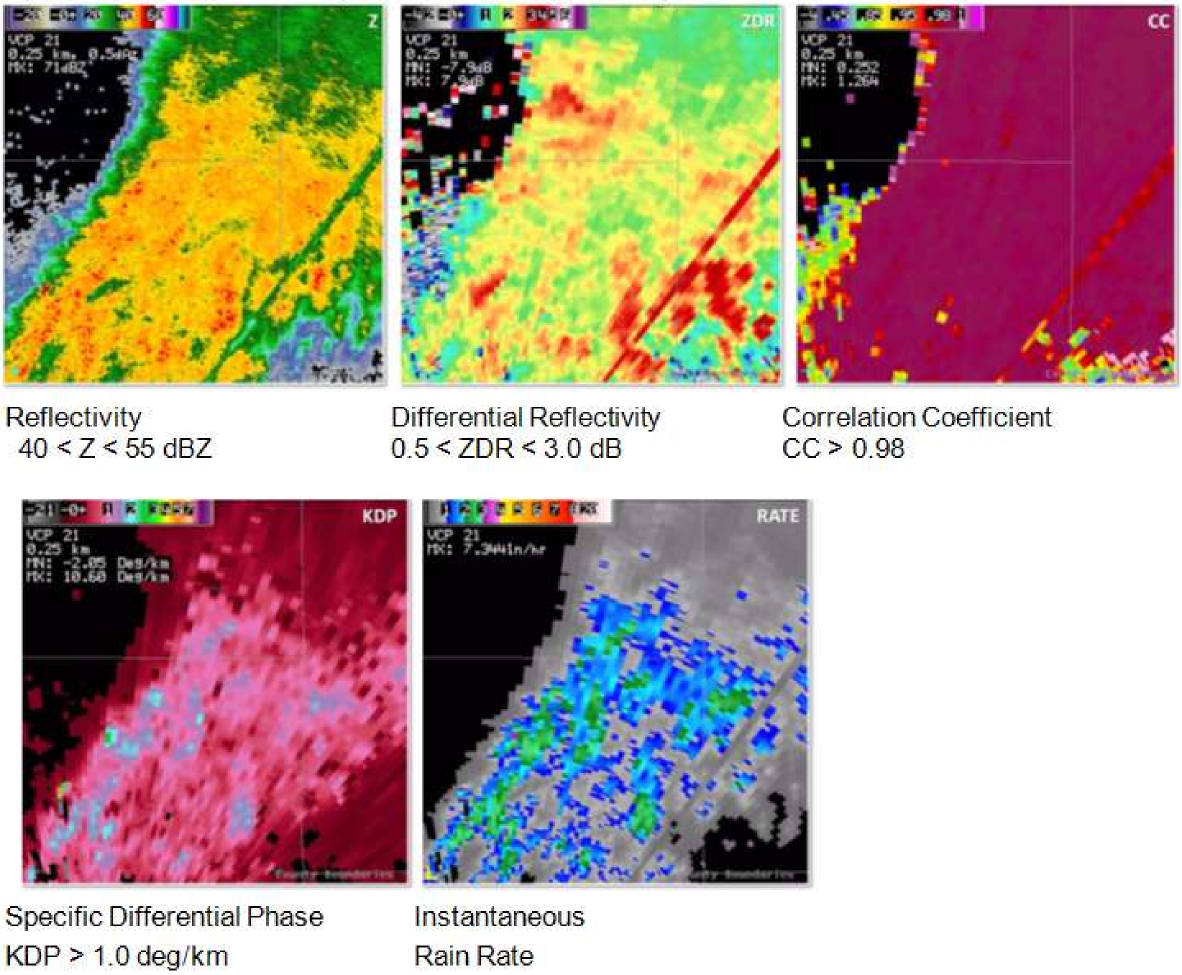
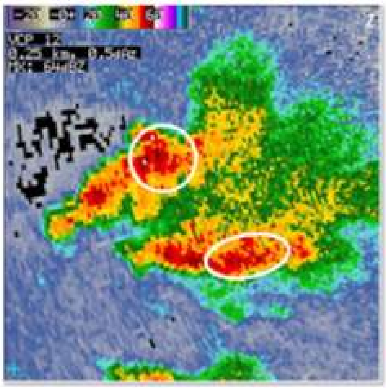


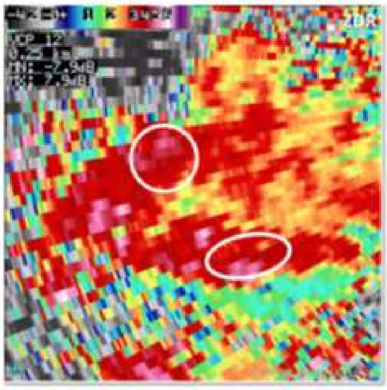
Figure 5.3: A few different dual-polarization products during a heavy rain event in a tropical environment.

A continental environment includes a mixture of cold and warm rain processes that lead to the production of heavy rainfall, normally associated with deep, moist, and possibly severe convection. With this type of heavy rain, reflectivity values should be higher (45-60 dBZ) than the tropical case because the drops are larger. We'll focus on the two white ovals that contain 50-60 dBZ echoes in Figure 5.4. Like reflectivity, ZDR values will also be higher in this case, and this is the primary discriminator between tropical and continental heavy rain. Expected values will be between 2 and 5 dB. In this example, values are roughly 4 to 5 dB, indicating large drops.

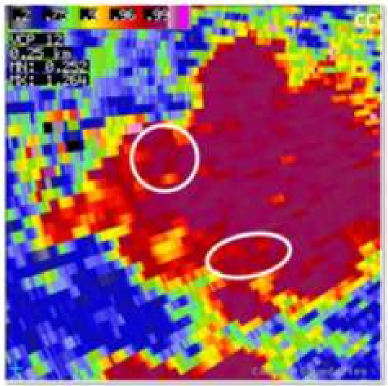
With reflectivity values in the 50 to 60 dBZ range, there could be hail contamination. The best way to rule out hail is to check the CC. If CC is greater than 0.96, the high reflectivity is most likely due to rain. In the white ovals shown in Figure 5.4, only a handful of gates are around 0.95. The vast majority are very high, indicating pure rain. Lastly, check KDP. Since the drops are large it would take a great number of them to result in heavy rain, and KDP is the perfect product for the job. KDP needs to be high (greater than 1.0 deg/km), with higher values indicating heavier rain.



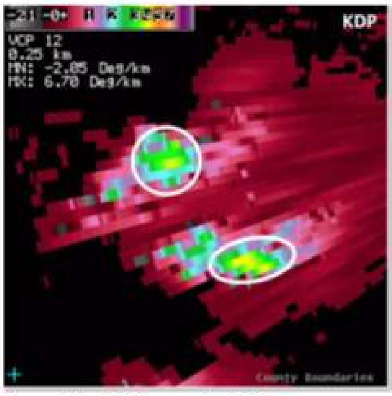
Reflectivity50 < Z < 60 dBZ
50 < Z < 60 dBZ



Differential Reflectivity
2.0 < ZDR < 5.0

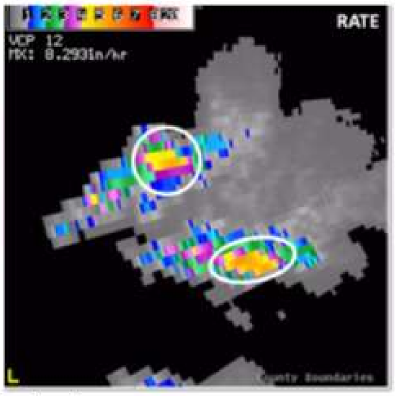


Correlation Coefficient
CC > 0.96



Specific Differential Phase

KDP > 1.0 deg/km



Instantaneous

Rain Rate

Figure 5.4: A few different dual-polarization products during a heavy rain event in a continental environment.

There will be situations where Z will be 30 to 45 dBZ, ZDR greater than 5 dB and CC around 0.98 which might indicate heavy rain. However, if KDP is below 1.0 deg/km, it is not heavy rain; instead it's an area of very large drops in low concentration, leading to minimal rain rates. Figure 5.4 verifies that the highest rain rates are inside those two white ovals. The final type of heavy rain that you can identify with dual-pol is heavy rain mixed with hail, which is normally associated with severe or borderline severe convection just like the previous example.

Heavy rain mixed with hail tends to produce the highest reflectivity values possible with S-band weather radars like the WSR- 88Ds, but at a minimum, values of Z for this precipitation type should greater than 55 dBZ. In the situation below the reflectivity core has very high reflectivity. ZDR is strongly biased toward the largest hydrometeors, so if the heavy rain contains severe hail, ZDR will be low but positive. If the heavy rain contains hail that is almost melted and completely coated in water, ZDR could be as high as +6 dB. In general, for heavy rain mixed with hail, the meteorologist would not rely on ZDR.

Correlation coefficient values are probably the best discriminator for heavy rain events that con- tain hail. CC will be much lower with these events than with the other two heavy rain signatures due to the co-location of rain and hail. The meteorologist would expect to see values 0.95 or less. Most of this region may have CC values lower than expected for pure rain, indicating that hail is present.

As with the other heavy rain types, the radar meteorologist should examine KDP to get the best picture of where the heaviest rain is. In storms containing heavy rain mixed with hail, KDP will be extreme, perhaps as high as 8 deg/km. The co-location of very high reflectivity, very high KDP, and CC lower than 0.96 is an excellent indicator of heavy rain mixed with hail.

In light of these considerations, MDA has recommended dual-polarization radars for Uganda.

5.3.1.2 Site Selection For Radars in Uganda

Radar data are used extensively for short-term forecasting and warnings of hazardous weather, including hail, flash floods, damaging winds, lake waves, wind, and storms and wind shifts. Dual-polarization radar data will provide enhanced information on regions of hail growth, hail fall, heavy rain, and regions of wind shifts, microbursts, and other damaging winds. It will also allow discrimination between insects, birds, hydrometeors, and smoke and fires. Data from these radars will also provide valuable, in fact, critical information for input into the Department of Water Ministry hydrologic models. Even during stratiform precipitation or clear skies, radars provide an important data set for short-term forecasts, nowcasts, and warnings prepared by the UNMA. Besides these, radar data users include fire fighters, agriculture specialists, managers, and farm workers, the aviation sector and Civil Aviation Administration (CAA), the roadway community, lake weather services, the military, and the disaster reduction community. Because insects are very easily radar detected, radar can be used to time the applications of certain insecticides as is done at times in the U.S.

To adequately cover the land and lake waters of Uganda, three polarimetric Doppler radars should be located strategically across Uganda using geographic information such as topography, power and communications infrastructure, shipping roadway routes, military, and the population base.

The MDA Team has considered the type and locations best suited for weather radars in Uganda. These recommendations are generalized, but allow for sufficient guidance in the conduct of a formalized siting analysis. Three priorities are assigned in the deployment of weather radars as presented below. Section 14 presents a detailed listing of performance specifications for the radar equipment. Each radar site should be complemented with personnel to measure and report other weather phenomena.

- 1st priority -- An S-band weather radar about 25 km to 35 km northwest of Entebbe, perhaps near Mpigi. A UNMA office should be constructed along with the radar.
- 2nd priority -- An S-band radar near Lira. The radar should be placed such that it is located some 120 km from both Gulu and Soroti.
- 3rd priority – An S-band radar positioned some 30 km west of Mbarara, perhaps near Kabwohe.

Note that site surveys for each radar are critically important. This survey will select locations based on a minimum of beam blockage. Trees can be topped or taken down periodically to assure this. Further the electromagnetic environment is surveyed, such that frequency interference is minimized.

Radars situated as proposed will provide essentially full radar coverage of Uganda. The full volume scan (i.e., digital base moments output from the signal processor at selected and scanned elevation angles) from each radar are buffered and transmitted. These data will be sent in real time to the UNMA headquarters and NMC as well as the military and CAA for additional processing and product distribution. Algorithms and derived products from all radars may be requested as needed, analyzed, and used by the UNMA forecast, nowcast, and warning facilities collocated with the NMC. As such, nowcasts and warnings will be centrally located. Observations should comply with WMO requirements (e.g., free data exchange, cooperation with member countries) as much as practicable. Communications should be two-way to allow remote operation and control. The technical configuration of the network should be fully documented by the Radar Operations Center (ROC). Rainfall estimates generated from radar data must be calibrated to rainfall observations from well-calibrated and well-maintained rain gauges. Rainfall products will include 1-hour, 3-hour, 24-hour, and storm-total. As mentioned, a variety of other algorithms will be implemented and are detailed later in this report. For example algorithms will generate information and products related to storm motion, derived winds, hydrometeor classifications, hail and mesocyclones. In addition, a national mosaic of near-surface base reflectivity will be produced every 5 to 10 minutes. . Certain products may require human input such as vertical cross sections for generation. Most nowcasts and warnings will be generated by meteorologists via use of the base data and will be independent of error-prone algorithms until such time as these algorithms are much improved.

The military and the Civil Aviation Administration will also use the base data streams from the same radars to generate their own derived products for flight route and mission planning. Their use of the data shall be entirely independent of the UNMA and NMC use. For example, each agency such as the military will receive the same base data stream but will independently process these base data. In this way each agency will use the radars as though they are dedicated for that user. However, via a radar data use committee explained below, volume scans will be developed in order to assure all users' needs will be met. Thus, the UNMA will coordinate with the Civil Aviation Administration and military such that all will receive the radar data required for their agency.

This Radar Users Committee shall be established which will include the UNMA, NMC, the military, and the CAA. This committee will establish coordination of the radar users and their needs and will work out any and every conflict for satisfying the simultaneous radar needs.

A Radar Data Quality Committee shall be established to continually monitor data quality and any hardware or software needs to improve and maintain the radars. While the radar is under warrantee, this committee will formulate the statement of needs and data quality problems and communicate these needs and problems with the radar vendor. They will also, along with the Radar Operations Center, monitor the vendor's warrantee services and satisfactory correction or repair of the aforementioned needs or problems. Following the warrantee expiration, the committee will continue the above data quality monitoring but will also work with the ROC engineering group for the upgrading, modernization, software and hardware maintenance, or repair of the radars.

The UNMA shall also establish a Radar Operations Center for the configuration management, repair, upgrading of hardware and software, and servicing of each radar and the radar network as a whole. Other responsibilities shall be established as at the US radar ROC. The ROC shall also establish a Radar Hotline for the 24/7 support of the radars, radar technicians, and warning and forecast meteorologists. The Hotline shall answer questions of these technicians and forecasters to assist in trouble shooting of hardware and software problems or in interpretations of detected targets.

5.3.2 LIGHTNING DETECTION

Lightning kills scores of Ugandans each year and causes significant property damage. Some of these deaths and economic losses could be avoided with adequate warning, and decisions about allocation of resources to improve lightning protection could be more efficient if the climatology of lightning strikes in Uganda was well understood. Real-time knowledge of lightning flash locations can also lead to much improved storm tracking and flash-flood warnings where radar is not available, saving additional lives.

Cloud-to-ground lightning (CG) detection is available globally through the World Wide Lightning Location Network (http://wwlln.net). This network makes use of an array of VLF (very low frequency, 3-30 kHz) radio wave detectors. By measuring the time of arrival of the radio signal emitted by the cloud-to-ground lightning stroke at a large number of widely spaced detectors, it is possible to constrain the location of the lightning stroke with good accuracy. However, because there are no active detectors in the network in East Africa, the fraction of CG strokes observed (about 8% of the total) is small compared to the global detection rate. Three detectors deployed in Uganda (provided by the WWLLN at no cost, if they can be supplied with a consistent power supply and access to the internet from a fixed IP address (pers. com., Prof. Robert Holzworth). This would allow this detection efficiency to be doubled, and would provide the UNMA with an instantaneous view of existing lightning, allowing much improved issuance of thunderstorm watches and warnings and of SIGMETS.

The MDA team strongly recommends that UNMA join the WWLLN as soon as possible.

However, CG lightning alone does not provide storm severity information. By contrast, Gatlin and Goodman (2010) show that total lightning detection networks, which by observing higher frequency radio waves can detect intracloud lightning (IC) as well as CG lightning, can do a good job identifying storms that will produce severe weather of various kinds in the near future. Thus, a total lightning detection network can be used to predict severe weather of various kinds. In much of the world, total lightning may also provide a good proxy for precipitation. The detection of total lightning does not require very complex instrumentation, and a number of vendors provide observing networks. However, a few vendors offer very sophisticated processing systems that convert the total lightning observations into near-term forecasts of convective activity.

Because Total Lightning observing systems offer the ability to detect convective activity over all of Uganda with little chance of missing lightning events of any size or consequence, and are available at a low price compared to radar systems, the MDA team recommends the acquisition of a total lightning detection system as part of the UNMA modernization.

We do not believe that a total lightning system can replace a radar network in a modern Ugandan meteorological observing system. Total lightning detection systems cannot observe either wind shear or hail, and their ability to retrieve total rainfall has not been established. In particular, “warm rain” or associated with very little lightning so these potentially flood-producing rains would go undetected by a total lightning network. We recommend that the national lightning detection system be installed either well before radar installation or simultaneously with a first radar system covering the Entebbe airport. This would allow comparison between rainfall retrieval and storm warnings in areas with both radar and lightning detection, so that the benefit of additional radars for non-aviation needs (watches, warnings, and high resolution rainfall retrieval) can be accurately assessed. Because a total lightning system is a proxy for radar detected rainfall, then an early deployment of a total lightning system should be considered during the modernization program.

A total lightning system should at a minimum offer location precision of strikes to within 1 km, should detect at least 50% of total lightning flashes, and should make the information available on a graphical display to forecasters in near-real time.

5.4 WINDSHEAR AND TURBULENCE

Windshear and turbulence aloft are aviation impact variables that are not well monitored in Uganda. Lack of observations from a number of sensors impedes the detection of these variables and the ability to generate appropriate forecasts and warnings. These weather phenomena are discussed in the sections that follow.

5.4.1 WINDSHEAR

In recent years, operational windshear detection systems such Terminal Doppler Weather Radar (TDWR) and Low-Level Wind Shear Alert Systems (LLWAS) have been introduced at an increasing number of international airports. These warning systems combine dedicated sensor systems (networked anemometers with automatic processing software) to produce real-time hazard alerts and alarms for air traffic controllers and supervisors. These alerts are then voice-communicated to aircraft. At some future date, it is anticipated that the LLAWS alert will be transmitted directly to the aircraft, thus minimizing the time to convey the warning and take corrective piloting action.

Low level windshear has been reported at Entebbe International Airport by the pilot community, although there is some debate about the frequency of occurrence because there is inadequate instrumentation at the Airport. The combination of Lake Victoria and the surrounding plains is responsible for the generation of lake/land breezes, which can be dry or wet depending on the degree of atmospheric instability. The Lake Effect has also contributed to the occurrence of over 300 thunderstorm days per year near the Airport. The MDA Team recognizes the need for indications of differential and directional wind speed that is the primary output of the LLWAS, and supports the action taken by DoM to acquire an LLAWS for installation at the Airport from the Italian company, Vistrociset, Sp.A.

Another method of observing the boundary layer and lower level winds is the tropospheric wind profiler radar, which uses a square, gridded, vertically pointing antenna. Profilers can provide high resolution winds and some thermodynamic data as well, and one or more could be deployed. They run continuously and are generally extremely affective. Placing one profiler at the Entebbe International Airport would provide continuous winds that can be sampled instantaneously, but normally they provide five-minute averages. The data can also be used as input to local and regional numerical models. Adding a sound generator converts the radar sounder to radio acoustic sounding system, or RASS, which adds the capability to retrieve temperature. Radio profilers can reach up to 3 km above the surface, and would typically cost from $150,000 to $250,000, depending on range and on inclusion of a RASS upgrade.

A lower-cost option for boundary layer wind observations is sodar- observations of the Doppler shift of sound waves reflected from density gradients in the atmosphere. The range of these detectors is typically smaller than that for radar (up to 700 m), but accuracy is adequate, and cost is relatively low. (~$70,000).

Pibal balloon soundings would be another option for boundary layer winds. Some DoM employees are trained in the launch and monitoring procedures, and sufficient hydrogen can be generated at the NMC to supply many balloon launches (though transport of the hydrogen throughout Uganda may be difficult logistically). Theodolites are present at some synoptic stations; launch costs would consist of the balloon ($40), and the cost of hydrogen delivery. At $60/launch, 4x daily observations would cost $90,000/year, which is more expensive than a sodar system that would generate continuous observations, though only up to 1000 m, versus the 14000 m height that can sometimes be observed by pilot balloons. A thorough discussion of a recent attempt to revive pibal balloon soundings during the AMMA experiment in West Africa can be found in Douglas et al. (2008).

5.4.2 TURBULENCE

Radar is a necessity for inspecting the three dimensional structure of the atmosphere. Radar detects thunderstorms, which contain a number of hazards both at the surface and aloft. Turbulence near thunderstorms (TNT) can occur within 35 km of the thunderstorm and merits a SIGMET for convection. An advantageous feature of Doppler weather radar is the ability to generate a Velocity-Azimuth Display (VAD) and a Wind Profile (VWP) product that gives a time series estimate of the horizontal wind at specific heights above the radar. VWP has a default radius of about ~ 32 km around the radar. However, an algorithm subroutine adjusts the default radius for optimal coverage when needed. The VWP will sample from near surface up to 21 km (70 kft) if tracers are available and depending on the radar sensitivity. Deformation and vertical motion can be calculated across the radius of VWP measurements. Those wind measurements apply only to the area immediately surrounding the radar. It is useful in diagnosing the locations and structure of wind shifts, windshear and the movement of moisture bands. All of these features can lead to turbulence both in cloud and cloud-free conditions. Thunderstorms are also responsible for low level windshear associated with downbursts, microbursts, and gust fronts generated by the thunderstorms.

As discussed above, monitoring the atmosphere, especially in the vertical, may also be accomplished through the use of radiosondes. Doppler radar can, at times, report a near instantaneous profile of winds over the radar site up to an altitude of 21 km depending on atmospheric tracers that permit radar detection. The radiosonde, on the other hand, returns more detail in the vertical and reaches into the stratosphere and is usually deployed twice daily (and of course, radiosondes supply moisture and temperature profiles as well as wind). The detection of upper level winds can help establish the location of stronger winds aloft associated with the African Easterly Jet and the Easterly African Waves as well as the Low-Level Jet circulation. These features and their associated Mesoscale Convective Systems are most often north of Uganda but do move south periodically in association with the Monsoon in the Indian Ocean. At times, clear air turbulence can be associated with these features and even more importantly a sheared atmosphere can result in intense convective storms with hail and strong winds.

Radiosonde data can be examined to determine the thermodynamic profile of the upper atmosphere and if convection is possible on any given day. On days when there is a lack of windshear aloft and a chance for thunderstorms, strong convective rainfall can lead to the initiation of wet microbursts. Thus, a combination of the radiosonde describing the vertical wind profile and Doppler weather radar detecting heavy rainfall can be used in tandem to identify the potential for microbursts. The availability of radiosonde observations also improves the performance of model forecasts of turbulence aloft. Experience in other countries has shown that knowledge of the flow pattern aloft, supplied by Pilot Reports (PIREPS), or automated Aircraft Reports (AIREPS) and model output, contribute to the ability to generate more reliable forecasts of turbulence aloft.

Given the weakness of the aerological network in Africa and the importance of Aircraft Meteorological Data Relay (AMDAR) data for observations and forecasts at the airport level, Regional Association I (Africa) of WMO has recommended (WMO, 2012) that National Meteorological Hydrological Services (NMHS) and Agency for Aerial Navigation Safety in Africa (ASECNA) consider, in cooperation with airline companies, the further extension of the AMDAR program in Africa and the assimilation of AMDAR data in the forecasting models in order to improve the usefulness of these data and the quality of the model output. Currently South African Airways (SAA) flies into and out of Entebbe and overflies Ugandan airspace. SAA provides valuable vertical profiles of upper air data for Entebbe. At last count, there were 182 vertical profiles at Entebbe during the eight month period from January through August 2011. This valuable data set is available on GTS. SAA is considering placing a turbulence sensor on its aircraft that will give in situ measurements of turbulence along its route of flight. The UNMA needs to finalize the installation of GTS and make this valuable data set available to its forecasters.

6 POTENTIAL U.S. SOURCES OF SUPPLY

Implementation the weather modernization plan will require the acquisition of new equipment as outlined in the Capital Investment Program. The Uganda National Meteorological Authority will be purchasing this equipment through a tender process that will circulate globally in order to assure open competition. A requirement of the United States Trade and Development Agency, which provided a grant for this feasibility study, is that the UNMA ensure that U.S. manufacturers and suppliers are afforded equal opportunity to compete for the sale, installation and servicing of the equipment to be purchased. There is no requirement that such equipment be acquired from U.S. companies, but that the UNMA take measures to announce their tenders and afford opportunity for such open competition. It is recommended that the Authority coordinate all tenders with the United States Embassy in Kampala to fulfill its grant commitment.

To facilitate these actions, listed below are representative U.S. companies that are qualified to respond to tenders for the primary equipment and services recommended for acquisition. This listing is not all-inclusive and it is anticipated that the circulation of the tender requests will reach beyond this listing. Many of these companies have experience in overseas markets and understand and utilize financing resources available to U.S. companies when selling their products and services in international markets. Some of the companies listed are capable of responding to multiple tenders for the major equipment and services provided, which can result in economies of scale when bids are submitted. The UNMA is encouraged to contact these and other companies that they identify independently as it moves toward implementation of the modernization program.

Although the MDA Information Systems Team has knowledge of those companies listed and confirmed their interest in the UNMA modernization program, they do not carry the endorsement of the MDA Information Systems Team nor does the Team have a financial interest in these companies. The companies contacted would respond to requests for tenders provided that the terms and conditions reflect an open and fair competitive situation. The companies are listed in alphabetical order by type equipment and services as presented in the staged Capital Investment Program for convenience of referral.

6.1 LIGHTNING DETECTION EQUIPMENT

Contact: Mr. Relko; relko@astrogenic.com (Astrogenic writes the software used with the Boltek detectors).
Boltek Corporation
2316 Delaware Avenue
Buffalo, New York 14216 USA
+1-905-734-8045 (voice)
+1-905-734-9049 (fax)
www.boltek.com

Contact: Mr. Ari Davidov, darkadii@gmail.com
Earth Networks, Inc.
12410 Milestone Center Dr, Suite 300
Germantown, MD 20876
+1-301-250-400
+1-800-544-4429
www.earthnetworks.com

Vaisala, Inc.
194 South Taylor Avenue
Louisville, Colorado 80027 USA
1-303-499-1701 (voice)
1-303-499-1767 (fax)
www.vaisala.com

Contact: Prof. Robert Holzworth, bobholz@ess.washington.edu
World Wide Lightning Location Network (WWLLN)
University of Washington
Department of Earth and Space Sciences
Johnson Hall, Room 070
4000 15th Avenue, N.E.
Seattle, Washington 98195 USA
1-206-543-1190 (voice)
1-206-543-0489 (fax)
www.ess.washington.edu

6.2 WEATHER RADAR

Baron Services, Inc.
4930 Research Drive
Huntsville, Alabama 35805 USA
1-256-881-8811 (voice)
1-256- 881-8283 (fax)
www.baronservices.com

Lockheed Martin Corporation
6801 Rockledge Drive
Bethesda, Maryland 20817 USA
1-301-897-6000 (voice)
www.lockheedmartin.com

WSI (in association with Electronics Enterprise Corporation)
400 Minuteman Road
Andover, Massachusetts 01810 USA
1-978-983-6300 (voice)
1-978-983-6400 (fax)
www.wsi.com

6.3 RADIOSONDES

Intermet Systems, Inc.
3854 Broadmoor, S.E., Suite 107
Grand Rapids, Michigan 49512 USA
1-616-285-7810 (voice)
1-616-957-1280 (fax)
www.intermetsystems.com

Lockheed Martin Sippican, Inc.
7 Barnabas Road
Marion, Massachusetts 02738
1-508-748-1160 (voice)
1-508-748-3626 (fax)
www.sippican.com

Vaisala, Inc.
194 South Taylor Avenue
Louisville, Colorado 80027 USA
1-303-499-1701 (voice)
1-303-499-1767 (fax)
www.vaisala.com

6.4 WIND PROFILERS

Contact: Mr. Jorge Lana, jl.remtechinc@gmail.com
Remtech, Inc.
1350 Avenue of the Americas, 4th Floor
New York, NY 10019 USA
1-303-772-6825 (voice)
1-303-772-6827 (fax)
www.remtechinc.com

Atmospheric Systems Corporation
26017 Huntington Ln Unit F
Santa Clarita, CA 91355 USA
1-661-294-9621 (voice)
1-661-294-9667 (fax)
www.minisodar.com

Scintec Corporation
197 South 104th St
Louisville, CO 80027 USA
1-303-666-7000 (voice)
1-303-666-6803 (fax)
www.scintec.com

6.5 AIR POLLUTION, WEATHER AND SOIL TEMPERATURE/MOISTURE SENSORS

Dynamax, Inc.
10808 Fallstone Road, Suite 350
Houston, Texas 77099 USA
1-281-564-5100 (voice)
1-281-564-5200 (fax)
www.dynamax.com

Decagon Devices, Inc.
2365 N.E. Hopkins Court
Pullman, Washington 99163 USA
1-509-332-2756 (voice)
1-509-332-5158 (fax)
www.decagon.com

Global Water Instrumentation (Xylem, Inc.)
2440 Gold River Road, Suite 210
Gold River, California 95670 USA
1-979-690-5560 (voice)
1-9790690-0440 (fax)
www.globalw.com

Also refer to AWOS manufacturers

6.6 EVAPOTRANSPIRATION SENSORS

Campbell Scientific
815 West 1800 North
Logan, Utah 84321 USA
1-435-227-9000 (voice)
1-435-2276-9001 (fax)
www.campbellsci.com

Davis Instruments Corporation
33465 Diablo Ave
Hayward, California 94545 USA
1-510-732-9229 (voice)
1-510-732-9188 (fax)
www.davisnet.com

Hunter Industries
1940 Diamond Street
San Marcos, California 92708
1-760-744-5240 (voice)
1-760-744-7461 (fax)
www.hunterindustries.com

6.7 AUTOMATED WEATHER OBSERVATION SYSTEMS

All Weather, Inc.
1165 National Drive
Sacramento, California 95834 USA
1-916-928-1000 (voice)
1-916-928-1165 (fax)
www.allweatherinc.com

Belfort Instrument Company
727 South Wolfe Street
Baltimore, Maryland 21231 USA
1-410-342-2626 (voice)
1-410-342- 7028 (fax)
www.belfortinstrument.com

Coastal Environmental Systems, Inc
820 First Avenue South
Seattle, WA 98134
1-206-682-6048
www.coastalenvirontal.com

Vaisala, Inc.
194 South Taylor Avenue
Louisville, Colorado 80027 USA
1-303-499-1701 (voice)
1-303-499-1767 (fax)
www.vaisala.com

Campbell Scientific
815 West 1800 North
Logan, UT 84321-1784 USA
1-435-227-9090 (voice)
1-435-227-9091 (fax)
www.campbellsci.com

Texas Weather Instruments, Inc.
9766 Skillman St.
Dallas, TX 75243
1-214-340-4293 (voice)
1-214-340-6264 (fax)
www.txwx.com

6.8 MANUAL READ METEOROLOGICAL INSTRUMENTS

Barometers
Aquatech Scientific Instruments LLC
Edgewood Village Executive Plaza
680 Heacock Rd., Suite 204
Yardley, PA 19067 USA
1-215-428-9400 (voice)
1-267-790-0404 (fax)
www.digitalbarograph.com

Thermometers
Cole-Parmer
625 East Bunker Ct.
Vernon Hills, IL 60061 USA
1-800-323-4340 (voice)
1-847-247-2929 (fax)
www.colepalmer.com

Wind vane/Anemometer
Barani Design
525 Nelson Rising Ln. #909
San Francisco, CA 94158 USA
1-478-227-2644 (voice)
1-925-905-4142 (fax)
www.wind101.net

6.9 COMPUTER HARDWARE

Dell Computers, Inc.
1 Dell Way
Round Rock, Texas 78682 USA
1-504-338-4400 (voice)
1-504-338-4401 (fax)
www.dell.com

Hewlett-Packard Company
3000 Hanover Street
Palo Alto, California 94304 USA
1-650-857-1501 (voice)
1-650-857-5518 (fax)
www.hp.com

6.10 TRAINING FOR WEATHER SENSORS, SYSTEMS AND RADAR APPLICATIONS

Refer to manufacturers listed above by equipment type

6.11 CONSULTING SERVICES

MDA Information Systems LLC
820 West Diamond Ave, Suite #300
Gaithersburg, MD 20878
1-240-833-8200
www.mdaus.com

NOAA Office of International Affairs
Herbert C. Hoover Building, Room 6224
MS 5230
14th and Constitution Ave, NW
Washington, DC 20246
1-202-482-6196
www.international.noaa.gov

Gulezian Consulting Service
6 Emily Circle
Meredith, NH 03253
1-631-235-8654
www.gulezianconsulting.com

Riverside Technology, Inc.
2950 E. Harmony Rd., Suite 390
Fort Collins, CO 80528
1-970-484-7573
www.riverside.com

6.12 EQUIPMENT MAINTENANCE PROVIDERS

ARINC Incorporated
2551 Riva Road
Annapolis, Maryland 21401 USA
1-410-266-2266 (voice)
1-410-266-2020 (fax)
www.arinc.com

Enterprise Electronics Corporation
128 South Industrial Boulevard
Enterprise, Alabama 36330 USA
1-334-347-3478 (voice)
1-334-393-4556 (fax)
www.eecradar.com

Met One Instruments
1600 Washington Boulevard
Grants Pass, Oregon 97526 USA
1-471-541-7111 (voice)
1-471-541-7116 (fax)
www.metone.com

Also refer to AWOS and Sensor Manufacturers listed above

7 ORGANIZATIONAL RECOMMENDATIONS

7.1 ORGANIZATIONAL AND MANAGERIAL DEMANDS OF MODERNIZATION

Concurrent changes are needed in the organizational structure of the Uganda National Meteorological Authority (UNMA) in order for it to meet its 21st Century obligations as an Authority with new technology, software, and systems. Further, the DoM is understaffed for its existing and future mission and will have to begin a strong recruitment process in order to meet that mission.

The proposed expansion of the Civil Aeronautics Authority (CAA) programs and airports in Uganda will require a change in the staffing levels of the DoM. Conversations with agriculture officials and researchers indicate that UNMA needs more specificity with additional human resources to meet the needs of Uganda's agricultural community for accurate and crop-specific short- and long-range forecasts. Improvement and addition of weather sensors to support the UNMA will require establishment of a Quality Data Center and an Instrument Calibration Center. Hazards from Uganda's frequent thunderstorms require more trained forecasters and outreach resources not only at field offices but in the headquarters. Improved outreach will require a modernized Internet Web site and as the capacity to reach large lists of cell phones subscribers by text message. Having these new offices and a stronger outreach program requires the establishment of communication links that will move information from border to border and office to office to the stakeholders and general public. Ensuring these features are continuously operating will require trained technicians and maintenance personnel. Training will be crucial as the modernization program moves forward. This will require upgrading of the facilities of the National Meteorological Training School, and incorporation of the school into UNMA. A combination of new staff positions and additional education for existing staff at NMTS should insure that senior staff positions are filled by PhD-level meteorologists. Human resources personnel at the UNMA headquarters should maintain a specific training plan for each employee in UNMA, and monitor progress along the plan.

One way the UNMA can meet its staffing needs is to take advantage of the high quality of modern automated weather station (AWS) units to move staff away from manual observations using antiquated equipment, and into forecasting and communications operations. Some observational staff will be needed to perform data quality checks on AWS data and to perform maintenance and calibration of these units. But many other observational staff can make use of their meteorological training to provide crucial human contacts between the UNMA and consumers of weather forecasts and data. We envision some UNMA staff embedded in District government offices of those districts with the most pressing weather concerns. These staff could be competitively allocated to those District offices willing to provide office space and residential allowances in return for the tailored nowcasting, forecasting and interpretation services these UNMA staff would provide.

Finally, the modernization of Uganda will require a paradigm shift for many UNMA employees both in headquarters and in the field structure. This shift will manifest itself in the birth of a new organization that will be the envy of the East African Community. But this will only occur if there is buy-in at all levels, so that old ideas and structures can be renewed or replaced and everyone moves forward always keeping their eye on the ball of modernization.

7.2 PROPOSED ORGANIZATION AND MANAGEMENT STRUCTURE

7.2.1 HEADQUARTERS AND MANAGEMENT

The management structure for UNMA consists of an Executive Director, and five Headquarters Directorates to manage the new organization. The Executive Director will have ultimate responsibility for providing weather, water, and climate data, forecasts and warnings for the protection of life and property to aid in the enhancement of the national economy of Uganda. Within the office of the Executive Director will be public relations officers, a marketing officer and an administrative assistant. The office of executive director will be responsible for plans to generate revenues to sustain and develop the UNMA for now and the future. Within the headquarters, the Executive Director will have to appoint a Modernization Program Manager who will assist the Executive Director in managing the implementation plan. Note in Table 1 below, the Executive Director of the UNMA must be a trained meteorologist with at least a Master of Science degree in Meteorology, and have prior experience in business finance and economics. The six Directors will report directly to the Executive Director as outlined in Figure 1.

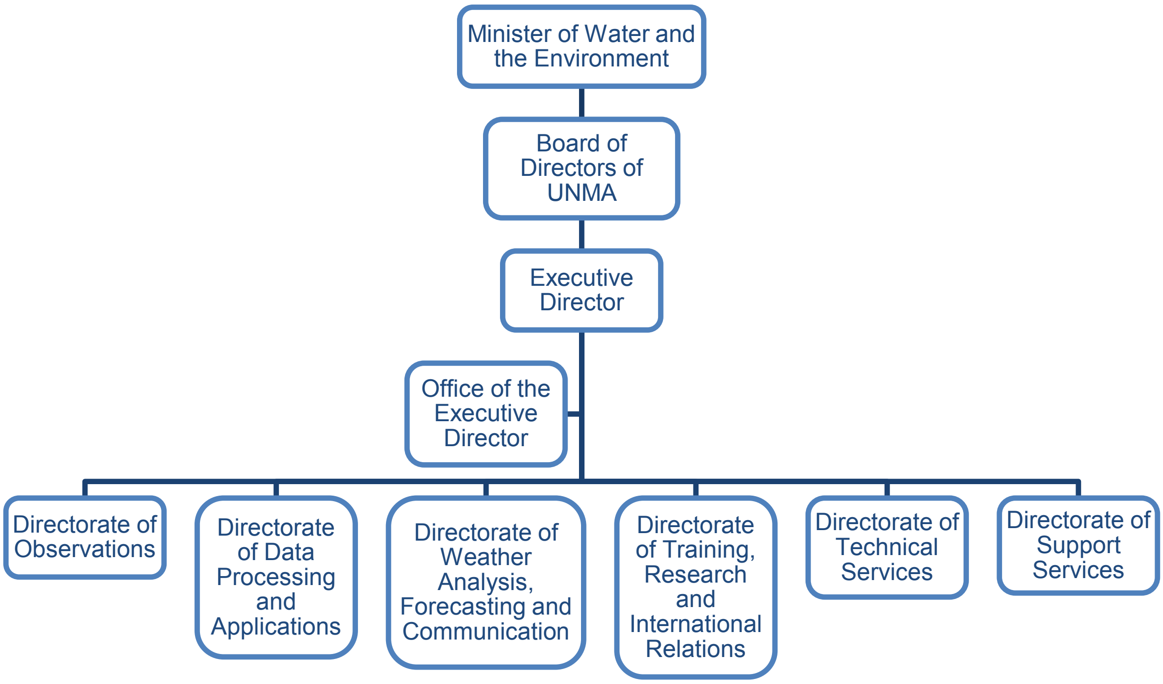


Figure 7.1: Structure of the Headquarters of the UNMA.

Table 7.1: Positions in the Office of the Executive Director

Staffed Positions	Meteorologist	Nonmeteorologist	Number of Positions
Executive Director	Yes		1
Modernization Officer	Yes		1
Manager Public Relations		Yes	1
Manager Marketing		Yes	2
Public Relations Officer	Yes		1
International Relations Off	Yes		1
Admin Assistant		Yes	1
Driver		Yes	1
Office Attendant		Yes	1

7.2.1.1 THE WEATHER ANALYSIS, FORECASTING AND COMMUNICATION DIRECTORATE

The Forecasting Directorate will oversee delivery of hydrology, meteorology and climate services and design and implement new products including the workstation program change and implementations, and services in service areas including public, aviation, marine and agriculture and hydrological sectors. The Directorate will ensure an engaged, responsive UNMA that delivers state-of-the-art, timely, and reliable climate information and support services to help Uganda address environmental impacts. This will be done through user engagement, policy development, data stewardship, incorporation of research into operations, training, education, and outreach in collaboration with internal Directorate partners and external stakeholders.

The Forecasting Directorate will be responsible for the day to day operational products issued by the UNMA field offices and a Climate Prediction Center located within the UNMA headquarters. Within the Forecast Directorate will be a meteorologist who will be responsible for forecast, warning, and response services to Uganda. There will also be a meteorologist who will have oversight for the provision of aviation weather services to Uganda and the International community and interact with the CAA. The programs will include products and services for domestic and international aviation communities in the terminal, en route, and for FIR airspace systems. There will be a meteorologist who will be responsible for oversight of the agricultural weather services and will interface with the Climate Prediction Center in the provision seasonal agriculture forecasts. The Climate Prediction Center will deliver climate prediction, monitoring, and diagnostic products for timescales ranging from days to years for Uganda and the global community for the protection of life and property and the enhancement of the economy of Uganda. Four long-term/seasonal forecasters shall provide new and improved climate services; help Uganda develop a government response to climate change, and issue seasonal outlooks for temperature and precipitation every two weeks, valid for 0-3 months. They will provide long-range and seasonal predictions and focus on specialized forecasts for agriculture, air quality, and fire weather. The long-term/seasonal forecasters also shall assist with quality assurance of data that enters the long-term archives and with the UNMA verification programs.

Table 7.2: Positions in the Forecasting Directorate

Staffed Positions	Meteorologist	Nonmeteorologist	Number
Director	Yes		1
Manager of Climate Prediction Center	Yes		1
Manager Forecasting Services	Yes		1
Manager of Aviation Services	Yes		1
Manager of Climate Analysis & Apps	Yes		1
Manger of Aviation Services	Yes		1
Manager of Workstations and Programs	Yes		1
Principal Climate Officer	Yes		2
Climate Science Officer	Yes		2
Administrative Assistant		Yes	
Driver		Yes	2
Office Attendant		Yes	2

In the staffing Table 7.2, the principal meteorologists at NMC, Soroti, and Kasese have not been included. Those personnel will report to the Director of Forecasting but will be shown in their own staffing tables at the three offices. See Figure 7.2 below. As shown in Figure 7.3 below, the Climate Prediction Center is envisioned to be a Branch of the Forecasting Directorate. Additionally, all Communications and Information and Communications Technology (ICT) functions have been centralized in the Technical Services Directorate to help get configuration management issues and software support better focused.

The Forecasting Directorate will rely on the Information Technology Branch of the Technical Services Directorate to develop and maintain software to produce bias-corrected multi-model ensemble forecasts for Uganda. This forecasting system will have complete, reliable and high-speed access to the archives maintained by the Quality Data Center. In the near term, the computational resources made available to the UNMA by the NOAA International Activities Office (contact Kelly.Sponberg@noaa.gov) are sufficient to allow such a system to function, until adequate computing power can be brought online at UNMA. These resources will be used to prepare model output statistics-based forecasts for Uganda, as described in Section 8.1.

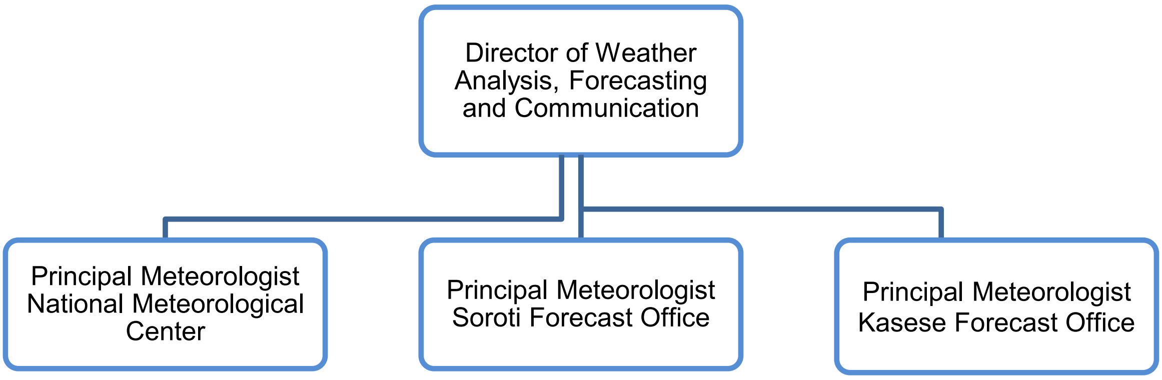


Figure 7.2: Meteorological Managers at NMC and Soroti report to Director WFC

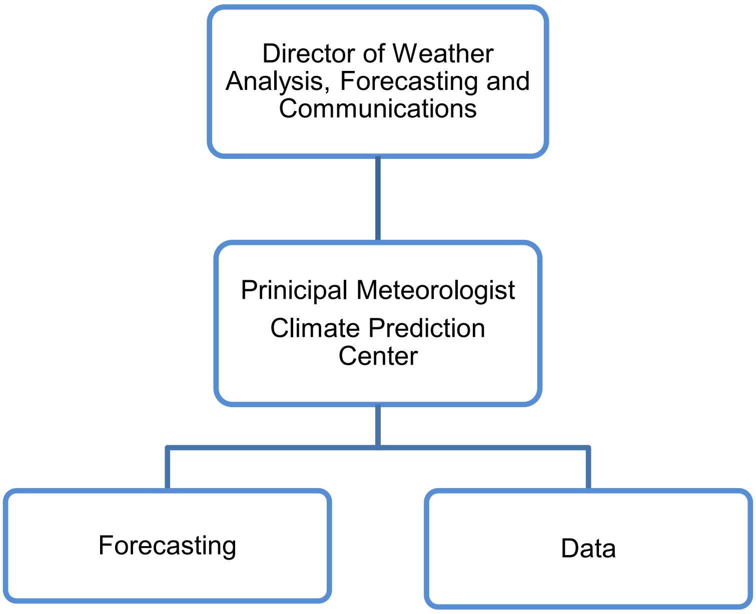


Figure 7.3: Climate Prediction Center established in the Forecasting Directorate of UNMA

7.2.1.2 Weather Analysis, Forecasting and Communication Directorate

The Weather Analysis, Forecasting and Communications Directorate will manage operational systems and provide software management, facilities, and logistical services for the equipment. The Directorate will develop policy for implementation, operations, support, and evaluation of operational weather systems. The Directorate will have four regional centers assigned to it which will be called field level operational centers. These regional centers sustain the field logistics and acquisition activities, the upper air program, the radar program management, the surface AWS operational management and upgrade implementations, and the management of any future buoys in Lake Victoria.

It will serve as principal focal point for the UNMA field offices on surface and upper air operational issues. It will manage deployment of surface and upper air system enhancements and new system. It will maintain network configurations and reporting of stations and it will support the Engineering Directorate in the development of new sensor technology. Within the Directorate will be located a Quality Data Center that will be responsible for the quality assurance of all data gathered by the observing systems of the UNMA. See Figure 7.4 Below. The Information Technology Branch of the engineering Directorate will be responsible for the development and maintenance of the computer hardware and software needed for the Quality Data Center to perform its function.

Table 7.3: Positions in the Observations Directorate

Staffed Positions	Meteorologist	Nonmeteorologist	Number
Director	Yes		1
Manager Quality Data Center	Yes	Yes[1]	1
Principal Instrument Officer	Yes	BIP-MT[2]	1
Manager Met. Observatories	Yes	BIP-MET[2]	1
Quality Data Officers	Yes	BIP-MT[1]	5
Principle Radar and Upper Air Officer	Yes [1]		1
Instrument Officers at Regional Centers	Yes	BIP-MT[1]	4
Administrative Assistant		Yes	1
Driver		Yes	1
Office Attendants		Yes	1

The Officers in charge of the UNMA Meteorological Observatories will report to the Director of the Observations Directorate. They are not shown in Table 7.3 but will be shown in their own table. The same is true for the Meteorological Officers at the Agrometeorological offices. Those are shown in Figure 7.4 below.

The MDA Team does not recommend any staffing at the Hydromet stations. In Section 2.2.5.4 we have made the recommendation that UNMA accept the current network operated by the Water Resources Department of the Ministry of Water and move immediately to gain access to the data through establishment of a working agreement. After reviewing the duties of personnel at the Agrometeorological stations, we recommend that a Meteorological officer and a meteorological technician/driver be assigned to each of the 10 stations. Hydromet stations are not shown in Figure 7.5.

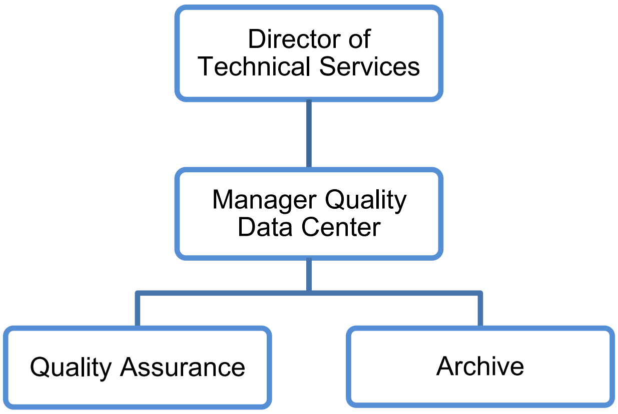


Figure 7.4: Quality Data Center at UNMA located in Operations Directorate.

[1]The manager and various positions within the Quality Data Center and the regional centers can be meteorologists or meteorological technicians. The principle radar meteorologist will closely interact with the Radar Operations Center (ROC) in the Technical Services Directorate.

[2]In Table 3 above there is listed the acronyms BIP-Met and BIP-MT. WMO Document 580 defines these acronyms as personnel who are working to become full-fledged Meteorologists or full-fledged Meteorological Technicians. Requirements including education are defined the referenced WMO document.

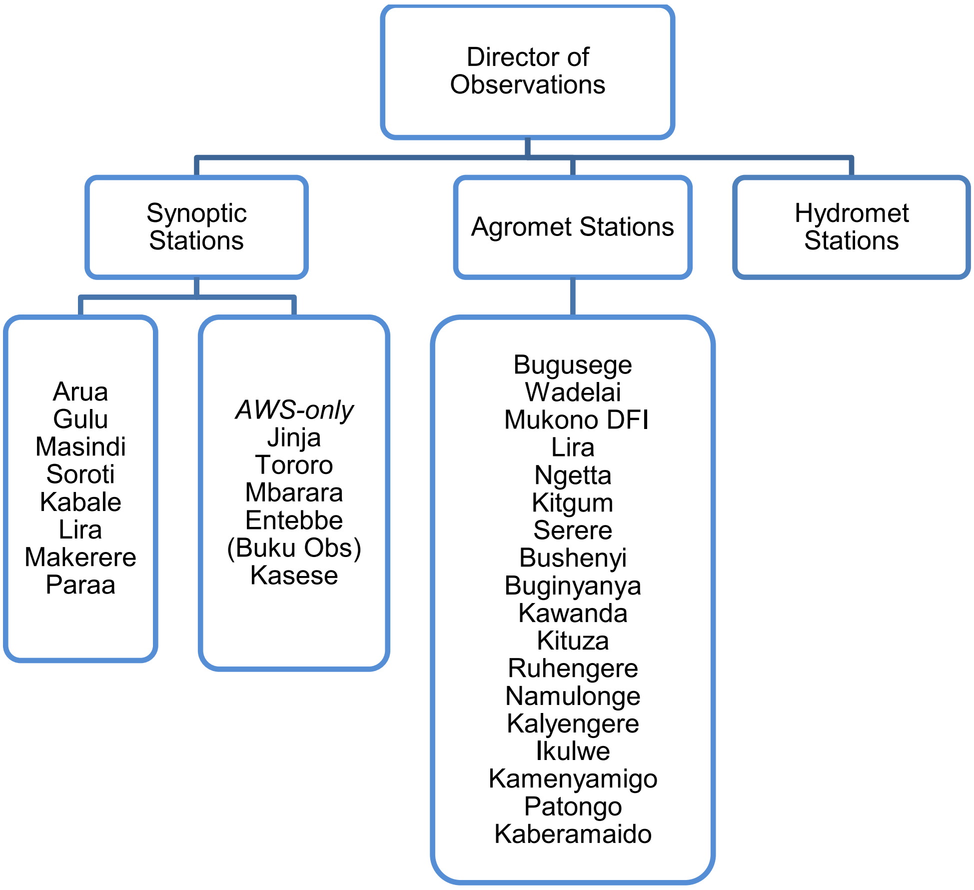


Figure 7.5: Offices and Sites under control of Director Operations Directorate.

7.2.1.3 Training, Research and International Relations Directorate

The Training, Research and International Relations Directorate will be responsible to train or guide training of manpower at all levels for sustainable development while maintaining excellent standards in Education, Training and Research in the fields of Meteorology, Climate and Water in the UNMA.. In addition, the Directorate will be responsible for discharging Uganda's responsibilities to international bodies such as the World Meteorological Organization and under treaties such as the UN Framework Convention on Climate Change. Routine training of UNMA staff will occur at National Meteorological Training School whose Principal will report to the Assistant Director of Training and Rearch. UNMA may also send its employees to Universities or other established training centers in the East African Community and other parts of Africa. There are eight Regional Training Centers (RTCs) in Africa. Another way of training is distance learning. Two among other centers in the United States specializing in distance learning are the Meteorology Education & Training (MetEd) Web Site in Boulder Colorado and the Warning Decision Training Branch (WDTB) in Norman, OK. Finally, the Training Directorate will work with the Support Services Directorate to ensure all employees of UNMA have an annual implementation plan (IP) for training and science support to ensure responsiveness to field requirements and to sustain the high level of science and technical infusion required to maintain the high forecast standards of the UNMA.

The MDA Team recommends that UNMA invest substantially in an improved Training School. This should be done in a phased approach. Elsewhere in our recommendations, we have proposed that UNMA build a new headquarters. The new headquarters building should contain adequate facilities for the school. In its first year, the UNMA should add a Director for the newly created Training Directorate with some limited staff to begin creating a formal training program within UNMA that can include the administrative IP's, distance learning, and other sources of training beneficial to a modernized workforce. Then as the UNMA moves to a new Headquarters, the additional staff should be added to build a quality training center. In the staffing table below, we project the whole Directorate while realizing it will be a phased approach.

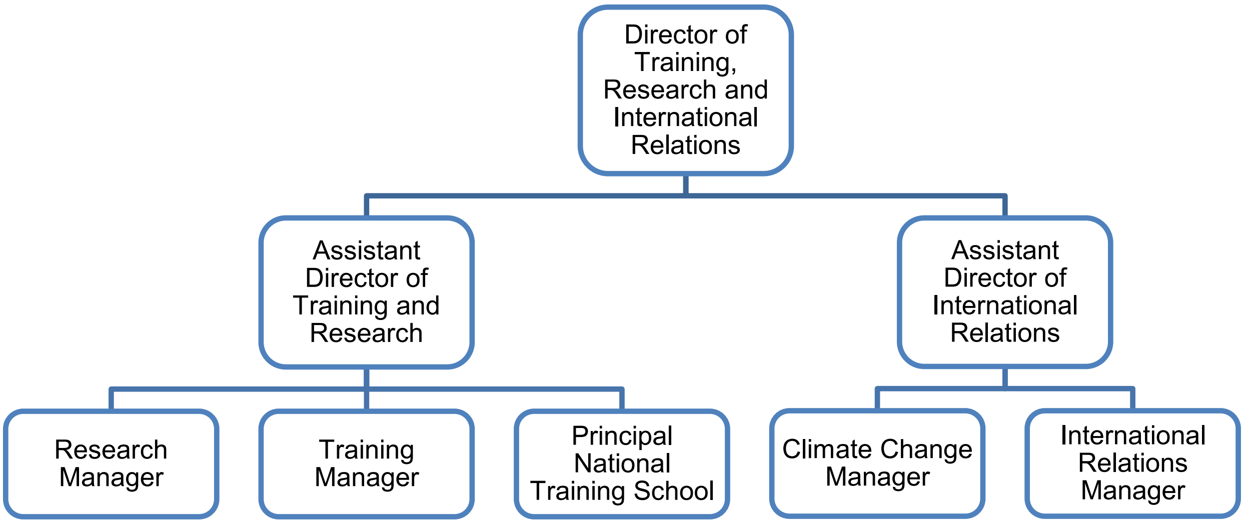


Figure 7.6: Organizational Structure of the Research, Training and International Relations Directorate

Table 7.4: Positions in the Training Directorate

Staffed Positions	Meteorologists	Nonmeteorologists	Number
Director	Yes		1
Assistant Director for Climate Change and International Relations	Yes		1
International Relations Manager	Yes		1
Climate Change Manager	Yes		1
Climate Change Specialists	Yes	Yes	6
Assistant Director for Training and Research	Yes		1
Research Officers	Yes	Yes	6
Staff Development and Training Manager	Yes		1
Training Officers	Yes	Yes	3
Principle National Training School	Yes	Yes [1]	1
Senior Development Officers	Yes		2
Senior Lecturers	Yes	Yes [3] BIP-MT [2]	6
Lecturers	Yes	Yes [3] BIP-MT	10
Librarian		Yes	2
Development Officers	Yes	Yes [3] BIP-MT	2
Administrative Assistant		Yes	1
Driver		Yes	1
Office Attendants		Yes	1

In the staffing table above, there are both meteorological and meteorological technician lecturers and training development officers since observing and meteorological technician training should be offered at the training center.

[1] In Table 4 above, a Yes in both meteorologists and non-meteorologists columns means either personnel type can occupy the position. However, there is only one position.
[2] Previous discussion applies here also. These terms are defined in WMO Document 580

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7.2.1.4 SUPPORT SERVICES DIRECTORATE

This Directorate will have two branches. The Directorate will formulate the budget of the UNMA; manage UNMA's process for identifying and acquiring budgetary resources; manage UNMA's programmatic and performance assessment processes; manage the integration of financial, property, and human resources information to support managerial decisions.

The Finance branch is responsible for the financial management function that covers all aspects of UNMA budget execution, including the development of Financial Operating Plans, allowance advices, reimbursable task planning, and financial management for supply accounts. The Finance branch is responsible for financial accounting, reporting, and analysis, including the development and implementation of cost accounting methodologies, the implementation of standardized automated account programs, development of financial statements, conducting liaison for financial audits, and for analyzing and developing financial systems requirements. The Finance branch also tracks and reports financial commitments and exposure to assure an accurate status of available funds and endeavors to meet timely payment of its obligations as well as assure compliance with all terms and conditions of those obligations including their warrants and covenants.

The Administrative branch manages all UNMA human resource policy activities, controls and allocates UNMA staffing and FTE resources, manages organizational design, position management and orientation activities, and provides organizational development and training support.

The Administrative branch conducts and/or coordinates organizational and/or staffing studies and cost analyses designed to meet current and future mission needs in the most efficient and cost-effective manner. The Administrative branch will assist Directors and Program managers to develop systematic and realistic monitoring plans that capture quantitative and qualitative data to report on project performance indicators.

The Administrative branch provides a liaison with other Ugandan government agencies to coordinate activities to provide reasonable assurance that UNMA programs are free from waste, fraud or abuse, and assures compliance with Ugandan contracting out initiatives. The Administrative branch also provides general executive and administrative support including management of the UNMA Directives System and incentive awards programs. The branch is also responsible for recruitment and performance activities.

The Administrative branch is responsible for the coordination of all legal matters involved in and concerned with the activities and interests of the UNMA in the field of administrative law. The Administrative branch is the source of legal expertise in specific areas of administrative law, appropriations issues, civil rights, collective bargaining, conflicts of interest, employee benefits, ethics, fiscal law, labor relations, management, personnel, property, and travel allowance. The two branches in the Office of Finance and administration are shown in Figure 7.7. The fully staffed position division is shown in Table 7.5.

All administrative and financial positions should be put into one Directorate to optimize and centralize that type of work. Several positions that were identified in the Business Plan of the UNMA as being in other Directorates were moved to the Support Services Directorate.

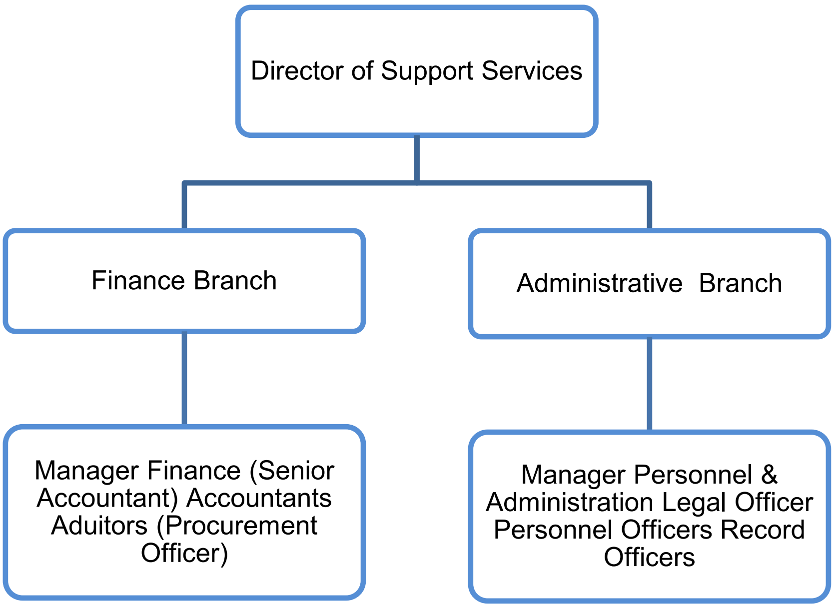

Figure 7.7: Positions under Director Office of Support Services

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Table 7.5: Staffed Positions in the Office of Finance and Administration

Staffed Positions	Meteorologist	Nonmeteorologist	Number
~~Director~~		~~Yes~~	~~1~~
Manager Personnel & Admin		Yes	1
Manager Finance		Yes	1
Legal Officer		Yes	1
M & E Officer		Yes	1
Principle Internal Auditor		Yes	1
Senior Accountant		Yes	1
Senior Internal Auditor		Yes	1
Senior Personnel Officer		Yes	1
Senior Procurement Officer		Yes	1
Accountant		Yes	3
Personnel Officer		Yes	1
Procurement Officer		Yes	1
Senior Records Officer		Yes	1
Records Officer		Yes	1
Administrative Assistant		Yes	1
Driver		Yes	1
Office Attendant		Yes	1

7.2.1.5 Technical Services Directorate

One of the most important steps in the modernization is to establish an infrastructure that will be capable of handling all of the data sets, supplying far flung entities with data and creating situational awareness for all the warning, forecasting and observing components both at UNMA headquarters and in the field structure. Without the infrastructure tying Local Area Networks (LANS) to Wide Area Networks (WANS) with the proper communications protocol including software and hardware components, the modernization of the UNMA will not take place. While this may be a harsh statement, the reality is that the backbone of the entire modernization of UNMA will be tied to the modernization of communications. A strengthened Technical Services Directorate will provide vital support for the modernization of the communications network.

The Technical Services Directorate will have three branches. They will be the Information Technology branch, the Maintenance Branch and the Instrument Calibration Laboratory Branch. These three branches will manage operational systems and provide engineering, software, management, facilities, communications, and logistical services to UNMA. Maintenance of existing observing systems within Uganda will be centered in this Directorate. Both maintenance by UNMA technicians and outsourced maintenance managed by a COTR will be found in this Directorate.

The Information Technology Branch provides technical software support to UNMA field operations. These services include the maintenance of the UNMA workstations, development of software enhancements,[1] and maintenance fixes for existing UNMA observation and dissemination systems and expert technical software support to field users. The branch maintains the system baselines in an internal configuration management system. The Information Technology Branch will also be responsible for the UNMA web site, both the maintenance of the site and the future development of the site.

The Maintenance branch will be responsible for the repair of all electronic, telecommunications, electrical, mechanical and meteorological instruments. The branch will be capable of fabrications as per client specification of gates, windows and other mechanical structures as related to the facilities of UNMA. The branch will also provide consultancy in electronic, telecommunications, electrical and mechanical engineering. The Maintenance Branch has four equipped Engineering Workshops in the

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[1] This type of enhancement will be in concert with the requirements and needs as outlined by the Forecasting Directorate.

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UNMA Regional Centers to carry out all the electrical, electronic, calibration, telecommunications and mechanical work.

Within the Technical Services Directorate will be a Radar Operations Center (ROC). The ROC will provide centralized meteorological, software, maintenance, and engineering support for all Uganda radars. [1] The radar systems will be modified and enhanced during their operational life to meet changing requirements, technology advances, and improved understanding of the application of these systems to real-time weather operations. The ROC will also operate radar test systems for the development of hardware and software upgrades to enhance maintenance, operation, and provide new functionality.

Maintenance and repair can be handled several ways. It can be done in house or it could be outsourced. We are recommending an initial period of outsourced maintenance, with a transfer of this function to UNMA staff over time.

The Instrument Laboratory Calibration Branch will provide calibration of meteorological instruments. Its objective is to maintain the standards of meteorological instruments to WMO and ICAO standards through: calibration; measurement; and intercomparison experiments.

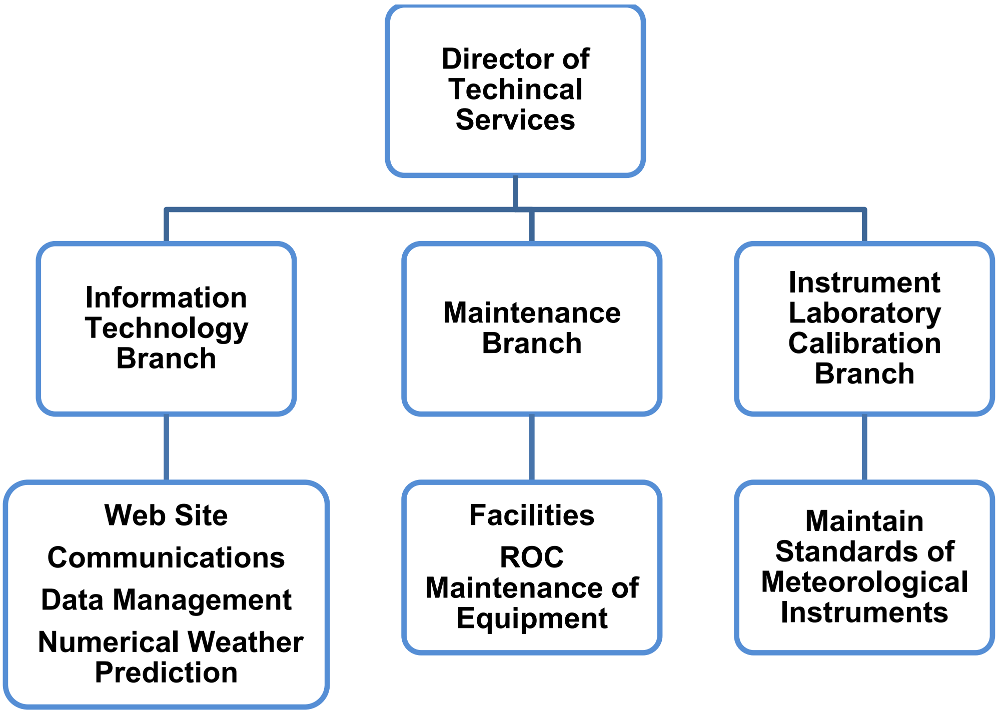

Figure 7.8: Branches and Functions under the Director of Technical Services

[1] The ROC will work closely with the manager of the radar program in the Observations Directorate.

Table 7.6: Staffed Positions in the Technical Services Directorate

Staffed Positions	Meteorologists	Nonmeteorologists	Number
Director	Yes	Yes	1
Manager IT Branch	Yes	Yes	1
Manager Maintenance. Branch		Yes	1
Manager Inst. Lab Branch	Yes	Yes	1
Senior ICT Officer		Yes	1
Senior Telecom Engineer		Yes	1
Senior Software Engineer		Yes	1
Software Engineers		Yes	4
Telecom Engineer		Yes	1
Senior ROC Officer	Yes	Yes	1
ROC Officers	Yes	Yes	5
Main. Technicians		Yes	2
Main. Technicians at Reg. Offices		Yes	4
Senior Instrument Officer	Yes	Yes	1
Instrument Officers	Yes	Yes	4
Administrative Assistant		Yes	1
Driver		Yes	1
Office Attendant		Yes	1

7.2.1.6 TOTAL STAFFING FOR THE UNMA HEADQUARTERS

Table 7.7 below shows overall staffing proposed for UNMA headquarters. Note also in Table 7.7 that some positions can be filled by meteorologists and some by nonmeteorologists. Therefore the total table numbers for meteorologists and non-meteorologists may not be equal to the number of staff.

Table 7.7: Staffed Positions for the UNMA Modernization

Organization	Number of Staff	Meteorologists	Non Meteorologists
Office of Executive Director	12	3	11
Weather Analysis, Forecasting and Communications Directorate	14	10	4
Weather Analysis, Forecasting and Communications Directorate	16	13	15
Training and Research Directorate	20	17	10
Support Services Directorate	20		20
Technical Services Directorate	32	7	32
Total	117	50	92

It will take several years for the Headquarters to spin up into an organization that can provide effective leadership for the modernization program. UNMA should appoint a Modernization program manager whose full time duty will be to maintain oversight of the whole project. Such an individual could be a full time UNMA person who is detailed to the job or it could be a contractor hired to manage the process. That position is reflected in the staffing tables and should be one of the first decisions made by the new Executive Director of UNMA.

7.2.2 UNMA OPERATIONAL FIELD STRUCTURE

The Uganda National Meteorological Authority will provide and maintain a field structure that supports its mission and is equipped to provide the protection of life and property within Uganda and support the national economy. The modernized National Meteorological Center (NMC) will be responsible for short-term and medium-term forecast and nowcasting operations for all districts across Uganda. They will be aided in the nowcast periods by the forecast offices at Soroti and Kasese. The Climate Prediction Center (CPC) located in the UNMA Forecasting Directorate will be responsible for long-term forecasts and climate prediction. The NMC along with the forecast offices at Soroti and Kasese will be responsible for public forecasts, air quality forecasts and agricultural forecasts. The aviation program, which will be identified as the Meteorological Watch Office (MWO), will be maintained within the NMC. As buoy data becomes available, the NMC will more accurately focus on marine weather forecast for Lake Victoria. Monitoring of the streams and rivers in Uganda is now handled by the Ministry of Water, but as the forecast process matures in UNMA, this can become a shared responsibility.

The NMC will be modernized to provide 24x7x52 warnings, forecasts, advisories, alerts, and other products. Products should be issued according to a specific schedule, with the exception of products issued during nowcasting operations. During those operations, products will be issued as the situation requires. The NMC should define the forecast periods for their products as follows:

- “short-term” or “short-range” will cover less than 24 hours,
- “medium-term” or “medium-range” will cover 1-3 days,
- “nowcasts” will be defined as very short-term forecasts, usually 0-6 hours.

Soroti and Kasese will add value to the “nowcasts” in their areas of responsibility.

To protect lives and property, the NMC, Soroti and Kasese must provide warnings, alerts, advisories, and forecasts of threatening hazards that are within its mission area. In fact, the NMC, Soroti, and Kasese should provide for severe convective storm forecasts and nowcasts to alert (warn) the public and government agencies within Uganda or on the adjoining waters of Lake Victoria.

The meteorological and hydrological forecast and warning system is a critical component in the UNMA’s mission “to act towards the preservation of life and material goods from natural and manmade hazards and disasters”. Forecast operations in the NMC, Soroti, and Kasese must be enhanced significantly to meet the ever increasing needs of its users and to take full advantage of the modernized observing systems and IT infrastructure. Figure 7.9 provides an overview of the functions of the forecast system for the modernized NMC. On the far left of the figure, observations and numerical guidance are input into the forecast and warning system. On the far right, forecast and warning products are disseminated (via the IT system) to the users. Between these inputs and outputs are the automated and human decision processes required to produce timely, high-quality forecasts and warning products.

Three physically distinct, but organizationally linked components to the modernized NMC forecast and warning system are proposed:

- a weather forecast office in NMC
- a weather and aviation weather forecast office in Soroti
- a forecast office in Kasese.

Responsibilities of each office must be clearly defined and all offices should issue their products under the NMC name and logo/branding (rather than by a particular office name) so as to present a single identity to the customers. The offices should coordinate backup procedures for personnel (similar to those procedures developed for the IT infrastructure) in the event of loss of communication at NMC, Soroti, or Kasese. During any given shift, a Senior Meteorologist will be appointed; however, there should be overarching administration of the three forecast components so that operations are well integrated between all offices. An urgent necessity to modernize the forecast and warning operations of NMC is access to modern facilities including quality, high technology IT infrastructure: the buildings currently housing the NMC and the Kasese and Soroti forecast offices do not supply adequate space or infrastructure for these purposes. In addition, as the UNMA modernization gets underway, strategic plans should be developed within the Forecasting Directorate to look beyond the modernization of the forecast and warning services. These plans should aim to:

- Capitalize on advances in science and technology so as to increase the societal value of weather and related environmental information.
- Plan for a continual incorporation of scientific and technical advances in the operational weather systems of future decades.
- Routinely examine and anticipate the needs of primary customers and ultimate users.
- Provide continuing education and training for the ongoing professional development of a knowledgeable, flexible workforce.

- Begin long-range strategic planning to develop the infrastructure and technology that support the services for future constituents.

In the modernized UNMA, many of the same products and services will be provided to users as were provided by the DoM; however, the data and decision processes to create those products will be different. For example, high-resolution, real-time radar data, surface observations, and other measurements will revolutionize short-term forecasts and related products. New methods to complete subjective human decisions will result in scientifically sound, timely, and relevant forecasts to be made, even during hazardous weather operations.

Several new products should be issued from the weather forecast offices in NMC, Soroti, and Kasese, focused primarily on nowcasting hazardous weather on the mesoscale (0-6 h and 2-400 km). Note that these same techniques are required in the aviation program when writing and monitoring TAFS, GAMETS, and SIGMETS. A modern nowcasting program should issue alerts/warnings, advisories, watches, and outlooks for severe thunderstorms. A “severe thunderstorm” is defined as a thunderstorm capable of producing hail 2.5 cm or larger, surface wind gusts greater than 25 m s-1, tornadoes, or flash floods (occurring on a scale of 0-3 hours).In particular, the following products should be developed and issued:

1. thunderstorm outlooks
2. mesoscale convective discussions
3. severe storm watches
4. severe storm alerts/warnings

In addition, the weather forecast offices should issue other hazardous weather warnings (e.g., fire weather, dense fog).

Compared to current operations, the weather forecast office in NMC will require additional staffing for its transition to 24x7x52 shift rotation and additional forecast duties. Shifts will last eight hours and each forecaster will work five shifts per week (or equivalent).

Day-to-day operations of the office will be led by Principal Meteorologist, assisted by a Senior Duty Meteorologist (SDM). They will be assisted by an administrative assistant who will provide office support (e.g., answer phones, order supplies, set meetings) for all personnel in the weather forecast office. The meteorologist-in-charge and his/her chief forecaster will set office policies and be responsible for maintaining a station duty manual that lists the prioritized duties and products for each shift and each type of employee. This important manual will include the priority basis for dispatching maintenance personnel, for backup operations in the event of a disaster, and for site inspections of satellite hardware. These administrative leaders also will be responsible to ensure that adequately trained personnel are working during hazardous events and that the office layout maximizes staff performance and collaboration. These leaders serve as role models by inspiring excellence through innovation and creativity. A senior meteorological forecaster will lead office operations outside of normal office hours (e.g., weekends, nights) and when the meteorologist-in-charge is not in the facility. A minimum of 20 operational forecasters are required to fulfill the weekly shifts, five of whom are senior forecasters who are charged to lead forecast operations. Thirty percent of these forecasters time will be devoted to professional development through additional research, development, and education. The Warnings and Coordination Meteorologist (SDM) and the Science and Operations Officer (SOO) will split their time between operations and training at the office and outreach to media broadcasting (e.g., via television, radio, web), media interviews, weather forecasting.

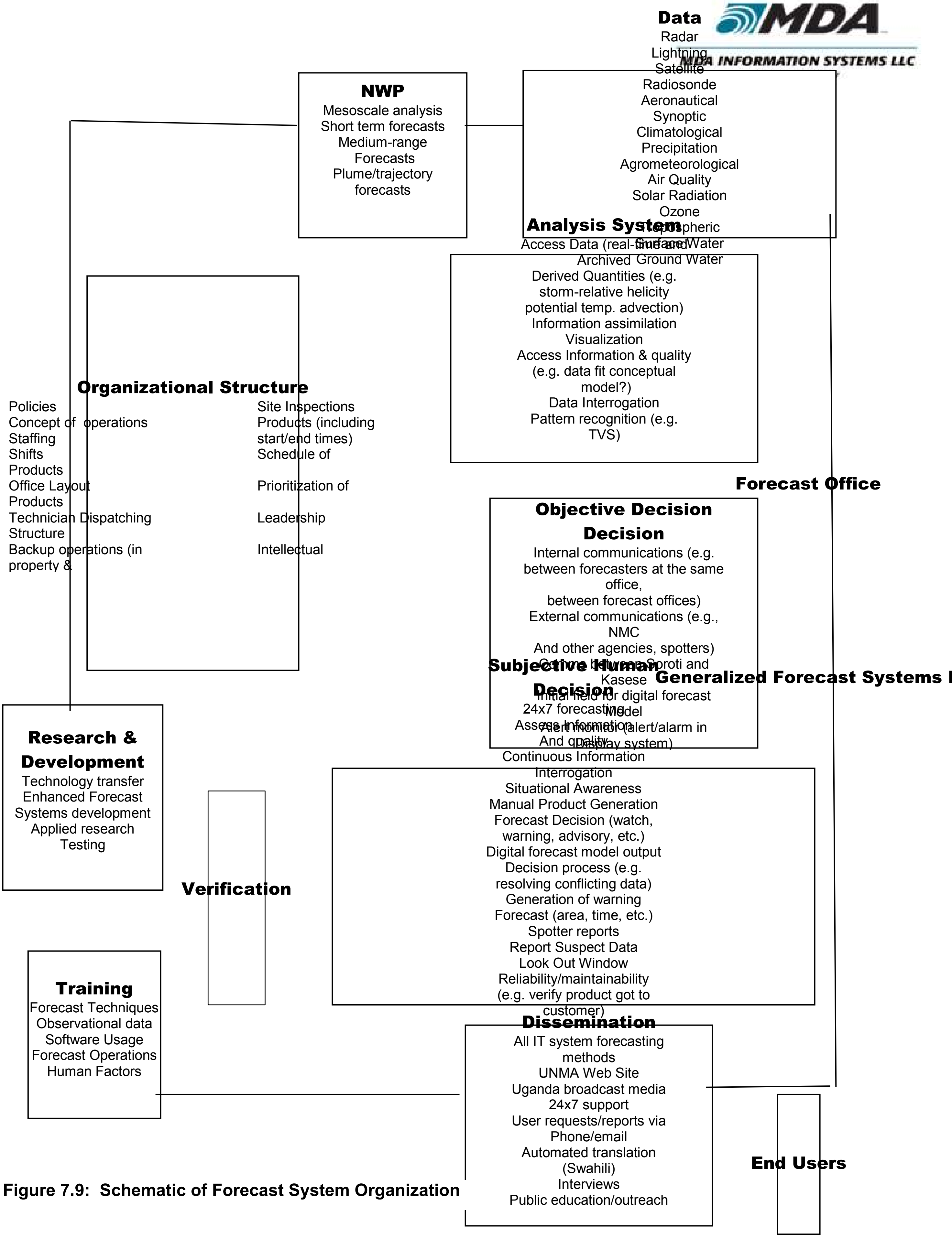

Figure 7.9: Schematic of Forecast System Organization

During normal forecast operations, one forecaster will focus on aviation as the MWO is part of the NMC office. One forecaster will focus on nowcasts and short-term forecasts; the other will focus on medium forecasts. During hazardous weather an additional forecaster (on call) may be necessary to help with alert and advisory duties. If necessary, a member of the forecast office (or other staff member experienced with emergency situations) should be temporarily assigned to a remote location (e.g., emergency operations center) to support decision-making during major natural hazards.

After the radar/radars are installed and the understanding of its use increases there will be greater use of the radar. With current sensitivity and large insect and bird population year-round there will always be echoes causing real-time use of the radar. With severe weather outbreaks sometimes covering the country there will need to be at least three warning forecasters on duty simultaneously. Moreover, the radar is also a fire detection and agricultural system, even in “clear air” echo. Finally, warning forecasters, nowcasters, and journeyman forecasters will need to maintain proficiency through onsite training and research. For these reasons NMC will need to assign perhaps one or two additional forecasters for 24/7 radar coverage. This can be accomplished somewhat by use of the WCM and SOO positions.

Using the U.S. model, the SDM will always have to be cognizant of the radar/radars and ensure these vital data are used to enhance the modernized warning and forecast program.

The SOO will develop and deliver training modules to keep the state-of-the-science at peak performance levels within the minds of the professional staff. This individual will spend 25% of his/her time working operational shifts.

Ten meteorological technicians at NMC will provide coverage for three shifts per day during every day of the week. They will answer incoming phone calls, maintain operation of all modernized equipment, help monitor data quality and report problems to the QA staff at the Quality Data Center and address other office issues so that the operational personnel can concentrate on time-critical tasks.

At such time as the UNMA assumes full equipment maintenance responsibilities, two maintenance personnel will be responsible for emergency and routine maintenance of all hardware in the forecast office. They will work Monday-Friday but are subject to call when maintenance issues arise.

7.2.2.1 THE NATIONAL METEOROLOGICAL CENTER

The National Meteorological Center, which is currently located at the Entebbe Airport, has quite a mixture of personnel. In the stage zero of the UNMA modernization, the NMC will add some functions that will dictate some changes in personnel duties. In copying the current shift schedules at the NMC, it appears there are four shift supervisors and five forecasters. There are eight observers and eight communication officers. Then there are 12 personnel who are in some stage of training. This appears to be 37 personnel not counting the MIC and the electronic technicians.

The modernized weather forecast office at Entebbe and then NMC Kampala will be responsible for short-term, medium-term, and nowcasting operations for all districts across Uganda. These include, in addition to aviation products, the air quality forecasts, agricultural forecasts, and public forecasts. It is assumed that the long-term forecasts (greater than seven days) will issued by the Climate Prediction Center in the Forecasting Directorate. The MDA Team proposes staff for NMC shown in table 7.8.

Table 7.8: Staffed Positions at the NMC prior to a new headqurаters building.

Staffed Positions	WMO Class 1	WMO Class 2	WMO Class 3	WMO Class 4	Total
Principal Met	BIP-M				1
Science and Operations Officer	BIP-M				1
Warnings and Coordination Officer	BIP-M				1
Senior Meteorologists	BIP-M				5
MWO(1)		partial BIP-M			5
Public & Ag	BIP-M	partial BIP-M			10
Briefing	BIP-M	partial BIP-M			5
Observing				(BIP-MT)	10

Senior Comms					1
Comms				(BIP-MT	5
Electronics					2
Security Guard					1
Driver					2
Office Attendants					2
Administrative Asst.					1

The MDA Team believes it is in the best interest of the UNMA to move the MWO, Public and Agriculture forecasting positions as well as the Communications unit to the newly built UNMA headquarters to take account of the synergy provided by a climate-conditioned and modern office with modernized communications and support. As the Radar network is implemented, increased observational data flow will introduce requirements in the nowcasting and warning operations that are not occurring now. This a large training issue and will require that normal forecasting operations are curtailed while the forecasting staff takes up the issues of severe weather and flash flood events.

After the move, the NMC would have two parts to its operation, NMC-Entebbe and NMC-UNMA Headquarters.

Table 7.9: Staffed positions at NMC-Entebbe after move to UNMA headquarters building.

Staffed Positions	WMO Class 1	WMO Class 2	WMO Class 3	WMO Class 4
Briefing		5 partial BIP-M		
Observing				10 (BIP-MT)
Electronics (2)				
Driver (1)				
Office Attendant (1)				
Security Guard (1)				

Table 7.10: Staffed Positions at NMC-UNMA headquarters after move.

Staffed Positions	MWO Class 1	WMO Class 2	WMO Class 4
Principal Met (1)	1 BIP-M		
Senior Forecasters	5 BIP-M		
MWO	5 BIP-M		
Public and Ag	10 BIP-M	10 partial BIP-M	
Senior Comms (1)			
Communicators			5 (BIP-MT)
Administrative Asst. (1)			
Driver (1)			
Office Attendant (1)			
Total	21	10	5

In Table 7.10, the positions Public and Ag can be a mix of Class 1 meteorologists and Class 2. Those in Class 2 would be working on getting their classification upgraded to Class 1 and would require the close supervision of an on-duty Class 1 meteorologist. There the total forecasting staff is 21 with the caveat that some of these are partial BIP-M meteorologists.

7.2.2.2 SOROTI FORECAST OFFICE AND REGIONAL CENTER

The Soroti Forecast Office will have an important role in the modernized UNMA. As the aviation industry expands in the East African Community, there will be a need for additional pilots and aviation personnel. The Soroti Office will provide the meteorological briefings for the existing aviation school. Due to land laws in Uganda that allow the landlord to make all final decisions with respect to improvements, additions, and modifications; the physical office of the Soroti facility will more than likely be located off the airport grounds. Thus, a briefing component to the Aviation school of five officers will be required at the airport office. Additionally, five observers will also be present at the airport initially to handle observations and remarks to observations. Soroti will also function as a synoptic and climate station and the observers will handle that aspect of the program until it is automated.

At the Soroti forecast office, there will be a need for five forecasters who will help in the forecasting of severe thunderstorms and flash flooding in the eastern part of Uganda. The MDA Team recommends that adequate modernized communications be established between the NMC and the Soroti office that will allow guidance products that are issued by NMC arrive in a timely fashion and that radar data pinpointing heavy rainfall and its implications be a part of the communications. Establishment of adequate modern communications will also allow the communication staff to turn their attention to outreach or maintenance tasks.

Soroti will also have importance with a regional office attached to it that will be responsible for the maintaining and upkeep of satellite observational systems in the defined areas of northeast Uganda. Soroti can also be a backup office to NMC where redundant equipment will allow Soroti to take over forecasting and warning services in the event that NMC has a failure. The proposed staff is shown below in Table 7.11.

Table 7.11: Staffed Positions at Soroti Weather Forecast Office.

Staffed Positions	WMO Class 1	WMO Class 2	WMO Class 4	Total
Principal Met	Yes			1
Senior Forecasters	Yes			5
Briefers		Yes	Yes	5
Observers			Yes	5
Senior Comms				1
Communicators				5
Electronics				1
Driver				2
Office Attendant				2

7.2.2.3 KASESE FORECAST OFFICE AND REGIONAL CENTER

The MDA team is proposing that the Kasese Meteorological Observatory be upgraded to a forecast office. With the exception of the aviation training academy, Kasese has the same issues as Soroti and can better perform the mission for western Uganda. The mountainous southwestern and western parts of Uganda have the same severe thunderstorm and flash flooding risk potentials as the eastern part of Uganda and need additional staffing and recognition to aid in the warnings and forecasts of hazards that threaten western Uganda.

Table 7.12: Staffed Positions at the Kasese Forecast Office.

Staffed Positions	WMO Class 1	WMO Class 2	WMO Class 4	Total
Principal Met	Yes			1
Senior Forecasters	Yes			5
Observers			Yes	5
Senior Comms			Yes	1
Communicators				5
Electronics				1
Driver				2
Office Attendant				2

7.2.2.4 REGIONAL FIELD OFFICES

At such time as the UNMA assumes full operational control of the equipment maintenance functions, the four designated regional field offices will be staffed and equipped to maintain, inspect and repair the equipment utilized in the forecasting and observing functions of the UNMA. In order to meet the requirements of the UNMA and its far flung offices and equipment, it will be important to maintain a presence closer to the equipment and facilities through such decentralization of the maintenance operations. This is best accomplished by staging the personnel who will be responsible for inspection, maintenance and upkeep closer in various areas of Uganda.

The positions in these regional offices will include electronic technicians whose jobs include repair and maintenance of the organization's electronics equipment. This means the ability to test and troubleshoot the equipment, read schematics and maintenance manuals, solder and unsolder components (if needed), research parts availability and costs.

There will be Hydrometeorological and Agrometeorological technicians whose job it is to ensure needed agriculture and precipitation stations are operating, and the data is of high quality. They also assist in establishing new stations, maintain a computer database of observing stations and ensure that the appropriate forecast office and the Weather Analysis, Forecasting and Communications Directorate are kept informed. These technicians will assist in station maintenance. They have close contact with the Quality Data Center in the Weather Analysis, Forecasting and Communications Directorate. These technicians are the frontline contact with the observation community in Uganda.

Where possible the Regional Field Offices should be collocated with an UNMA facility. For example, one of the Offices should be collocated with UNMA headquarters to service the southeastern part of Uganda. The MDA team proposes that the Soroti office have a collocated Regional Office to service northeastern Uganda. The Kasese office would be a candidate to have a regional office to serve western and southwestern Uganda and Gulu would be a candidate to host the regional office serving the northwestern part of Uganda.

Table 7.13: Staffed Positions at Regional Offices

Staffed Positions	Meteorologists	Nonmeteorologists	Number
Maintenance Officer NMC		Yes	1
Maintenance Officer Soroti		Yes	1
Maintenance Officer Kasese		Yes	1
Maintenance Officer Lira		Yes	1
Instrument Officer NMC		Yes	1
Instrument Officer Soroti		Yes	1
Instrument Officer Kasese		Yes	1
Instrument Officer Lira		Yes	1
Driver at each Regional Office		Yes	4

7.2.2.5 OBSERVATIONAL OFFICES IN UGANDA

In previous sections of this report, the MDA Team raised the importance of a quality assured data set in the modernized UNMA and that new, modern equipment and hardware be installed in the UNMA observational network. We need to stress again that the physical infrastructure of the modernized UNMA must not be allowed to deteriorate over time. As a result, a stable, annual investment from the Authority for spare parts, regularly scheduled hardware upgrades, and system maintenance is required for successful modernization.

The modernization of the existing surface observation networks that are owned and maintained by the UNMA will result in the building of a national Mesonet for Uganda. For this Feasibility Study, this modernized observing system hereafter will be called the “UNMA Mesonet.” The observational offices described in this section will for the backbone of the UNMA Mesonet.

The UNMA Mesonet will help save lives; enhance national security; protect property; support, agriculture, energy, and; transportation and promote the economic well-being by providing high quality real-time weather, water, climate, and air quality data.

Currently, data from many of the networks across Uganda are difficult to access because of minimal or no automation of stations. In our information-dominated world economy, the current networks are neither cost-effective nor sustainable. As a result, the MDA Team strongly recommends again the automation and standardization of the UNMA’s surface observations.

A UNMA Mesonet and the integrated, quality assured surface observations it will produce should serve Uganda well because improved weather, aviation, agriculture hydrologic, and air quality forecasting are critical needs whose solutions are within reach. Furthermore, the vast economic dividends from establishing a UNMA Mesonet are unquestioned.

To follow up on our previous section on a Data Quality Center and to stress the importance a quality assured data set, the MDA Team calls attention to the Figure 7.10 on the next page that alludes to the importance of the data through a functional overview.

As we look at the proposed system design for a modernized UNMA. The MDA Team focused its primary attention to areas where the largest gaps exist currently, including the modernization of the UNMA observing systems, its IT infrastructure (particularly in how the UNMA processes observations), and forecast office operations which we have previously discussed.

Figure 7.10 shows an overview of the primary functions of the UNMA. Primary functions are divided into the following categories: observing stations, data processing, research and development, operations, dissemination, professional development, end users, and independent review. Although many of these functions overlap somewhat with each other, the FDA Team deemed it useful to diagram these functions and their interconnections.

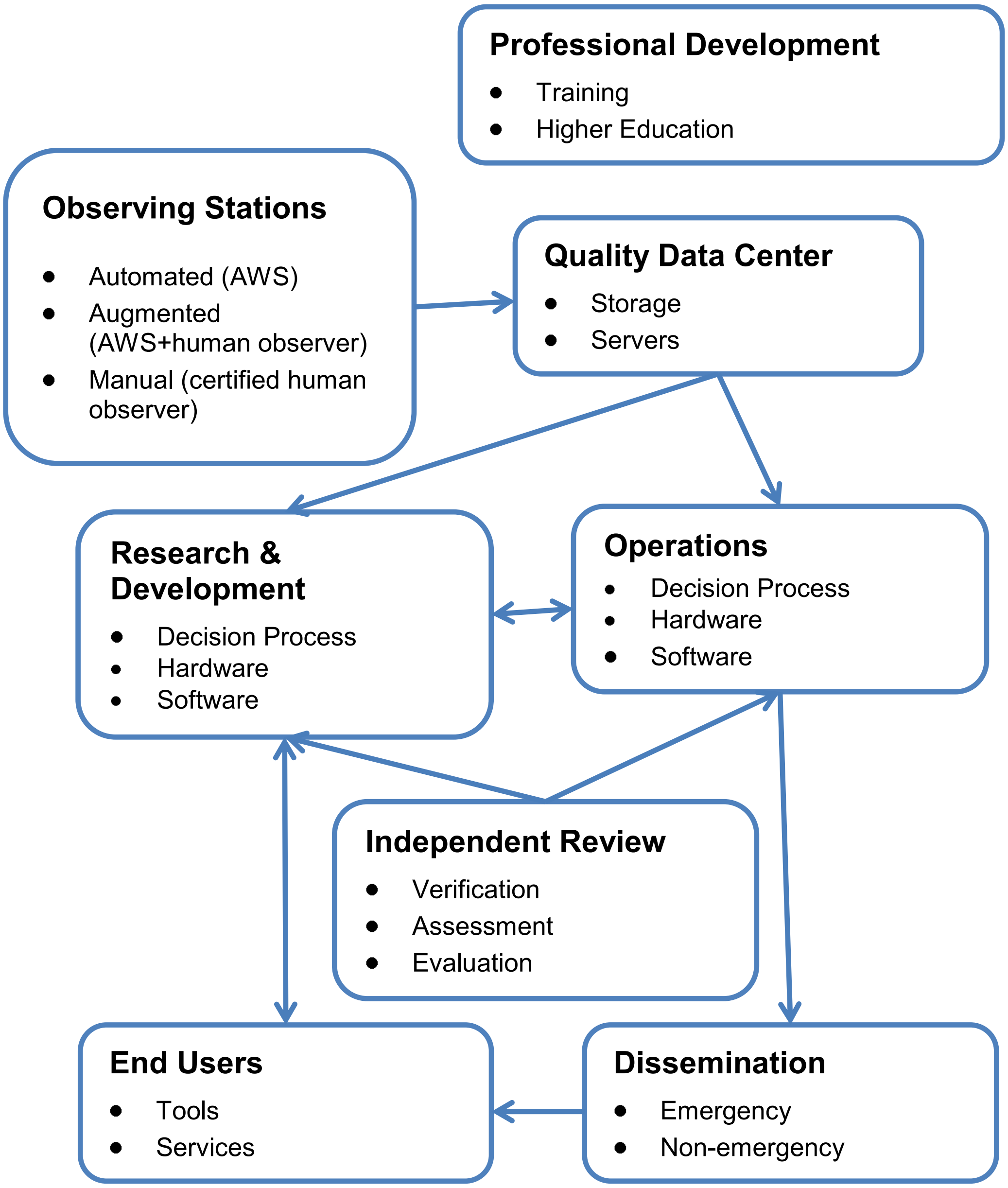

Figure 7.10: Diagram of the proposed functional structure of a modernized UNMA.

Within each function, major sub functions are listed in light gray boxes. For example, within the dissemination function, the MDA Team viewed emergency and nonemergency sub-functions as important. Next to each box representing the main functions, a list of specific tasks or examples is provided. For example, for the dissemination function, methods used include direct line, web pages, text messages, television, radio, newspapers, printed materials, presentations, and journal articles. None of these lists are exhaustive, and some of the tasks or examples may apply to other functional areas.

Information exchange between functions is designated by lines and arrows in Figure 7.10. For example, human-processed information and products derived using computer programs are provided to the dissemination function by both operations and by research and development. Information then is provided to end users. For clarity, Figure 7.10 does not show all of the linkages between functions; rather it identifies the main processes and information to be communicated.

With all of the above in mind, the importance of the observational network is clearly delineated and will remain one of the key cogs as the modernization goes forward.

7.2.2.5.1 Synoptic Stations

To the process of staffing and equipping the synoptic stations, the MDA Team recommends that an inventory of both personnel and equipment be accomplished.

As previously noted, the MDA Team is recommending 10 synoptic stations and UNMA has suggested two additional stations be designated as synoptic bringing the total to 12. We have already discussed the forecast offices at Entebbe which is listed as Entebbe (Buku Obs) and we have accounted for five observers at that office. We have listed five observers at Soroti and five observers at Kasese.

There is a need for more sophisticated AWS's to support aviation at Arua, Gulu, Kidepo, Kasese, Soroti and Pakuba. The Ugandan CAA has designated these airports as secondary/other international (Category A) aerodromes. Arua, Gulu, Kasese and Soroti are already designated as synoptic stations; therefore, a five person observer staff is needed at those offices. As the automated equipment is operational and the aviation presence increases, the observer staff can be used to both augment the automated observations and provide aviation briefings and support. The airports at Kidepo and Pakuba should be standalone AWOS units with no additional personnel.

Currently the synoptic stations Masindi, Jinja and Tororo have observational staffs. The MDA Team recommends that an AWS be installed at each site especially on the airport with proper communications for real time access and a security fence and guard to deter vandalism. A similar station should be opened at Masaka to fill a gap in the synoptic network in a heavily populated area. Once the equipment is commissioned and deemed operational, the staffs at both offices will be reduced, and their function converted to information officers, who will maintain frequent high-level communications with local government and civic and business organizations, providing them with guidance on available meteorological forecast and data resources, and providing the NMC with up-to-date information on the specific needs of those communities for meteorological services.

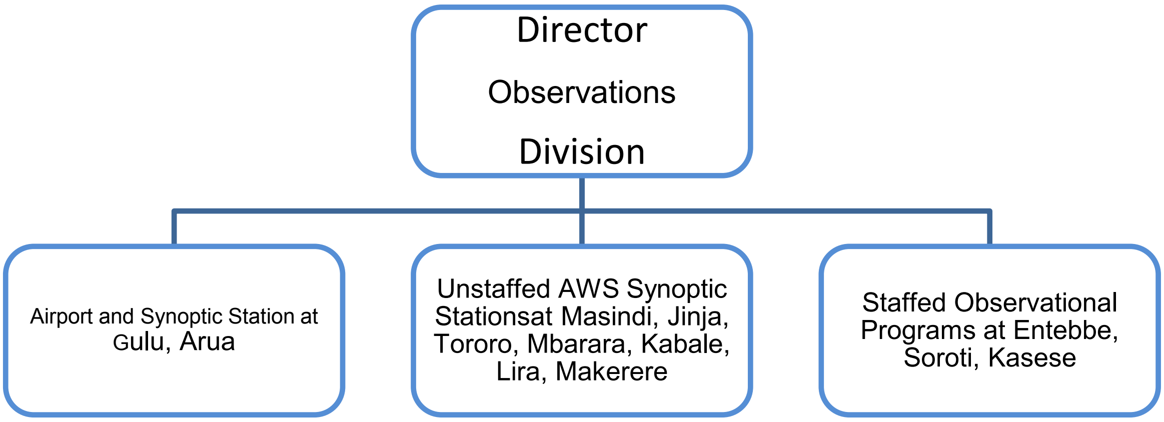

Figure 7.11: Staffed and Unstaffed Synoptic Stations in the UNMA.

Figure 7.11 above shows staffed and unstaffed synoptic and airport stations. Table 15 on the next page shows the numbers of observers for the surface observational program at each office.

Table 7.14: Staffing at Synoptic Stations currently and after modernization.

Station	First Stage	Modernized Stage	Principal Officer	Security Guard
Arua	5 observers	5 observers	1	1
Gulu	5 observers	5 observers	1	1
Masindi	3 observers	0 observers	0	1
Soroti	5 observers	5 observers	Forecast Office	1
Kasese	1 observer	5 observers	Forecast Office	1
Jinja	3 observers	0 observers	1	1

Tororo	4 observers	0 observers	1	1
Mbarara	3 observers	0 observers	1	1
Entebbe	5 observers	5 observers	1	1
Kabale	3 observers	0 observers	1	1
Lira	2 observers	0 observers	1	1
Makerere	0 observers	0 observers	1	1
Masaka	0 observers	0 observers	1	1

7.2.2.5.2 Climatological Stations

Eight of the12 synoptic stations will be proposed as climatological stations in the modernized UNMA. The stations are Arua, Gulu, Masindi, Soroti, Kasese, Tororo, Mbarara, and Entebbe (Buku Obs). In some instances additional sensors may be required but that should have no impact on the staffing at those locations.

7.2.2.5.3 Agrometeorological Stations

The Agriculture meteorological program is a vital program for the UNMA. The Ugandan population largely depends on Agriculture which is weather dependent. The Agriculture sector employs over 80% of the population and accounts for almost 20% of the GDP. Thus the MDA Team has recommended in the NMC forecast office a meteorologist position that will work with the Climate Data Center in the UNMA headquarters to establish more short term forecasts and advisories for the agriculture field. The observational aspect of that is no different. New AWS's will need to be installed at a recommended 10 locations.

The Knowledge, Skills and Abilities (KSAs) of the main person working at an Agrometeorological station require at least a Class I meteorologist. The additional duties are more in line with a Class III or IV and can be automated to a great extent. The daily measurement of normal meteorological parameters can be automated with adequate communication capabilities. Transmission of the data to the Climate Prediction Center and the National Meteorological Center will be part of the automation procedures. The recording and assessment of crop data will require mobility and if one is working in a region rather than locally at a farm there will probably be the necessity for a driver. A combination of a Class IV meteorologist who can also function as a driver would be best solution.

The MDA Team recommends that 10 new AWS equipped Agrometeorological stations be established in 11 regions in Uganda. The stations are listed in Table 7.16 below

Table 7.15: Personnel and staffing at the 10 UNMA Agrometeorological Stations

Station	District	Class I Met	Class 4 Met/Driver	Agriculture Crop
Namulonge	Wakiso	Yes	Yes	Farming and cattle
Kituza	Mukono	Yes	Yes	Coffee
Lira	Lira	Yes	Yes	Farming
Kitgum	Kitgum	Yes	Yes	Farming
Serere[1]	Soroti	Yes	Yes	Farming
Bushenyi	Bushenyi	Yes	Yes	Cattle and Farming
Buginyanya	Bugisu	Yes	Yes	Coffee
Bulindi	Masindi	Yes	Yes	Bananas
Kamenyamingo	Mesaka	Yes	Yes	Coffee and Beans
Kalengyere	Kabale	Yes	Yes	potatoes

7.2.2.5.4 Hydrological Stations

The rainfall and ground water observations in Uganda are being adequately covered by the Water Resources Department of the Ministry of Water. The UNMA should take immediate steps to work with the Water Resources Department to gain access to this network and bring the observations into the Wide Area Network (WAN) of the UNMA making them available to the all the facilities within UNMA

[1] Serere is very close to the Soroti Weather Office. UNMA should consider locating the Agricultural Meteorologist and Meteorological Technician/Driver at the Soroti facility while the AWS dedicated to Agriculture measurements could remain at Serere.

that need them. Therefore no staff or expenditure is recommended for recommended for this function. For completeness, Figure 7.12 depicts the network and location of the observations.

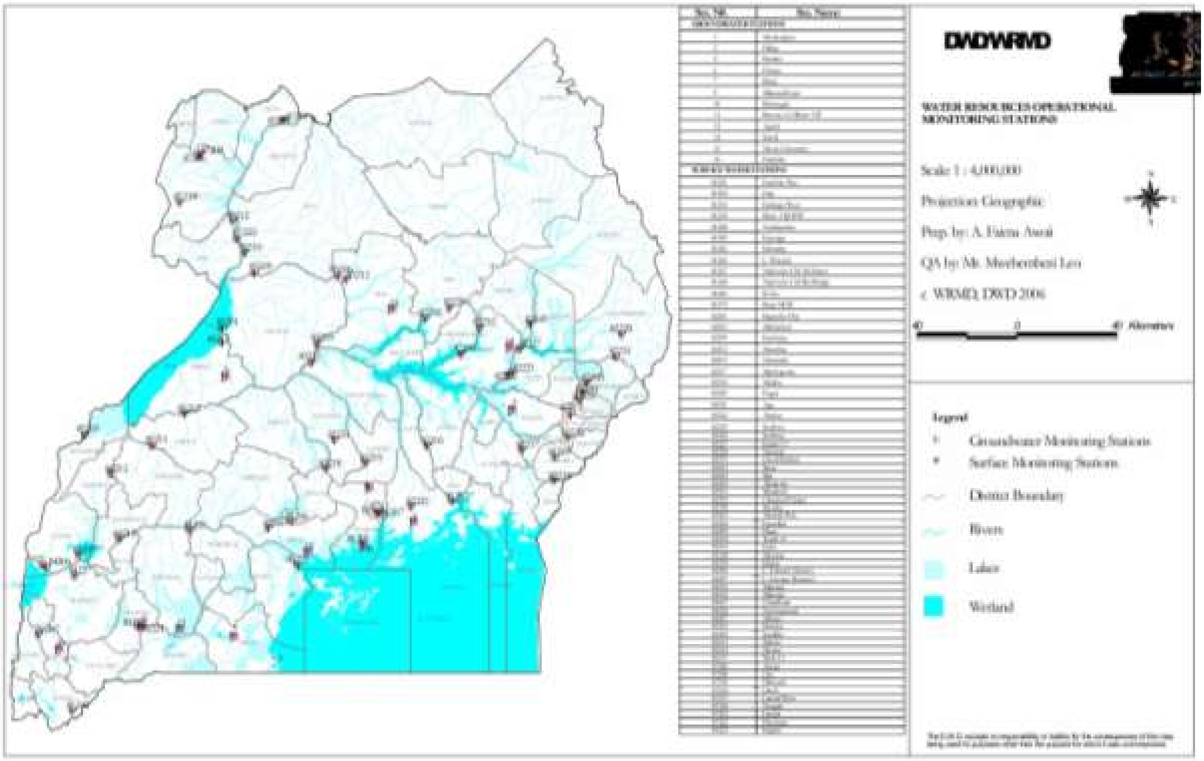

Figure 7.12: Water Resources Department Operational Rainfall Network

7.2.2.5.5 CALIBRATION OF UGANDA MESONET

Crucial to the performance of the UNMA's observational network will be the maintenance of the system's calibration against international standards. This process of Quality Assurance (QA) should be modeled after that of successful Mesonets such as the Oklahoma Mesonet, whose QA program is discussed at http://www.mesonet.org/index.php/quality_assurance. The process consists of a four-pronged approach including laboratory calibration, on-site intercomparison using mobile calibration and maintenance facilities (three vehicles carrying calibration equipment), automated quality assurance, in which computer programs routinely examine archived Mesonet data to look for and flag data that seem physically unlikely by various measures (e.g. data points more than three standard deviations from climatological mean for that date, time and location, or data points that differ dramatically from observations at near-by stations), manual QA, in which UNMA staff examine flagged data, and random unflagged data, for signs of hidden instrument errors.

7.2.3 FINAL STAFFING PROPOSED FOR UNMA

Table 7.16 shows the combined staffing in all offices for the UNMA as described above. Of 280 staff, 170 are assigned to headquarters or NMC, while 110 are in field offices.

Table 7.16: Final staffing proposed for UNMA. *Regional Offices staff includes staffing for Maintenance and Instrument Officers included in the Technical Services and Weather Observations Directorates.

Office	Personnel	Personnel
	1-5 years	6- 15 years
Office of Executive Director	12	12
Weather Analysis, Forecasting and Communications Directorate	17	17
Observations Directorate	17	17

Training and Research Directorate	20	20
Support Services Directorate	20	20
Technical Services Directorate	32	32
National Meteorological Center	52	56
Soroti	27	21
Kasese	22	16
Regional Offices *	4	4
Aura	7	7
Gulu	7	7
Masindi	4	1
Jinja	4	1
Tororo	5	1
Mbarara	4	1
Kabale	4	1
Lira	2	0
Makerere	0	0
Namulonge	2	2
Kituza	2	2
Lira	2	2
Kitgum	2	2
Serere	2	2
Bushenyi	2	2
Buginyanya	2	2
Bulindi	2	2
Kamenyamingo	2	2
Kalengyere	2	2
TOTAL	280	254

8 Operational Recommendations

8.1 MODEL-BASED FORECASTING

Accurate near-term forecasting of temperature, precipitation, wind other important fields is best achieved through the adjustment of numerical weather prediction (NWP) models to local conditions using model output statistics. The system could be implemented in Uganda in the near term, using computational resources currently provided by NOAA's International Office, as follows. Numerical Weather Prediction (NWP) model output grids available from international sources (NOAA, UKMO, ECMWF, Kenya Meteorological Department) will be interpolated to the location of every observing station in Uganda, and for all variables to be predicted (minimally: temperature, dew point, precipitation, wind, insolation). These interpolated model predictions will be archived for at least one month. Interpolated model predictions will be compared to observations at each location at the time for which the prediction is valid. The average bias of each model will be calculated separately for each time of day, for the past 30 days, for all forecast lead times less than 24 hours, and the correlation of the resulting bias-corrected model forecasts over the 30 day period will be noted. These "model output statistics" can then be used to prepare the bias corrected multi-model forecast. The most recent model runs will be interpolated to the locations of the observing stations, their bias (as determined by the comparison with past data for that location and for each time of day) will be removed, and the weighted average of all the models, with the weighting proportional to the correlation score of each model for that location over the past 30 days, will be calculated.

The output of this system will be made available via web portal to all UNMA forecasting staff, as a basis on which to prepare their forecasts. Forecasts may be adjusted by the staff based on conditions developing in real time that may reveal errors in model initial conditions, or based on experience which may demonstrate model biases in particular meteorological contexts not well-captured by the bias removal process described above.

As computing power at UNMA is increased, it will be possible (by 2015) to begin routine runs of a high resolution (2 km x 2 km) nested mesoscale NWP model centered on Uganda. The Weather Research and Forecasting (WRF) model, available here , http://www.mmm.ucar.edu/wrf/users/ , includes sophisticated data assimilation modules that will allow the incorporation of Uganda's mesoscale observing network as that develops and radar and lightning detection data when they become available, and should provide substantial additional forecasting skill in the near-term (0-12 hours).

Similar procedures may be adopted by the Climate Prediction Center to adjust the results of global long-range prediction models (such as the NOAA Climate Forecast System) to Ugandan conditions.

8.2 NUMERICAL WEATHER FORECASTING

Many national weather services now run Numerical Weather Prediction models locally, using global runs from US NWS, UKMO or ECMWF models to supply boundary conditions, and assimilating local observations (perhaps including observations not available to the international forecasting centers.) For example, the Kenya Meteorology Department runs both the WRF and COSMO Mesoscale models over a domain including all of east Africa at least once per day. The computer code for the WRF model is freely available on the web, and the code for the UKMO Unified model is available to collaborating national weather services under certain conditions. Mesoscale models could be run in a domain somewhat larger than Uganda, allowing computational power to be focused on a limited area with high horizontal and vertical resolution. This allows the model to better represent topographic forcing features in Uganda, and to more faithfully represent convective storms, leading to improved forecast skill for lead times less than three days.

To make a significant improvement in forecast skill, the UNMA would need to run the Advanced Research WRF (Weather Research and Forecasting) model or equivalent (e.g., UKMO Unified Model) including data assimilation module that allows incorporation of Ugandan and neighboring countries' AWS observation, upper air soundings, radar, and lightning detection (this is still experimental, but will likely become standard in a few years.). The model should be run at 5 km horizontal resolution or finer, so as to substantially improve on the ECMWF's ~12 km resolution. At 5 km resolution, with a domain of 900 km x 900 km, a 3-day forecast could be run in approximately 8 hours on a system with 4 processor cores running at 3.5 GHz, with 16 GB of memory. At 2.5 km resolution, running the same forecast in eight hours would require a system with at least 32 processor cores.

For short-range convective forecasts (less than eight hours lead time), extrapolation of observed motions of convective systems detected using radar or lighting detection systems can often be more skillful than NWP forecasts (see section 5.3.1). Because such forecasts are typically done in only two dimensions (perhaps including vertically averaged winds from soundings or model analyses), they are not very computationally demanding. Software for these forecasts is not currently available in the open literature, but the service may be obtained from commercial forecast providers.

8.3 HAZARDOUS WEATHER DETECTION AND NOWCASTING

Because of its geographic location, Uganda experiences many types of hazardous weather events such as Easterly African Waves and MCSs producing severe thunderstorms, floods and drought. Currently, the DoM forecast staff is not equipped or adequately trained to detect, forecast, or warn for hazardous weather.

Short-range forecasting or “nowcasting” is based upon the ability of the forecaster to assimilate large quantities of weather data, conceptualize a model of the environment and move and develop this forward in time. Much of the resulting information describes presently existing conditions, hence the term “nowcasting.” Because the time scales and the method of processing the data are essentially the same for short-range forecasting and nowcasting, the terms can be used interchangeably.

However, nowcasting is more than simple “thumb and pencil” extrapolation of features on maps. It involves close monitoring and integration of all data and the use of predictive and mesoscale and storm scale models. The nowcaster tries to match the data to conceptual models in order to recognize known severe storms. This is very similar to how a physician uses medical tools and tests to diagnose a disease. Once the physician recognizes the malady through the symptoms he/she knows how to treat the illness. In a similar way the meteorologists uses radar and all data to “diagnose” storm severity. If a severe storm has been recognized through the use of the conceptual models, then the meteorologist will know what warning is needed and the hazardous weather to include in the warning. The nowcaster or warning forecaster needs to recognize and foresee the most subtle changes in the atmosphere and match the observations to the conceptual model that encompasses the structure and evolution of the phenomenon Because the nowcaster and warning forecaster deals with “short fused” events, immediate warning formulation, transmission, and reception by those in harm’s way is essential. Use of a sophisticated workstation capable of providing a four-dimensional display of high resolution data will be of value only if the forecaster or nowcaster has an intuitive feeling for the small scale structure of the atmosphere and is well trained.

Skill in nowcasting can be developed, with practice, in three ways:

- Frequency of analysis–monitoring data on an hourly or more frequent basis day after day.
- Compositing–combining features from all sources of data on one presentation using a sophisticated workstation
- Post-nowcast analysis, a form of verification, to assess the accuracy of the nowcast in terms of occurrence or non-occurrence of predicted weather events.
- Using a Weather Event Simulator is an excellent way for forecasters to experience low-frequency and high impact storms and learn how to handle these events.

Note that there must be concerted effort to obtain all the reports or known occurrences of severe weather—a verification program is needed. The nowcaster can thus develop conceptual models that will improve with time. The availability of a sophisticated workstation can eliminate the time absorbing requirement of hand analysis. However, the quality of nowcasting is primarily based on the quality of the nowcaster’s memory, skills, and speed, and the quality and abundance of the data available to the nowcaster.

We have used the term “warning” and have recommended a warning program. Nowcasting deals with thunderstorms and involve short range forecasts of features that are considered mesoscale, or ~ 10 to 200 km in wavelength and time scales of minutes to 3 hours). Thus radar that observes on these scales becomes the nowcasting tool of choice. But in issuing a warning the radar or any other tool is never used alone. Instead, all observations are integrated or combined either physically or cognitively and used in concert. Thunderstorm warnings are nowcasts (short term forecasts) of usually 30 minutes to 1 hour and cover areas of a few hundred square kilometers. Flash flood

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warnings (short term forecasts) usually cover a time frame of 3 hours and somewhat larger scales. Nowcasts of hazardous weather on these time and space scales are normally referred to as “warnings”.

8.3.1 TOOLS FOR NOWCASTING

A major problem in observational nowcasting, in addition to real-time recognition of features including radar storm structure, is the need to combine all the data sets into one clear coherent picture of a phenomenon. The nowcaster can then match these base data to one of a variety of conceptual models. One such method of painting a clear coherent picture of a phenomenon is through the use of the Advanced Research WRF (Weather Research and Forecasting) model or equivalent data assimilation module that allows incorporation of Ugandan and neighboring countries’ automated weather station observations, radar imagery, satellite data, upper air soundings, and lightning detection into a fully self-consistent physical model of the atmosphere. But due to the heavy computational demands of explicit forward modeling of the atmosphere, and the need to transmit information as quickly as possible on weather that may threaten life and property, it is often preferable to use simpler models. These involve extrapolation of observed weather features using observed motion and trends and meso- or storm-scale numerical models.

Listed below are the key tools necessary for a modernized weather service to offer nowcasting to weather data users.

8.3.1.1 DOPPLER WEATHER RADAR

Not only is Dual Pol Doppler Weather Radar a unique and necessary tool for monitoring motion and strength of stratiform rainfall and showers, but especially necessary for convective storm flood and severe thunderstorm warnings. In fact, the number one tool for the issuance of severe thunderstorm warnings is radar. Moreover, the primary tool for nowcasting and warnings is radar.

Convective storms normally develop on mesoscale boundaries so following these boundaries is essential for forecasting where the storms will often initiate. Downstream storms may then become severe. Modern sensitive radars can often detect these boundaries through Brag Scattering and the accumulation of wind carried insects. In other words these boundaries may often be detected before precipitation through use of radar and satellite information. Normally, satellite will lack time and spatial resolution. Thunderstorms often will first be recognized with a “first echo” most often in mid-levels near the – 10^{o} C level. Hail normally develops and grows within the thunderstorm updraft in the region where temperatures range from -10^{o} to -30^{o} C. Polarimetric Radar is uniquely equipped to observe this process. Moreover, microbursts often develop 1 to 3 km above cloud base in a region of storm-scale convergence and perhaps hail. Once again radar is uniquely equipped to observe this. Finally, the observation of mesocyclones within the mid-troposphere down to the surface can only be accomplished by Doppler Weather Radar. For these reasons, as stated above, Doppler radar is the most used and relied upon tool for nowcasts and the issuance of severe thunderstorm and flash flooding warnings.

These advantages justify a substantial investment in radar infrastructure for Uganda. The exceptional benefits of Doppler weather radar to the Ugandan nowcasting and warning programs and its ability to sample the pre-storm environment and storm structure and flow cannot be overstated. Low level confluent boundaries as explained above may be located from the movement and accumulation of insects, birds, and density discontinuities with these boundaries. Equally valuable is Doppler weather radar’s scanning at elevation to sample mean vertical wind shear profiles within and outside of the storm, internal storm structure and flow, and to determine the depth of the moist layer in the environment. This allows the nowcaster to monitor these important phenomena, which often determine the likelihood of convective development and the possibility of severe weather and flash floods.

8.3.1.2 LIGHTNING DETECTION NETWORK

Along with flash floods, lightning is one of the largest weather-related killers in Uganda. A lightning detection network with attendant reports is a mandatory remote sensing tool for the modernized weather service. Tropical storms and flash floods are very often 'warm rain' processes that are not appreciably electrically active. In warm clouds, mixed phase precipitation is sparse and precipitation

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grows primarily by collision and coalescence. . However, Uganda's high terrain and relatively cool temperatures for the tropics increases the relative role of mixed phase processes and hail occurrence. And in electrically active storms, recent research has shown the ability of total lightning to serve as a proxy for rainfall rate. Moreover, total lightning "jumps" have been recently found to be excellent signatures for impending damaging winds and hail. Depending on the relative role of warm and cold rain processes, the Ugandan lightning detection network may very well play a prominent role in nowcasting of heavy rain. It will certainly play an important role in the Ugandan convective storm warnings.

Using a sophisticated workstation, lightning data, and radar should be used simultaneously in the NMC centralized Ugandan severe storm warning program. Additionally, thunderstorms with a high density of total lightning flashes indicate the very strong possibility of hail and turbulence aloft and strongly indicate the need for SIGMETs for convection as well as a nowcast for the possibility of heavy rain.

Because weather radar imagery may not be available throughout all of Uganda with its varied terrain, lightning data can be used as a proxy for radar. In fact, through the use of total lightning a proxy to radar reflectivity can be generated. Further, with the advent of helicopter operations in northwest Uganda and increasing use of helicopters, this becomes an important nowcasting tool for the UNMA.

8.3.1.3 Satellite Imagery

Used in conjunction with other sources of information, satellite imagery is a mainstay of the nowcaster's ensemble of tools. With routine observations taken every 30 minutes, sub- mesoscale elements can be monitored over all of Uganda. Infrared imagery is capable of providing information on ground surface temperatures, moist layers, and cloud heights. Water vapor imagery can clearly delineate moist and dry regions in cloud free areas.

Satellite data can be routinely overlaid on the composite chart (usually an hourly surface chart) and compared with prognoses of wind and temperature fields using a modern workstation. The nowcaster can then delineate and track cloud lines, low cloud areas, and/or warm, moist regions where fog may form and frequently airmass boundaries themselves. Growing cumulus can be monitored for incipient development before the first detection of a radar echo aloft. Outflow boundaries from thunderstorms can be followed by satellite as well as radar; new thunderstorms often develop along the outflow boundary and the boundaries are typically accompanied by sharp wind shifts and a sudden drop in temperature. Time continuity of features is a critical factor in analysis of satellite imagery, so the use of video loops is very helpful in determining the trajectory of cloud and moisture patterns.

Decoding the surface observations into ICAO defined ceiling categories and plotting them on the satellite image allows the meteorologist to immediately monitor the ongoing TAFS that are key outputs of the modernized aviation weather program in Uganda.

8.3.1.4 Vertical Soundings

The vertical sounding is a source of data often neglected by the nowcaster. Owing to the time periods in which the atmosphere is sampled (0300 and 1500 LST) in Uganda, forecasters are reluctant to spend time analyzing a vertical profile that may be unrepresentative of the atmosphere by the time convection begins. However, with today's storm scale and mesoscale numerical models the forecaster and nowcaster can generate model soundings and ensembles as well. Through the use of these models surface temperatures, moisture, changes in vertical lapse rates, and cloud bases and types can be generated. In fact, research is now being done to produce a "warn on forecast" via mesoscale and storm scale models. While the Ugandan forecaster and nowcaster will not be using such software in the immediate future, they will use model soundings and model vertical profiles of shear and CAPE to estimate when the capping inversion might break and when convection might fire. All of these techniques are supported by software on the MDA proposed workstation.

8.3.1.5 Surface Observations

Hourly surface observations and numerical models using these observations provide the forecaster with a mesoscale perspective and context crucial to interpreting and utilizing the story told by the other data sources. Surface observations not only sample the contact layer, but can provide a wealth of information on the vertical change of the atmosphere, which are closely tied to development of thunderstorms and to intensifying or relaxing of air pollution episodes. The current observation and time changes in pressure, temperature, dewpoint, wind direction and speed, cloud base, and cloud type along with numerical models can often provide valuable knowledge of the forcing mechanisms in the local environment greatly aid in nowcasts.

Dewpoint and dewpoint trend data, particularly when used with temperature data, can suggest the status of the vertical moisture profiles (the "hydrolapse"), onset of low clouds or fog layers, lake breeze, and outflow boundary passage. Visibility and changes in visibility can reveal the existence and destruction of capping layers, onset of fog and location of moist air. For example, a drop in visibility from 24 km to 11 km could mean moisture is increasing and the cap is intensifying. Ceiling information, pressure changes and wind observations can be overlain and displayed on the proposed Ugandan workstation and help the nowcaster assimilate, understand, and make adjustments to the information being presented by the WRF model. Fields such as moisture convergence are highly dependent on good surface observations and give the nowcaster another tool to detect convective initiation. Surface observations are an essential part of nowcasting, but must be fully integrated and assimilated with other data, model runs, and products to maximize its potential. The surface chart should normally serve as the base map for the nowcasting composite chart.

8.3.1.6 Pilot and AMDAR Reports

Pilot reports are particularly useful when bases and tops of clouds, tops of haze layers (often the base of the capping layer), and occasionally temperatures at altitude are given. Pilot reports should be monitored for reports of stratus, vertically developing clouds and other visual information. Winds aloft observations from aircraft are useful as are reports of turbulence for the SIGMET program.

At least two airlines operating at Entebbe airport provide AMDAR (Aircraft Meteorological Data Relay) reports. These will be available to UNMA meteorologists as soon as the GTS line between Nairobi and Entebbe is established. AMDAR reports are particularly useful for nowcasting situations where conditions are changing rapidly and are, therefore, of special use to the aviation industry. Such applications include:

- Surface and upper air forecasts of wind and temperature (including severe wind, onset of lake breeze and local topographical weather)
- Thunderstorm genesis, location and severity
- Wind-shear location and intensity e.g. dangerous low-level jets
- Low cloud formation, location and duration
- Fog formation, location and duration
- Turbulence location and intensity
- Jetstream location and intensity
- Environmental control information e.g. trapping inversions, etc.

Ingest of AMDAR from descending and ascending aircraft soundings will provide strategic input into the WRF model and help enhance the nowcasting program.

8.3.2 NOWCASTING TECHNIQUES

Techniques utilized to implement a nowcasting program are described below. These techniques assume that most of the nowcasting tools highlighted in the preceding sections and a mesoscale model output are available to the forecaster. Uganda has a seasonally bimodal rainfall pattern that is driven by the Intertropical Convergence Zone (ITCZ). The varied topography provides areas for ascent of moist air during the rainy seasons. The use of the mesoscale model and its enhanced gridded terrain will make this clearer to the nowcasters.

8.3.3 GENERAL CONVECTIVE WEATHER

For convection to occur, three ingredients are essential – moisture source, convective instability, and an initiating mechanism.

In Uganda, the major moisture sources are the Indian Ocean, evapotranspiration from the forests of the Congo Basin and localized water bodies such as Lake Victoria and other large lakes near the Rift Zone of western Uganda. The nowcaster may determine the boundaries of moist layers arriving from these sources by watching low cloud areas and warm nighttime infrared images that show the longwave-emitting character of water vapor. Although determining relevant stability and evolution remains as one of the most challenging aspects of nowcasting, WRF model output and satellite diagnostics combined with pilot reports, cloud base and top data, and changes in surface data and weather radar are key contributors to enhancing this capability.

The concept of capping layers, or lids, that must be eroded before deep convection can occur, has been employed in convective forecasting for many years. Intertropical Convergence Zone (ITCZ) inversions, trade wind inversions, tropical high-subsidence inversions, warm, dry high-plateau air masses, and early morning inversions all of which occur in Uganda can act as capping layers. Use of the sophisticated workstation to analyze the morning sounding, look for Convective Available Potential Energy (CAPE) and follow the forecast soundings from mesoscale models will help show how the lowest layer will change over the country. Regional nowcasts of potentially severe convection within Uganda may be obtained by noting areas that demonstrate high potential instability and a cap that can be eroded with available heat and surface moisture sources.

The initiating mechanism for convection is often difficult to identify. Clear-cut boundaries such as a lake breeze front, confluence lines, outflow boundaries from previous convection outflow boundaries often initiate convection, but sometimes storms will develop in areas where only subtle features can be found. The initiator actually consists of two components acting at different scales. The first is a destabilizing mechanism operating at mesoscale or even synoptic scale over the appropriate time interval (3-12 hours). An example might be an easterly wave moving along the ITCZ. The second is the so called “trigger”, usually a series of convectively generated thermals originating in the super-adiabatic layer near the surface, having vertical motions of the order of 1 m s-1 and possessing enough energy to break through the cap. The nowcaster must then deduce the presence of the forcing agent using the tools presented above. For example, visible satellite data can indicate clumped cumulus. Derived satellite products may indicate a deepening moist layer. Moisture convergence charts can indicate the possible presence of zones of destabilization. As UNMA modernizes, numerical models with four dimensional data assimilation of radar and other data can help to identify these mechanisms more definitively.

In summary, to make short-range forecasts or nowcasts of thunderstorms the nowcaster must do the following:

- Accurately analyze the morning Ugandan sounding and available neighboring soundings. Apply numerical models and model soundings for the next 0 to 6 hours.
- Determine the deep-layer and low-level CAPE, CIN, deep layer and 0 to 1 km shear, and amount of daytime surface heating and external lift necessary to break the capping inversion, if one is present
- Estimate time of first convective clouds
- Watch via radar, satellite, and models the evolution and motion of any boundaries that may be the focus of convective initiation
- Note evidence of moist layer deepening (using Doppler weather radar, pilot reports, and satellite imagery
- Note formation and distribution of the first convective clouds along with locale and mesoscale models to determine forcing mechanism at the mesoscale evident from either satellite or upper air data
- Continue to follow all boundaries and boundary character.
- Much of the above may be done by application of the Auto Nowcaster produced by the National Center for Atmospheric Research.

Thunderstorms can become severe, producing damaging winds and large hail. Based on a study by the European Aviation Safety Agency entitled “Hail Threat Standardisation”, hail is much more common along and near mountain ranges owing to topographic lift augmenting other forcing mechanisms intensifying the updrafts within thunderstorms. Otherwise forced convergence and ascent by upslope flow will often strengthen updrafts. In the referenced paper, the largest number of hail days was shown to be near the mountain ranges in Uganda. Looking at the height of the wet bulb zero and using forecast CAPE from the WRF, a hail model could be developed for Uganda. Storm structure, as revealed by the Doppler weather radar or lightning detection system, will also give clues as to the severity of the storm.

Much of the hail in Uganda is caused by ordinary convective storms growing in low shear environments. When shear > 17 ms^{-1} and significant CAPE is present, especially in the hail growth zone (-10^o to -30^o) then resulting convection can be much better organized resulting in much larger and more significant hail.

A forecaster, nowcaster, or warning forecaster should never begin using the radar until he/she is very familiar with the environment including shear, CAPE, locations of upper air disturbances, boundaries, and the model forecasts and soundings. Once these data are reviewed, the warning forecaster can use radar imagery and data with far more skill. The process of assessing storm strength and organization for warning purposes for all of Uganda will be done using a centralized warning team who will be trained in much of the above but even more importantly in Dual Polarization Doppler Weather Radar data application and interpretation. This is done via a careful evaluation of the storm scale radar base data and near storm environment while mentally comparing conceptual models of severe storm (and non-severe storm). This is done in real-time and is continuously evaluated as the storms evolve. Warnings are issued only when a severe storm model is recognized in the data. When that is done, the warning forecaster knows what severe weather that storm is capable of producing and warns appropriately. This process is similar to a medical doctor accumulating medical observations such as the X-ray and MRI data and more conventional observations and then comparing these data with mental conceptual models of diseases or conditions. If the preponderance of the base data and evidence align with a certain model, the doctor knows what to expect and what to prescribe.

8.3.4 FLASH FLOODS

A flood situation results when heavy rain occurs for an extended period in the same drainage basin. Fast moving cells are not usually candidates for flash flood warnings. However, individual cells that move very fast within systems that are stationary or moving slowly can produce flash floods. The condition necessary for such an occurrence is a fixed point for cell regeneration. This can be a terrain feature, an outflow boundary or a line of confluence. Most flash floods in Uganda occur in the eastern and western portions as a result of the mountainous terrain.

Doppler weather radar can integrate reflectivity over time to produce an estimate of accumulated rainfall in drainage basins. These estimates are then compared to “Flash Flood Guidance”. Similarly, total flashes from a total lightning detection system can be used to estimate rainfall associated with electrically active storms. Drainage basins can be displayed via the workstation with the estimate of accumulated rainfall displayed for each basin. With automated drainage models, an increase of stream or river depth can be estimated quickly and an appropriate warning or nowcast can be issued. Working with the reporting resources of the Uganda Department of Water Resources, i.e., estimate of accumulated rainfall overlain with the ground truth reports, a clearer picture of flash flooding can be had and appropriate agencies can be notified to move people out of harm’s way.

The challenge then for the nowcaster is to recognize the transition of convection into a flash-flood generating system. It usually begins when a group of convective storms gradually merge into one large convective area. In the mid-latitudes, this is called a mesoscale convective system (MCS). When such systems form in light wind regimes, they must usually move toward low-level unstable and moist flow to survive in Uganda, as new cells form on the equatorward edge of the complex. Doppler weather radar is the only nowcasting tool that can give a precise view of the storm’s organization. Satellite data or lightning detection can give an overview of the system, but is not as good in depicting warm rainfall regimes. As a result, flash flood indices can be developed for the various basins.

Flash flooding and prolonged heavy rainfall can also exacerbate problems with mudslides. The main areas for mudslides include the Mt. Elgon area (Kapchorwa, Bukwe, Sironko, Manafa, and Mbale). Mudslide prone areas are also prevalent in the Western Uganda Mountains of Rwenzori and Muhavura (Kisoro, Kabale, Kasese, Bundibugyo, etc.). A mudslide is a gravity-driven mixture of sediment, water and other dislodged objects caused by heavy rainfall and weakened terrain, creating a deadly slurry of dislodged rocks, soil and trees. These ingredients combine to resemble a wet concrete-like mass that can develop tremendous downhill force and leave a path of destruction in its wake.

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The combination of Doppler weather radar data and lightning detection flash data with hydro-sensor data available from the Uganda Department of Water and Conservation offers the nowcaster the ability to develop a hydrologic model that can yield input to early warnings for mudslide prone area.

8.3.5 AVIATION

ICAO Annex 3 stipulates the meteorology services recommended in support of aerodrome operations. These include the Aerodrome Forecast (TAF), Trend Type Landing Forecast (TREND), and Aerodrome Warnings. Annex 3 also sets forth meteorological services recommended in support of the Flight Information Region (FIR), and regional and global operations. These include AIRMETS and SIGMETS. Each of these products is highly dependent on nowcasting techniques.

In terms of aviation products, nowcasting is defined as an interval of between zero and two hours. The TAF, TREND, AIRMET and SIGMET are considered high-resolution and require rapid updates for efficient and effective utilization for pre-flight and enroute and contribute to tactical decision-making. In this case, the human will use the tools described in Section 7.1 to make meaningful changes. Each of the nowcasting tools described above allow for this capability. Forecasts beyond the two-hour time frame and up to six hours would blend in the output from the WRF model being run over Uganda airspace.

For the Ugandan airspace, aviation impact variables (AIVs) are defined as convection, visibility and cloud base, wind, and turbulence. Less common AIVs include volcanic ash, dust and sand storms. Convection monitoring is based on Doppler weather radar and lightning detection data. Satellite imagery can be used to infer cloud tops outside of the Doppler weather radar coverage area.

In terms of warnings for the Entebbe Airport, Doppler weather radar and lightning detection data can be used to inform airport operations that lightning is near and/or on the airport complex and will begin to impact such things as vehicle and aircraft fueling, passenger enplaning and deplaning, ground service equipment use, and baggage/cargo handling.

8.4 AGRICULTURAL FORECASTING

Our understanding of current agricultural forecast practices in Uganda is as follows. Seasonal precipitation forecasts for East Africa are generated at a regional meeting held twice yearly in Nairobi by representatives of several East African states. These forecasts are transmitted by the Department of Meteorology to Agrometeorologists and Agronomists in the Ministry of Agriculture, who then prepare advice to farmers about which crops might be favored by expected conditions, and on when seasonal dry-to-wet and wet-to-dry transitions are expected to occur, so that farmers may best time planting, harvest and crop residue disposal activities. In addition, daily forecasts are made available to regional agricultural research stations for transmission to local farmers.

We recommend the following improvements to existing procedures:

First, seasonal forecasts should be updated each week using the most recent short-range coupled climate prediction models. For example, the United States National Center for Environmental Prediction’s Climate Forecast System is run for a month period sixteen times daily, and four times daily for a ten month period. These runs are available in graphical format and as raw data via the internet (http://origin.cpc.ncep.noaa.gov/products/people/wwang/cfsv2fcst/). Since forecast skill increases dramatically at lower lead times, these forecasts could be used to issue one-month lead time forecasts of precipitation anomalies each week, and could include uncertainty analysis, for example by plotting all forecasts for the past seven days of precipitation averaged over Uganda.

Second, daily agricultural forecasts for Uganda should be prepared collaboratively by UNMA and Ministry of Agriculture personnel. An example of a daily forecast product, in this case made with respect to corn planting in South Africa, is shown in Figure 8.1 below. These forecasts must be made in light of the particular sensitivities of each crop and each agricultural activity, as determined by empirical studies of Agricultural yields and harvest times in Uganda. For example, in the United States many crops exhibit straightforward weather sensitivities, with precipitation averaged over the growing season, and length of growing season positively correlated with crop yield. However, other crops exhibit counter-intuitive sensitivities: almond yields in California increase when temperatures are cold in February, and rain is low in March and April, since these conditions are mostly likely to allow successful pollination of the almond flowers. Even in the more straightforward cases, crop sensitivity to precipitation may vary strongly across the growing season, and may differ depending on soil qualities, so that forecasts must make use of crop yield and phenology data from each forecast region.

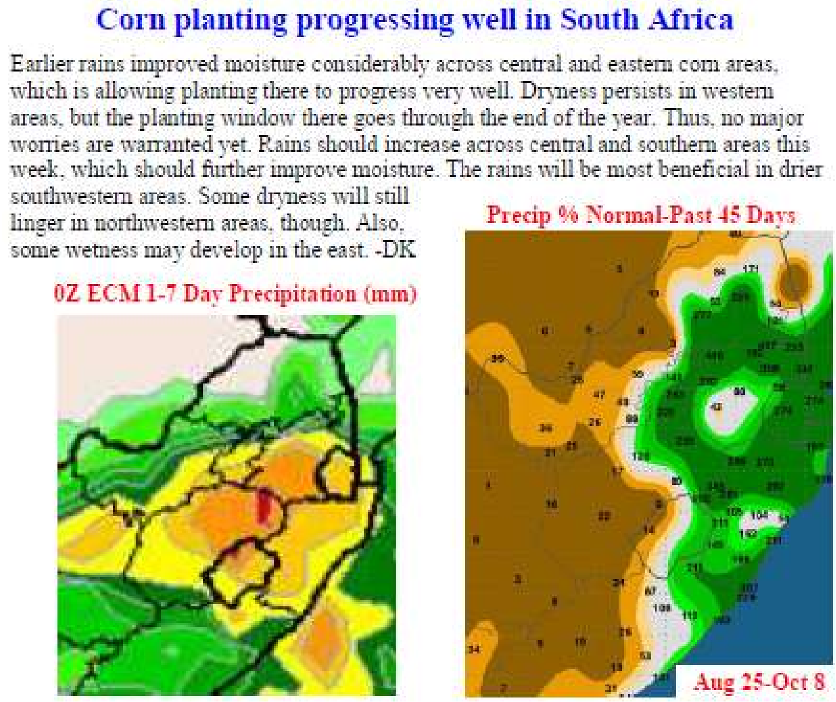

Figure 8.1: Example of daily agricultural forecast product produced by MDA EarthSat.

Improved data collection capability, as discussed in Section 2 of this document, will provide forecasters with knowledge of current soil and crop conditions (e.g. from satellite observations of NDVI). These can be incorporated in location-specific forecasts of the dates of planting and harvest of commodity crops across Uganda. Location-specific services for farmers, including provision of point-location forecasts by text-message, might provide a source of revenue to partially fund these improved agricultural forecasts.

8.5 METEOROLOGICAL WORKSTATIONS

Several of the challenges in modernizing the DoM concern keeping pace with accelerating scientific and technological advancement; meeting expanding and evolving user needs in an increasingly information-centric society, and partnering with an increasingly capable infrastructure that needs to get its message out.

At the heart of this modernization is a scientific workstation and technology that is designed to meet the needs of meteorological forecasting and warning in Uganda. Networked workstations can be used for the integration and display of meteorological information for aviation, public, agriculture, and hydrological forecasting as well as supporting non-meteorologist user workstations for providing pilot weather briefings and weather information over the web or at remote airports without DoM facilities.

The ability of UNMA personnel to integrate, display, and analyze real-time, quality-assured data in a dynamic and sometimes stressful environment will be essential for increased situational awareness and better decision making. Operational personnel should be using their skills and experience to prepare better forecasts rather than spending significant amounts of time on gathering data and data products. Although the primary users for this system component will be operational meteorologists and meteorological technicians, the optimal solution for a meteorological analysis and display system will allow forecasters, researchers, developers, and external users/partners to access and view the data and products in a similar, straightforward manner.

The DoM meteorological and hydrologic analysis and display system (hereinafter known as UMADS) should have real-time access to the quality-assured data sets from all available internal (i.e., UNMA-operated) and external observing systems and output from UNMA (WRF) and GFS/ECMWF operational models. The MDA team also proposes that an Advanced Research Weather Research and Forecasting (WRF) model of roughly 5 km be operational at the National Meteorological Center (NMC.) It is envisioned that the model with the appropriate ingest of data will run on a separate computer system that is specified in the section on Numerical Weather Prediction software requirements.

Data sets should not be degraded by any filtering, compression, or formatting techniques that reduce the spatial or temporal resolution of the data or reduce the accuracy of the data and other information that are accessible. Using UMADS should include, at a minimum, surface observations (both on land and water), radar data, upper-air observations, lightning data, geostationary images (supplied by EUMETSAT), model gridded fields, and model soundings. In addition, data or images of regional, hemispheric, and global model output out to 10 days should be accessible through UMADS. The system should be able to integrate data from similar observing systems (e.g., several radars) into a composite product.

The MDA Team recommends that any Radar Products Generator (RPG) associated with attendant radars be located at the NMC. This implies that Doppler radar Level II volumetric data will have to be shipped to NMC for processing, which further implies the need for high band width communication from the radar to the NMC. The RPG will again be a separate computer system from the UMADS. However, the UMADS will have the capability of ingesting all of the output from the RPG.

UMADS should display and animate gridded data, point data, time series, vertical cross sections, soundings, hodographs, raster images, lines, polygons, and radial data. Software should be able to display two- and three-dimensional views of radar volume scans in conjunction with tropospheric thermodynamic structure from upper-air data, analyses, or model output. UMADS should be able to render maps using different geographic projections and have the capability to objectively analyze data and generate derived fields (e.g., divergence) and products (e.g., air quality) from the data. The system should be able to overlay multiple data sets of different types, formats, times, and time intervals.

Other features of UMADS are to display ranges of data (e.g., by threshold values) in different graphical representations (e.g., by color, in a digital or numeric readout at a cursor location) and allow color-blind users to differentiate letters, numbers, symbols, contour lines, and colored gradients.

Geographic overlays available for UMADS users should include political and administrative boundaries, topography, bathymetry (Lake Victoria), land use, transportation networks, populated areas, hydrological features, and significant facilities (e.g. outdoor public venues). Maps, graphs, and other display types should be able to be customized by the individual user, easily accessible for later use (e.g., without recreating a map for a different time), and shareable among users. UMADS should allow the user to select the data type, time, overlay order, color palette, symbols, and zoom level in a straightforward manner.

A suite of high-quality standardized products (e.g., current temperature maps), as defined by UNMA personnel, should be generated and disseminated automatically by this system for both internal and external users.

8.5.1 REQUIREMENTS

UMADS includes the data, equipment, facilities, personnel, procedures, and any other assets needed to integrate, display, analyze, and output observed data, model fields, products, and other graphical or textual information used by UNMA and its users/partners. The detailed functional requirements for UMADS are presented in tabular form in section 14.

The modernized observing telecommunication system of the UNMA will provide unprecedented quantity, quality, and timeliness of data that must be integrated into user-defined maps and graphs for interpretation by weather forecasters. UMADS will provide the required functionality for the forecasters and other UNMA professionals.

The MDA Team recommends that no single piece of software be used for analysis transmission and display functions required of UNMA personnel. Instead, there should be a suite of software, supported by a UNMA IT staff that provides most of the analysis and display capabilities for UNMA personnel. IT support for this suite should include installation, license management (if necessary), upgrades, basic troubleshooting, and training. Software that is used by only a few individuals should be supported by the users, in conjunction with the software vendor, rather than the UNMA IT staff.

Analysis software packages that the MDA team recommends be supported by the IT staff include the following: ESRI's ArcGIS and ArcServer, MathWorks' MatLab, and Insightful's SPlus. None of these packages, however, will serve the real-time UMADS, forecast preparation, and warning generation needs of the UNMA weather forecasters, or the general real-time and archived data display needs of all UNMA personnel. As a result, the MDA Team reviewed several commercial off-the-shelf packages used operationally.

Once the UNMA improves the availability of operational data sets, it is expected they will operate a Weather Research and Forecasting (WRF) Model tailored to Uganda. The current version of WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers. In such a scenario the WRF model for Uganda would run on a server with output that is compatible with a separate scientific workstation/s and internal communications within the office. The server would also be sized and wired to provide communications to UNMA facilities and Ugandan partners outside of the National Meteorological Center (NMC) at Entebbe.

Displayed below in Figure 8.2 and Figure 8.3 are prototypical workstation arrangements for the aviation forecaster at the AWC. In Figure 8.2, the National Centers AWIPS (N-AWIPS) is on the right hand side of the desk. It has four displays including one for alphanumeric product generation. N-AWIPS has specialized software that allows the aviation specific products including generation of graphics. On the left hand side of the figure is AWIPS. AWIPS is typically found in all NWS facilities and is used for model display and product generation. Note that the two monitors above the row of displays show only lightning data on the left and radar data on the right. These two fields are considered of utmost importance to the forecasters at the AWC and further allow the forecaster to discriminate between stratiform precipitation and convection. The monitor in the middle is the connection to the Internet. This keeps the forecaster from having to waste one of his valuable displays in accessing the Internet. The principal reason for Internet access is display of new research and forecasting techniques that have not made it to the quality assured displays of the N-AWIPS and AWIPS, and to make use of high internet bandwidth when dedicated NWS communications system are overloaded and slow.

Figure 7.8.2: Typical workstation module for the aviation forecaster at the U. S. National Weather Services' Aviation Weather Center (AWC) in Kansas City Missouri.

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Figure 7.8.3: In the figure above the AWC forecaster is preparing an aviation warning product from his suite of displays. Note the addition of a security monitor on the upper left that allows the meteorologist to review security outside of the building day and night.

8.6 NETWORK COMMUNICATIONS

The internal DoM communication system in Uganda is grossly underfunded and not optimally utilized. Meteorological stations are without outgoing telephone service and rely on calls from NMC to obtain hourly weather reports that are grouped into three-hour packages. Access to the Internet is not available and the computer hardware, where available on site, does not have the capacity to handle large volume data sets.

Additionally, the external DoM communication system in Uganda is not functional and is in the process of being replaced. In the latest report for which data is available, in the monitoring period from July 2009 to April 2010, only 21% of the synoptic reports and 8% of the climatic reports were reaching the International Communications network. In Figure 8.4 below, Entebbe is shown connected to the Regional Telecommunications Hub (RTH) Nairobi through a 33.6 baud connection. In reality, Entebbe is connected to Nairobi through the Internet. The DoM is currently negotiating with Nairobi to install a Global Telecommunication Switch (GTS) through existing fiber optic cable. Once that is finalized the throughput to Nairobi and return will allow the DoM products to flow to the international data network. It will also allow the forecasters at Entebbe access to external data from the adjoining nation states of East Africa.

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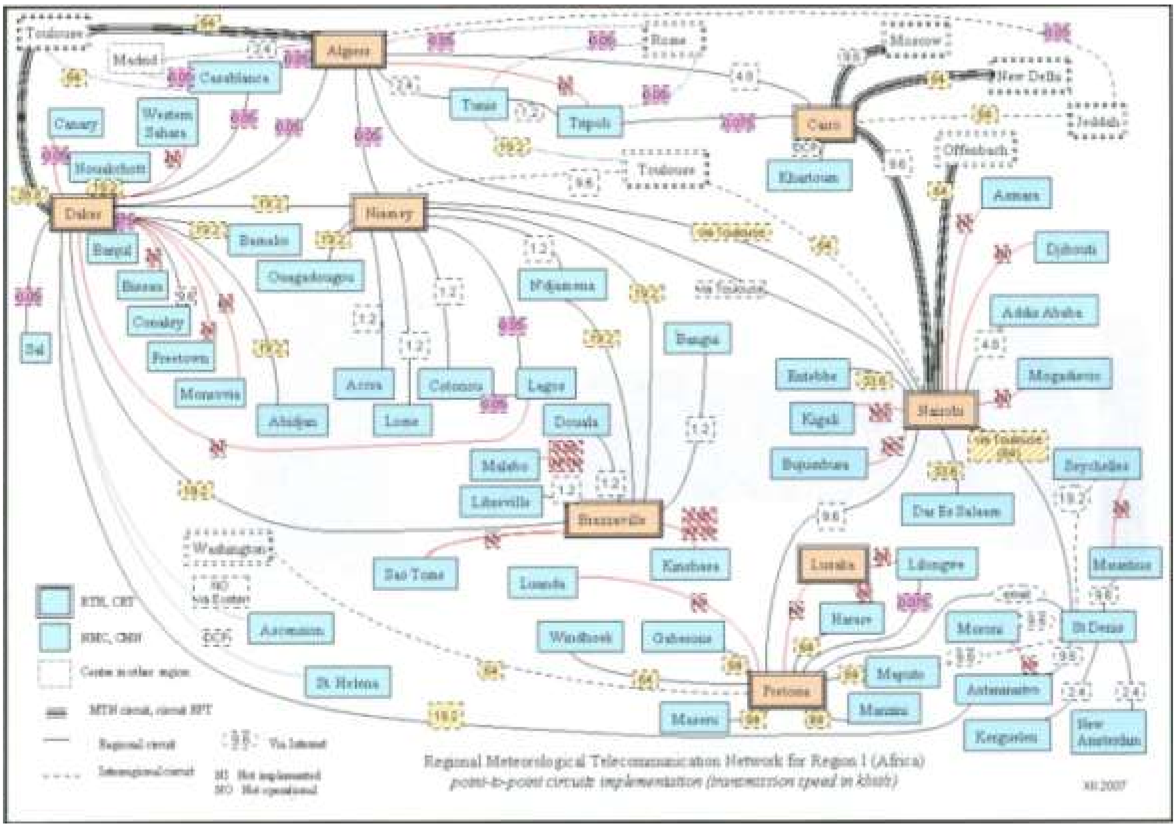


Figure 8.4: Regional meteorological Telecomunication Network for Region 1 (Africa).

The Meteorological Data Dissemination (MDD) is a service primarily for the African members of the World Meteorological Organization (WMO). It comprises observations, analyses and forecasts from major meteorological centers. NMC Entebbe has a connection to the MDD. Members of the WMO coordinate the MDD content provision. The service is available via EUMETCast and via Direct Dissemination, from the prime Meteosat satellite at 0° longitude.

In defining solutions to its communications challenges, it is imperative that UNMA move forward from the inside out. At the NMC, in order to facilitate modern scientific workstations and their input and output, fiber optic cable should be installed to connect the inter-offices and operations of the NMC, the CAA air traffic control tower air route traffic control center and the terminal operations center. Once these connections are made, action should be directed toward the installation of external communications links from NMC to the present downtown Kampala headquarters of DoM. Depending on the type of workstations installed at the headquarters and the location of the Climate Prediction Center (CPC), the UNMA should take advantage of existing optical fiber optic networks currently in place between Entebbe and Kampala. There should also be an investigation into establishing a fiber optic link with the Ugandan Air Base at Entebbe to allow meteorological data sets to flow in that direction. Cost sharing with the Ugandan Air Force should facilitate the project

Once this network is in place, it becomes important that a communication system be designed to reach from Kampala or Entebbe to the upcountry. The first candidates for high speed communications are Kasese, Soroti and Gulu. It is extremely important that the UNMA collaborate with the CAA in establishing these upcountry networks, because the meteorological data sets will be important to the CAA as they work to improve the domestic aviation in Uganda.

A lower priority communication network such as Internet connectivity should be expanded to the other UNMA facilities and, over time, these networks can be improved and expanded.

Figure 8.5 represents a future stage of communications for the UNMA in the Kampala/Entebbe corridor. In the scenario depicted, it is assumed that UNMA has built a new building that is adequate for housing computers and communication network equipment, and that the NMC is moved to the new building where the CPC is established as are all of the UNMA administrative offices and its communication center.

At Entebbe Airport, there is a Meteorological Watch Office/Briefing Office in the terminal. Various observational functions are captured by a communications ring network that provides linkage to the Uganda Air Base, the CAA/ARTCC and the Meteorological watch office at the Airport.

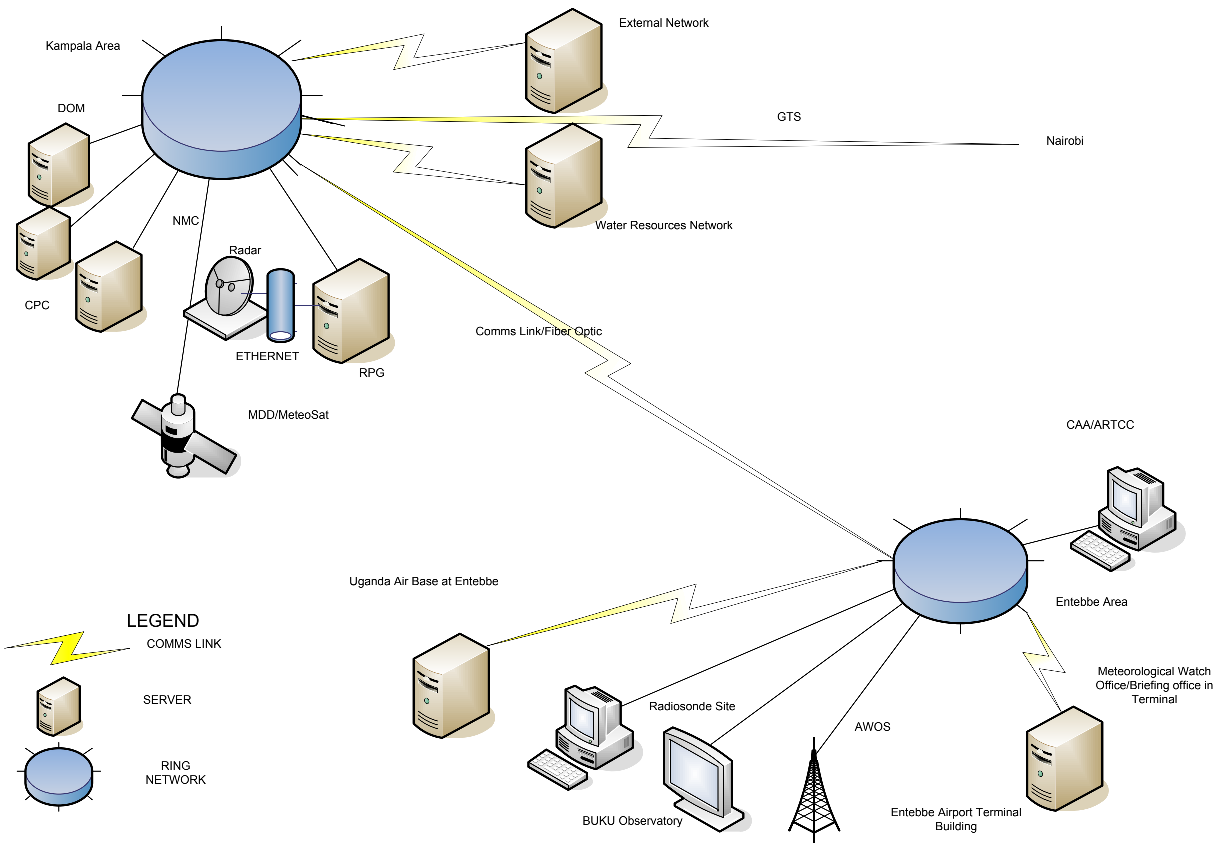


Figure 8.5: Schematic of proposed communications network for the Uganda Meteorological Authority.

8.7 PHYSICAL PLANT

8.7.1 CURRENT CONDITIONS AND PROBLEMS

The DoM uses facilities that take the form of land, buildings, plants, electrical power and telecommunications and some of these facilities are owned by DoM while others are owned by the CAA, local government administrations or private sector entities.

8.7.2 LAND AND BUILDINGS

The CAA owns and controls land and buildings at Entebbe, Kasese, Arua, Gulu (soon), Soroti, Tororo, and Jinja because all the buildings are located at the airports.

The local government administrations own and control land and buildings at Masindi, Tororo and Kabale. We recommend that these buildings be transferred to UNMA ownership, with compensation to the local governments. Improvements are needed to secure consistent power and internet connections.

The only locations that the DoM owns and controls are the land are in Mbarara, Kasese, and Entebbe Old Airport. The DoM HQ is housed on 10th floor Postal Building in rented office space from Uganda Post Corporation, a government autonomous agency. The office space is barely adequate and if more staff and equipment were to be deployed, it would not be able to sustain those new requirements. Modernization will require sufficient internet bandwidth to allow full access to the new sensor network, including all radars and the lightning detection network, as well as to global satellite imagery, and to the output of the global numerical weather prediction models run by the various national and multinational weather services.

At Mbarara, DoM has a large piece of land and a perimeter fence has been constructed around it. It is large enough to allow for the construction of an office block and residences for the staff. However, the land is under threat of take-over by the Mbarara Town Council. We recommend negotiation with the Town Council to either confirm the long-term tenancy of the Department on its land, or to secure an alternative location less threatened by urban encroachment.

The land at Kasese airport is secure and large enough to allow for the construction of an adequate office for Kasese Met Office. However, there is no demarcation line to indicate the actual location and size of the property and that ambiguity has the potential to transform and degenerate into a dispute between the CAA and the DoM. The existing residential buildings shoudl be rehabilitated to house some of the staff members.

The DoM has land situated at Entebbe Old Airport and houses the Upper Air Station. It is an old dilapidated and unsafe building that houses the upper air sounding equipment, the hydrogen generation plant and room for a security guard. The land is secured by a perimeter fence but working relations with the security personnel is poor. The building should be razed and replaced with a modern building with reliable electrical power that would also house calibration facilities for the department.

At all locations where DoM is renting office space, there is a chronic problem of erratic and late payments of rent due to inadequate and irregular release of funds. It is expected that conversion of the DoM to the UNMA will improve this situation.

8.7.2.1 TELECOMMUNICATIONS

Telecommunications is inadequate in many locations or non-existent in some locations. At DoM HQ, the Internet service is not reliable with frequent down-time incidences and when it is working, the speed is low. At the Upper Air station, located at the Old Airport Entebbe, there is no telephone or Internet connection. At synoptic stations where telephones or modems are installed, Internet usage is frustrated by insufficient funds to buy airtime or to pay for the telephone bill. The conventional means of communicating SYNOP and METAR messages from synoptic stations to the Entebbe NMC is the HF radio set, but its utilization rate has been low due to a combination of factors such as incorrect installation procedures, ineffective maintenance strategy, and use of unfiltered power supply.

8.7.2.2 ELECTRICITY AND WATER SUPPLY

In nearly all DoM locations, there is supply of electricity and water. Over the last ten years, the electricity supply from the grid has not been reliable in terms of quantity and quality. The implication of this operational situation is that the electrical equipment and other IT infrastructure rely on uninterruptible power sources that last, at most, thirty minutes when fitted with new with batteries. There is no back-up power supply (standby generator) in all locations, except at Entebbe Airport and the Postal Tower building in Kampala. However, the standby generator in the Postal Tower building is for the exclusive use of the Office of the Prime Minister. There is supply of water at all locations.

8.7.3 NEW FACILITY REQUIREMENTS

The existing office space in nearly all the synoptic stations is inadequate and lack suitable furniture and basic staff amenities. In order to modernize the service, the MDA Team recommends that new computing and communications systems. A summary of recommendations is presented in Table 7.1, which provides an indication of where the various facilities should be installed. However, other constraints, such as funding and qualified staff, will largely determine when the constructions and installations will be implemented. Costs are estimated in the Capital Investment Program in Section 13.

Table 7.1: Summary of Facility Requirements

Met Office Location	Land	Offices	Optical Fiber Link	3G internet	Clean Power	Residence
UNMA HQ	✓	✓	✓	✓	✓	×
Entebbe NMC	×	✓	✓	✓	✓	×
Entebbe UA	×	✓	×	✓	✓	×
Entebbe Obs	×	✓	×	✓	✓	×
Entebbe Airforce	×	×	✓	✓	✓	×
Entebbe WRMD	×	×	✓	✓	✓	×
Arua	✓	✓	×	✓	✓	✓
Gulu	✓	✓	✓	✓	✓	✓
Soroti	✓	✓	✓	✓	✓	✓
Tororo	✓	✓	×	✓	✓	✓
Jinja	✓	✓	×	✓	✓	✓
Masindi	✓	✓	×	✓	✓	✓
Mbarara	×	✓	×	✓	✓	✓
Kasese	×	✓	×	✓	✓	✓
Kabale	✓	✓	×	✓	✓	✓
Mpigi Radar	✓	✓	✓	✓	✓	✓
Kabwohe Radar	✓	✓	✓	✓	✓	✓
Lira Radar	✓	✓	✓	✓	✓	✓
Hydro-Met Stations	✓	✓	×	✓	✓	✓
Agro-Met Stations	×	✓	×	✓	✓	✓
Legend: ✓ = Required × = Not Required						

8.8 MARKETING AND OUTREACH

Government services are most useful when citizens are aware of the services offered, and know how to make the best use of them. For example, the Government of Uganda is aware of the need to effectively communicate long-range weather forecasts to farmers so that they can plan planting and harvesting schedules, and has organized cooperative efforts in which staff from the Ministry of Agriculture use long range forecasts from the DoM to prepare specialized agricultural forecasts with specific advice about planting and harvesting particular crops in various locations in Uganda. However, our survey of condition in June 2012 indicated that these efforts are limited by a lack of interactive communication between the agriculture specialists and meteorologists. Our survey also showed a much broader pattern of inadequate communication of meteorological forecasts from the DoM to the general public. Forecasts are generally not present in printed news media, are not regularly communicated to radio stations, and are not presented through social media or internet with any regularity. We propose a multipronged approach to enrich communication of meteorological information and forecasts to the general public in ways that maximize the usefulness of the information transmitted.

8.8.1 TRADITIONAL MEDIA

We were informed through conversations with DoM staff that in past years Ugandan newspapers included weather forecasts, but that recently they changed their policy, requiring the DoM to purchase advertising space in which to present forecasts. Since the department does not have authorization to spend funds for this purpose, there has been little weather forecast information in the newspapers. Informal conversations with a broad range of Ugandans lead us to believe that this situation has its roots in a general skepticism about the ability of the DoM (or anyone) to issue weather forecasts with useful skill in Uganda. This skepticism is not irrational- weather is fairly consistent from one day to the next in Uganda, and tropical weather is more difficult to forecast than midlatitude weather. However, modern forecast and nowcast methodologies, based on the assimilation of abundant observational data into high resolution numerical weather prediction models has demonstrated substantial skill at forecasting variations in chance of precipitation as well as intensity and the likelihood of hail or severe winds. We believe that an aggressive effort at dissemination of daily forecasts via the UNMA website and will generate renewed interest in weather forecasts by newspapers, leading them to seek out weather forecasts and perhaps pay for enhanced graphical or narrative presentations of weather forecasts by the UNMA.

Radio is well-suited to the promulgation of watches and warnings in Uganda, since it is widely available, and a large number of regional FM radio stations exist. A key component of the development of the watch and warning system described in Section 7 must be effective provision of these forecasts to radio stations in near-real time. UNMA personnel should be trained to read and record forecasts in a clear and effective manner, and in all major Ugandan languages, so that alerts, watches and warnings can be transmitted to radio stations in affected areas and broadcast in a timely manner. A studio for this purpose should be included in the new NMC building.

Television is, of course, especially well-suited to the provision of animated visual information. Radar loops and animated watch and warning maps prepared from a lightning detection network will be of great interest to broadcasters, and should be made available in high-resolution format via dedicated ftp servers for this purpose. The UNMA could potentially derive revenue by using the training facilities as the new NMC headquarters to train television reporters in meteorological concepts and in the visual presentation of weather data. We are recommending the construction of a Weather Media Center as part of the new Headquarters/NMC building, that would allow preparation of sophisticated video and audo presentations of weather information for distribution via radio and television stations, or via the Internet.

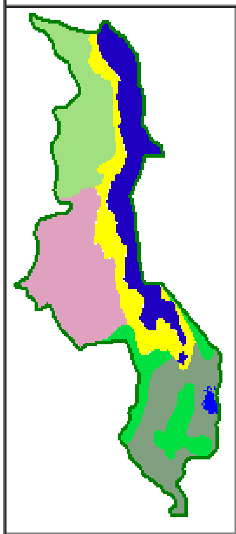
8.8.2 NEW MEDIA

Weather data and weather forecasts will only be able to serve Uganda when they are widely available, and their availability is known and understood by the Ugandan people. Renovation of the UNMA website to make forecast that are highly specific as to time and location, and tailored to particular interests (people operating boats on Lake Victoria, farmers, drivers, school officials) should be one of the highest priorities of modernization. There are a number of national meteorological services that might serve as models for improvement of the UNMA website. In increasing order of sophistication, we particularly point out the following three national weather service websites.

The Malawi Weather Service website is found at http://www.metmalawi.com/ . As shown in Figure 8.6 below, the front page shows a simple map of the nation, with regional forecasts listed in table and color-coded to match the map. This format is simple, easy to read, and simple for the Meteorological staff to update. Archived agrometeorological forecasts are available, but they are out of date. A data request page is available, but no live data are directly accessible.

Latest Weather News

18/10/2012: Warm and north easterly airflow will continue blowing into Malawi. It will be hot over most areas with very hot conditions over Shire valley and lake shore areas. Read more...



Area	Expected AM / PM		Temperature (Â °C) min	Temperature (Â °C) max
Shire Valley			27	40
Southern Highlands			17	33
Central Areas			17	32
Lakeshore Areas			23	38
Northern Areas			14	31

Winds: Light to moderate north easterly.

Figure 8.6: Malawi Weather Service Website

The Ethiopia National Meteorological Authority is found at http://www.ethiomet.gov.et/daily_weather . The website has a more active front page (Figure 8.7). In addition to the graphical presentation shown in the upper right, the main map shows all available observation stations. Moving the computer mouse to position a pointer over the stations results in the display of a pop-up box displaying the observed temperature and weather conditions at that station. Satellite cloud and NDVI imagery is also available on the website. Past data appears to be available in principle, but the link is not currently working.

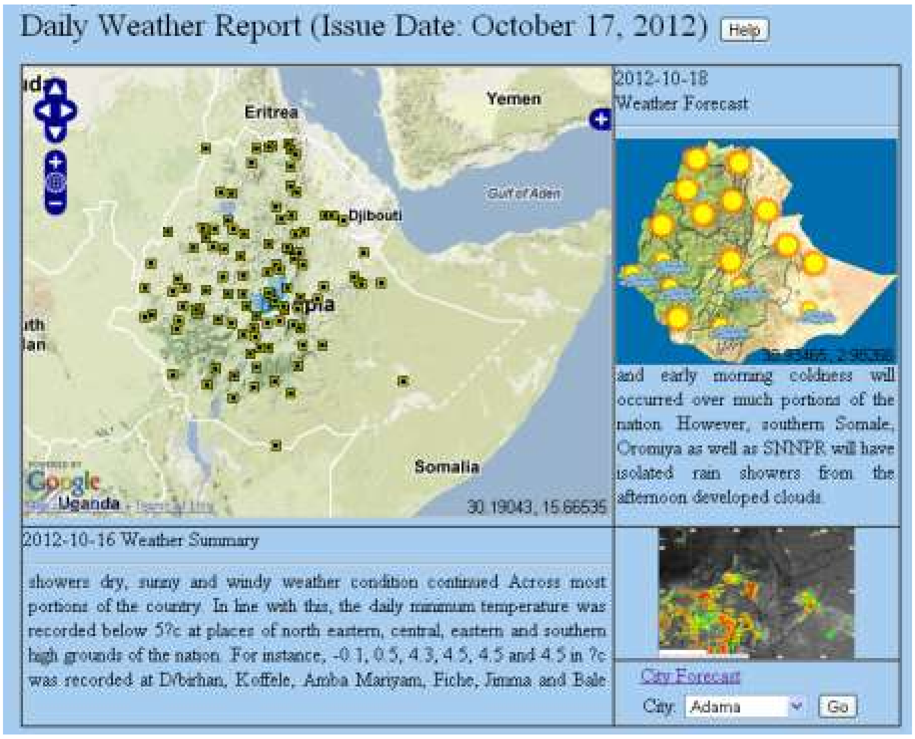


Figure 8.7: Ethiopia National Meteorological Authority Website

The United States National Weather Service site is found at http://www.weather.gov . The default front page (Figure 8.8) shows a color coded map of watches and warning. Mouse-clicking on any point on the map takes the user to a regional weather office webpage with a standardized design, and a click on the map at that page results in a narrative weather forecast for that location on a page with present weather conditions and local radar and satellite imagery. The "Past Weather" tab leads to a page where the user can choose a location on a map, and be shown a webpage with links to (limited) past weather data at that location. Although the site is quite comprehensive, it has substantial gaps. For example, lightning data, although available to the Weather Service, is not available to web site users, by agreement with the private company that provides the lightning data to the weather service.

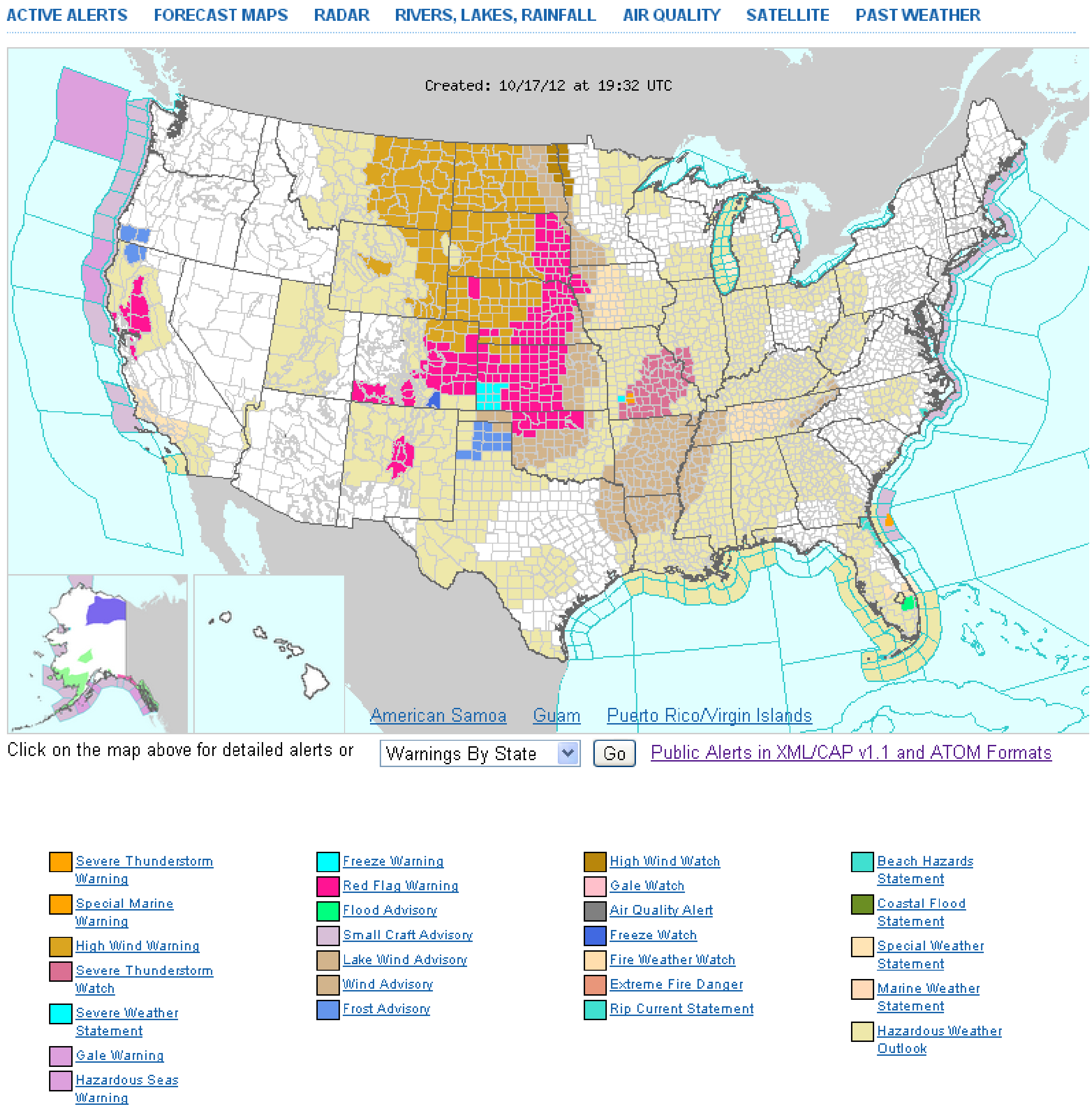


Figure 8.8: US National Weather Service Website

We believe that the emphasis of the US NWS web page on watches on warnings serves as a good example for the future Uganda Meteorological Authority website. Uganda's 111 districts are a good size for this purpose. Forecasters could be provided with a simple map-based interface that would allow them to color districts where intense precipitation, or hail or other hazards are likely, and this information would appear instantaneously on the public web site (perhaps after approval by a responsible Meteorological officer).

Data from all stations in Uganda should be provided for a fee- at least enough to recover costs of building and maintaining the website, but not so high as to significantly discourage those who could benefit from the data from using it.

An effective website makes possible an effective social media outreach strategy. For example, Facebook or Twitter posts by the UNMA could be used to alert social media users to important information on the UNMA website.

SMS messaging has already been deployed for both transmission of forecasts from DoM to customers (in a WMO-sponsored pilot program to provide boating forecasts for fishermen on Lake Victoria), and to allow volunteer observers to transmit precipitation observations to the DoM (in a WMO-sponsored pilot program in the Kasese area). The success of the outgoing text-message campaign depends entirely on the usefulness to recipients of the forecasts and alerts transmitted by text message. These will be greatly improved by the availability to forecasters of radar and lightning detection networks. The deep penetration of cell phone service and the wide ownership of cell phones in Uganda (52% of households have access to cell phones according to reporting at All Africa http://allafrica.com/stories/201208050118.html) makes exploitation of SMS messaging a vital component of effective marketing of weather services. SMS messaging also has the advantage of being viable en masse without causing the cell network to become congested (far less problem than handling large numbers of phone calls) and without much battery drain on the receiving cell phone (far less than internet browsing on a "smart phone"), making it a viable communications mechanism during times of emergency and power outages.

9 FINANCIAL ANALYSIS

9.1 INTRODUCTION

The Financial Model of the Department of Meteorology has been created in the context of its conversion to the Uganda National Meteorology Authority covering the period from 2013-2028 (15 years), and the results are presented in terms of:

- Capital Investment Program
- Income Statement
- Cash Flow Statement
- Sensitivity Analysis

The information and data presented in the Income Statement, Cash Flow Statement, and Sensitivity Analysis of the Financial Model are designed to provide a basis for UNMA to make financial judgments based on the Capital Investment Program (CIP) and to serve as a tool that ultimately assist the UNMA with the development of an implementation plan that meets its mandate.

Accordingly, the Financial Model's structure allows assumptions on key financial variables to be changed to discern the impact of these variables on overall project viability and sustainability. These variables include among others, capital expenditures, financing and its relative costs, revenues, and expenses,

All of the inputs to the Financial Model are calculated in U.S. Dollars. The rate of exchanged used to derive the dollar is Uganda Schillings 2,653 equal U.S. $1.

The MDA Team has not attempted to empirically measure the macroeconomic, social, and political impacts of the capital improvements and financial forecasts proposed for UNMA. Note however, in Task 12, covering Developmental Impact Assessment, the MDA Team reports the favorable benefits accrued from investment made in the meteorological and hydrological infrastructures were estimated to be, in several countries.

9.2 CAPITAL INVESTMENT PROGRAM (CIP)

The capital investment program is shown on the following pages covers the years 2013-2028. In this program, based on the recommendations set forth in Sections 5 through 8, the following assumptions are made:

- **Inflation**: all costs are assumed to increase at 3% per year to account for inflation.
- **Internet**: costs assumes Ethernet connections in Kampala and Entebbe starting in 2013 ($3,200 set-up cost, plus $400/month for 512 kbps bandwidth), with unlimited mobile internet at all UNMA offices (@$1000/year/location). In 2014, Soroti, Kasese, Gulu and Kabale are assumed to get Ethernet connections ($4,200 set-up cost each), and bandwidth is increased to 2 Mbps at Kampala and Entebbe ($1300/month, each) and to 1 Mbps at Soroti, Kasese, Gulu and Kabale ($700/month, each) to allow for efficient use of radar imagery. Costs are based on a proposal from Orange.
- **Upgrades to Manual Observation Instruments**: Costs are based on purchase of twelve sets of wet and dry-bulb thermometers and barometers, all certified by the U.S. National Institute of Standards and Technology, and digital read-out windvanes and anemometers, to bring the synoptic stations up to full working order, with additional money to support upgrades of the relevant instruments at Agromet and Hydromet stations.
- **Lightning**: costs assume purchase of a basic system in 2013 (including associated hard-wired internet and power connection costs), followed by an evaluation period. If system performance (uptime, detection efficiency, etc.) are not adequate to identify 95% of lightning-producing storms, and to rank storms correctly by intensity of lightning production, requests for proposals for a more advanced system should be released. Costs for advanced system listed in 2016 reflect Vaisala's current offer. Maintenance costs are assumed to be 5% of system cost.

- **Radar:** Radar instrumentation costs are based on survey of radar manufacturers. Radar infrastructure costs are based on queries of Ugandan construction companies.
- **Radiosondes:** Costs are for expendable balloons and sounding instruments: 2/day @$200 each.
- **Surface stations:** Maintenance/replacement costs are assumed to be 10% of cost of all equipment installed to date (i.e. we assume each instrument on the station has a lifetime of about 10 years) with 3% annual inflation.
- **AWOS:** costs assume a single station (@$250,000) installed at Soroti in 2014, followed by three stations installed at Gulu, Kasese and Arua in 2015.
- **Air Pollution:** Eight stations (@$100,000) are assumed to be installed, once every six months, at Kampala, Kabale, Mt. Elgon, Gulu, Mbarara, Kasese, Jinja, Apoka.
- **AWS:** After existing stations donated by GIZ are deployed, plan assumes two additional stations deployed each year, to fill out a 50 station network.
- **New instrumentation:** Soil moisture, soil temperature, and evapotranspiration sensors are added to the existing synoptic network, and should be part of all future Mesonet installations.
- **Training:** Assumes two full-time staff, each paid $38,000/year (equivalent to Makerere University professor), plus $12,000/year for improvements to teaching equipment (computer lab, equipment maintenance/calibration lab), plus $150,000/year in the first five years, and $60,000/year thereafter to support graduate studies for staff. Staff studying for PhD degrees abroad should receive support from research grants as a condition of study leave, but should receive supplemental income to maintain standard of living.
- **Computers:** July 2013-July 2014 costs are for 30 new workstations: one for each synoptic station, plus 20 additional workstations for Kampala and the NMC at Entebbe. $50,000 in January 2015 is for servers adequate to take over operation of the data archive/multi-model ensemble forecast task from the server provided by the NOAA office of International Programs.
- **Field Office:** costs assume one field office will be rebuilt each year until all (Gulu, Soroti, and Kasese) are complete.
- **New NMC/Headquarters Construction:** Cost based on estimate for DoM senior staff: $500,000 for land acquisition, $3,000,000 for building construction.
- **Headquarters Office rent:** Rental is assumed before completion and occupancy of the new combined NMC/headquarters building. We assume 400 m of class-A office space, @$18/m^2.
- **Mobile Calibration Facilities:** Requires purchase of three trucks and laboratory grade meteorological instrumentation: thermometers, hygrometer, pyranometer, barometer, and portable screen, to allow calibration of AWS and ASOS stations in the field.
- **Weather Media Studio:** a facility to allow preparation of video and audio weather forecasts for distribution via radio, television and internet.

The Capital Investment Program is also provided as an Excel file accompanying this document.

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Table 9.1: Capital Investment Program

	Cum 6 mos.	Yr. End	Cum 6 mos.	Yr. End	Cum 6 mos.	Yr. End	Yr. End	Yr. End	Yr. End	Yr. End	Yr. End	Yr. End	Yr. End	Yr. End	Yr. End	Yr. End	Yr. End	Yr. End
***Capital Investment Plan* US$'s**	**DEC-2013**	**JUN-2014**	**DEC-2014**	**JUN-2015**	**DEC-2015**	**JUN-2016**	**JUN-2017**	**JUN-2018**	**JUN-2019**	**JUN-2020**	**JUN-2021**	**JUN-2022**	**JUN-2023**	**JUN-2024**	**JUN-2025**	**JUN-2026**	**JUN-2027**	**JUN-2028**
Equipment																		
Information and Communication Technology Equipment (ICT)																		
Internet setup	7,000	14,000	16,400	16,400	-	-	-											
Internet bandwidth	10,000	20,000	37,000	74,555	38,118	76,808	119,570	82,708	85,190	87,745	90,378	93,089	95,882	98,758	101,721	104,772	107,916	111,153
Computers	10,000	20,000	10,000	35,000	25,000	30,000	15,452	10,689	11,009	11,340	11,680	12,030	12,391	12,763	13,146	13,540	13,946	14,365
Improved Security at Synoptic Observing Stations, followed by maintenance	36,000	39,600	3,654	7,363	3,764	7,585	11,808	8,168	8,413	8,665	8,925	9,193	9,469	9,753	10,046	10,347	10,657	10,977
Total ICT Equipment	**$ 63,000**	**$ 93,600**	**$ 67,054**	**$ 133,318**	**$ 66,883**	**$ 114,394**	**$ 146,830**	**$ 101,565**	**$ 104,612**	**$ 107,750**	**$ 110,983**	**$ 114,312**	**$ 117,742**	**$ 121,274**	**$ 124,912**	**$ 128,659**	**$ 132,519**	**$ 136,495**
New In situ observing equipment																		
New thermometers, barometers, wind vanes for station network	50,000																	
Soil Temperature, Soil Moisture sensors	13,000	13,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
New AWS stations for Mesonet	-	10,000	10,150	20,452	10,457	21,070	32,801	22,314	22,605	22,898	23,196	23,498	23,803	24,113	24,426	24,744	25,065	25,391
Evapotranspiration sensors	25,000	25,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AWOS-3PT systems	-	250,000	-	500,000	750,000	750,000		-	-	-	-	-	-	-	-	-	-	-
Air pollution sensors	100,000	201,500	103,023	207,590	106,136	213,865	220,329	-	-	-	-	-	-	-	-	-	-	-
Total In Situ Observing Equipment	**$ 188,000**	**$ 499,500**	**$ 113,173**	**$ 728,043**	**$ 866,593**	**$ 984,935**	**$ 253,130**	**$ 22,314**	**$ 22,605**	**$ 22,898**	**$ 23,196**	**$ 23,498**	**$ 23,803**	**$ 24,113**	**$ 24,426**	**$ 24,744**	**$ 25,065**	**$ 25,391**
Total Radiosondes, balloons	-	73,000	74,095	149,301	76,335	153,814	158,463	163,217	168,113	173,157	178,352	183,702	189,213	194,890	200,736	206,758	212,961	219,350
Wind shear Detection																		
Sodar systems								70,000	70,000	70,000								
RASS systems											250,000		250,000		250,000			
Total Wind shear Detection	-	-	-	-	-	-	-	70,000	70,000	70,000	250,000	-	250,000	-	250,000	-	-	-
Lightning Detection																		
Total Lightning Network Equipment	100,000	100,000	-	-	-	1,500,000	-	-	-	-	-	-	-	-	-	-	-	-
Total Lightning Detection	**$ 100,000**	**$ 100,000**	**$ -**	**$ -**	**$ -**	**$ 1,500,000**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
TOTAL EQUIPMENT	**$ 351,000**	**$ 766,100**	**$ 254,322**	**$ 1,010,662**	**$ 1,009,810**	**$ 2,753,143**	**$ 558,423**	**$ 287,096**	**$ 295,330**	**$ 303,806**	**$ 312,530**	**$ 321,512**	**$ 330,758**	**$ 340,276**	**$ 350,074**	**$ 360,161**	**$ 370,546**	**$ 381,236**
Maintenance																		
WWLLN data service	3,900	7,800	3,959	7,976	4,078	8,217	8,466	4,392	4,524	4,660	4,800	4,944	5,092	5,245	5,402	5,564	5,731	5,903
Total Lightning Network Software/Service	-	600	609	1,227	627	38,127	114,750	79,568	81,955	84,413	86,946	89,554	92,241	95,008	97,858	100,794	103,818	106,932
Other Maintenance and Replacement	13,800	63,750	111,217	233,922	232,168	476,170	722,316	378,843	390,208	401,914	413,972	426,391	439,183	452,358	465,929	479,907	494,304	509,133
TOTAL EQUIPMENT MAINTENANCE	**$ 17,700**	**$ 72,150**	**$ 115,785**	**$ 243,125**	**$ 236,873**	**$ 522,515**	**$ 845,532**	**$ 462,803**	**$ 476,687**	**$ 490,987**	**$ 505,717**	**$ 520,888**	**$ 536,515**	**$ 552,611**	**$ 569,189**	**$ 586,265**	**$ 603,852**	**$ 621,968**
Radar Procurement and Installation																		
Radar equipment	0	0	0	3,000,000	-	-	3,130,170	-		-	3,477,822	-	-	-	-	-	-	-
Radar maintenance	0	0		-	100,000	200,000	500,000	412,000	-	437,091	650,000	669,500	689,585	710,273	731,581	753,528	776,134	799,418
Radar infrastructure (roads, electricity, internet)	0	0	0	2,000,000	-	-	2,086,780	-	-	-	2,318,548	-	-	-	-	-	-	-
TOTAL RADAR	**$ -**	**$ -**	**$ -**	**$ 5,000,000**	**$ 100,000**	**$ 200,000**	**$ 5,716,950**	**$ 412,000**	**$ -**	**$ 437,091**	**$ 6,446,370**	**$ 669,500**	**$ 689,585**	**$ 710,273**	**$ 731,581**	**$ 753,528**	**$ 776,134**	**$ 799,418**
Personnel Training and Education																		
Training (including equipment, tuition)	50,000	100,750	51,511	103,795	53,068	106,932	110,140	113,445	116,848	120,353	123,964	127,683	131,513	135,459	139,522	143,708	148,019	152,460
Education	75,000	151,125	77,267	155,693	79,602	160,399	165,211	170,167	175,272	180,530	185,946	191,524	197,270	203,188	209,284	215,562	222,029	228,690
TOTAL PERSONNEL TRAINING AND EDUCATION	**$ 125,000**	**$ 251,875**	**$ 128,778**	**$ 259,488**	**$ 132,670**	**$ 267,331**	**$ 275,351**	**$ 283,611**	**$ 292,120**	**$ 300,883**	**$ 309,910**	**$ 319,207**	**$ 328,783**	**$ 338,647**	**$ 348,806**	**$ 359,270**	**$ 370,049**	**$ 381,150**
Facilities Construction (ex Radar)																		
Headquarters Rent	43,200	87,048	44,506	89,679														
New NMC Construction, maintenance	-	-	3,500,000	3,510,000	10,150	10,302	31,839	22,023	22,684	23,364	24,065	24,787	25,531	26,297	27,086	27,898	28,735	29,597
New Field Office Construction	75,000	76,125	77,267			-	-											
Field Office Maintenance	3,000	6,045	3,091	6,228	3,184	6,416	9,988	6,909	7,116		7,549	7,776	8,009	8,249	8,497	8,752	9,014	9,285
Mobile calibration facility, maintenance	50,000	52,500	2,538	2,576	2,614	2,653	2,693	5,507	5,672	5,842	6,018	6,198	6,384	6,576	6,773	6,976	7,185	7,401
Weather Media Studio, maintenance		200,000	1,250	1,269	1,288	1,307	1,327	2,713	2,794	2,878	2,964	3,053	3,145	3,239	3,336	3,437	3,540	3,646
TOTAL FACILITIES CONSTRUCTION	**$ 171,200**	**$ 421,718**	**$ 3,628,651**	**$ 3,609,751**	**$ 17,236**	**$ 20,679**	**$ 45,846**	**$ 37,152**	**$ 38,266**	**$ 32,085**	**$ 40,597**	**$ 41,815**	**$ 43,069**	**$ 44,361**	**$ 45,692**	**$ 47,063**	**$ 48,475**	**$ 49,929**
TOTAL CIP	**$ 664,900**	**$ 1,511,843**	**$ 4,127,535**	**$ 10,123,026**	**$ 1,496,590**	**$ 3,763,667**	**$ 7,442,102**	**$ 1,482,662**	**$ 1,102,403**	**$ 1,564,852**	**$ 7,615,124**	**$ 1,872,922**	**$ 1,928,711**	**$ 1,986,167**	**$ 2,045,342**	**$ 2,106,287**	**$ 2,169,055**	**$ 2,233,701**

9.3 REVENUE STREAMS

Revenue streams are divided into three main categories based on their source:

1. **Government Direct Billing**: Ugandan government entities that currently pay the DoM directly for meteorological services rendered including the Uganda Civil Aviation Authority and the Bank of Uganda.
2. **Private Sector**: Domestic and international private entities that could receive services from UNMA. This would include local banks and insurance companies, as well as other domestic and international entities requiring meteorological forecasting services. Sectors included in this category are banks and insurance companies, oil exploration and production, construction, tourism, NGO's and CBO's, and energy rendered.
3. **Government Reimbursements**: A key source of cash flow is through subsidies to support the operations of UNMA. Additionally, UNMA will receive reimbursements derived from UNMA services rendered to government entities. Current users for which the Government reimburses DoM include among others, National Environmental Management Authority, National Forest Authority, Uganda Bureau of Statistics, and Disaster Preparedness and Management.

9.4 EXPENSES

Breakdown of major expense items is as follows:

1. Personnel and training expenses based on a reorganization and human capacity development recommended by the MDA Team to support of the modernization of the UNMA and the CIP. Funding for training is likely to be strongly supported by international donors.
2. Maintenance and repair expenses in the CIP
3. Critical information and communications technology (ICT) expenses associated with technology enhancements.
4. Head Office and other facilities recommended in the CIP
5. Marketing expenses extrapolated from the UNMA Business Plan.

9.5 DEPRECIATION EXPENSES

Major assets (value greater than US$100 thousand) acquired as part of the Capital Investment Program have been depreciated down to zero book value based on life expectancy ranging between 10 and 20 years. Lesser assets (e.g. information and communication technology equipment were treated as an expense item and thus have been written off in one year.

9.6 CAPITAL SOURCES

The Financial Model assumes three sources of capital as follows:

1. **Government Direct Investments and Subsidies:** The Model assumes two alternative ways for the Government to provide capital funding to UNMA:
   a. Direct investment in UNMA as and when provided in the Government's Annual Budget.
   b. Subsidy Payments: A major source of capital funding as it provides the basis for covering all or part of the gap between revenues expenses arising from the implementation of the UNMA CIP.
2. **Multilateral/Donor Grants:** To help demonstrate the implications of grant funding, the Model has the ability to demonstrate the impact that assistance from a multilateral/donor source (e.g. WBG, UNDP, GIZ, and USAID) would have on the CIP. In this case, it is assumed that the grant recipient is the Government of Uganda, which in turn makes a capital contribution to UNMA and it complements the Government investments and subsidies.

3. **Debt Financing:** The Model has provisions for two sources of medium term and long term debt financing:

a. **Commercial Debt Financing**: The Model assumes ten year debt financing covering the procurement and development of three radar sites. The ideal structure would be export credit agency financing guaranteed by a regional or local financial institution. The financing would have a draw down period of one year and grace period to repay of one year. Repayment of the loan would be in equal installments over the remaining eight years. The Financial Model assumes interest rates ranging between 6% and 8% with the initial loan commencing in fiscal year ending June 2015.

b. **Multilateral Loans:** Long-term (40 years) funding principally from the World Bank's International Development Agency and the African Development Bank's African Development Fund, covering among others capital outlays and human capacity development.

Conceptually, the financing commitment for the aforementioned loans can be structured as a direct loan to UNMA. Alternatively, the Government of Uganda can make a capital contribution for goods and services procured, in which case there would be no interest or principal debt service and thus, a favorable impact on cash flow.

9.7 FINANCIAL MODEL RESULTS

Profit and Loss Statement

The forecast annual revenues and costs associated with a Profit and **Loss** Statement, with the loss assumed to be offset by Government reimbursements, and grant funding and loans from multilateral institutions and bilateral donors. For this analysis, these multilateral/bilateral donor grants are assumed to be made to the Government which in turn, makes a capital contribution to UNMA.

The Profit and Loss Table below (Table 9.2) shows revenues, expenses, earnings/loss before interest and depreciation (EBITDA), earnings before interest and tax (EBIT), and the amount required to offset losses by reimbursements and grants. Taxation has not been considered since UNMA is a government entity.

Table 9.2: Profit and loss table.

US$s 000	JUN-2014	JUN-2015	JUN-2016	JUN-2017	JUN-2018	JUN-2019	JUN-2020	JUN-2021	JUN-2022	JUN-2023	JUN-2024	JUN-2025	JUN-2026	JUN-2027	JUN-2028
Revenues	730	806	890	982	1,080	1,193	1,313	1,452	1,600	1,771	1,954	2,163	2,390	2,648	2,928
Expenses	5,519	7,044	7,874	9,342	9,032	7,716	8,195	8,415	8,581	8,797	8,984	9,235	9,699	10,116	10,659
EBIDITA	4,789	6,238	6,985	8,360	7,952	6,523	6,881	6,962	6,981	7,026	7,030	7,072	7,310	7,468	7,731
Depr. Exp	0	45	345	720	981	981	981	981	1,097	1,271	1,271	1,226	1,176	801	801
EBIT	4,789	6,283	7,330	9,080	8,933	7,504	7,862	7,943	8,078	8,297	8,301	8,297	8,486	8,269	8,532
Int Exp	0	300	300	646	609	549	465	846	763	651	510	387	284	203	145
Profit (Loss)	4,789	6,583	7,630	9,726	9,542	8,053	8,327	8,789	8,841	8,948	8,810	8,685	8,769	8,472	8,677

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Cash Flow

The Cash Flow Statement reflects all the cash inflows and outflows to the project on an annual basis.

- *Cash from operations* is derived from the Profit and Loss Statement by not including costs that have no effect on cash levels - namely depreciation. All other revenues and expenses are recognized on a cash basis within the forecast year and used to compute the cash flow from operations.
- *Capital expenditures* reflect the CIP described earlier.
- *Financing* cash flow includes debt, grant, and capital investments from the Government (including reimbursements to cover deficits from the profit and loss. for the CIP, which is assumed to be incurred in the same period as its associated expenditure, and repayments of principal).

The Net Cash Flow is the sum of cash from operations, capital expenditures and financing, and is shown in the chart below compared with the earnings from operations (EBITDA). The 15-year Financial Model Cash Flow Statement Table is below (Table 9.3)

Table 9.3: Cash flow table.

US$ 000's	JUL-2013	JUN-2014	JUN-2015	JUN-2016	JUN-2017	JUN-2018	JUN-2019	JUN-2020	JUN-2021	JUN-2022	JUN-2023	JUN-2024	JUN-2025	JUN-2026	JUN-2027	JUN-2028
Cash Flow																
Beginning Cash Balance		**2,500**	**2,500**	**2,500**	**2,500**	**2,500**	**2,500**	**2,500**	**2,500**	**2,500**	**2,500**	**2,500**	**2,500**	**2,500**	**2,500**	**2,500**
Profit and Loss		4,789	6,583	7,630	9,726	9,542	8,053	8,327	8,789	8,841	8,948	8,810	8,685	8,769	8,472	8,677
plus Depreciation		0	45	345	720	981	981	981	981	1,097	1,271	1,271	1,226	1,176	801	801
Profit and Loss *Plus* Depr.		4,789	6,538	7,285	9,006	8,561	7,072	7,347	7,808	7,744	7,677	7,539	7,459	7,594	7,671	7,876
Beg Cash *plus* Cash Flow from Operations		2,289	4,038	4,785	6,506	6,061	4,572	4,847	5,308	5,244	5,177	5,039	4,959	5,094	5,171	5,376
Uses of Cash																
Capital Expenditures		350	9,000	2,250	5,217	0	0	0	5,796	0	0	0	0	0	0	0
Loan Repayments		0	0	0	625	625	1,277	1,277	1,277	1,277	2,002	2,002	1,377	1,377	725	725
Sub Total		350	9,000	2,250	5,842	625	1,277	1,277	7,073	1,277	2,002	2,002	1,377	1,377	725	725
Sources of Capital																
Equity/Grants	**2,500**	5,139	10,538	9,535	9,631	9,186	8,349	8,624	9,086	9,021	9,679	9,541	8,836	8,970	8,395	8,601
Loans	**0**	-	5,000	-	5,217	-	-	-	5,796	-	-	-	-	-	-	-
Sub Total	**2,500**	5,139	15,538	9,535	14,848	9,186	8,349	8,624	14,882	9,021	9,679	9,541	8,836	8,970	8,395	8,601
Ending Cash Balance	**2,500**	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500	2,500

Analysis of Profit and Loss and Cash Flow Forecasts

Profit and Loss: The magnitude of the annual deficits is a function of the many years of limited investment in the Department of Meteorology thereby requiring capital, operating, personnel, and other expenditures particularly during the first five (5) years of UNMA's operations. This includes covering heavy expenditures for information and communications technology, the implementation of equipment and systems including lightning detection, radar, and AWOS as well as heavy expenditures on personnel and training.

Additionally, when comparing the UNMA Business Plan's Revenue Stream forecasts to the operating expenses, personnel expenses, and interest expense developed by the MDA Team, the forecasted revenue streams (extrapolated from the UNMA Business Plan) are far less than adequate. Therefore, in order to cover these costs, there is the need to actively solicit funding for these costs through a combination of Government Investment/Subsidies/Reimbursements, multilateral/bilateral donor grants, and loans. Discussion of such a strategy is previously discussed in Task 10 – Financing Options.

Cash Flow: The Capital Investment Program calls for significant capital, operating, and personnel expenditures during the first five years of UNMA operations. These expenditures call also for extensive training arising from the implementation of systems and equipment in such areas as ICT equipment, procurement, installation, and maintenance of radar equipment, and Headquarters and regional facilities construction.

Due to the significantly inadequate revenue streams covering these expenditures, the Model assumes annual funding to generate cash flow as follows:

1. **Initial Government Capital:** US$2.5 million equivalent initial paid in capital to support immediate operational needs set forth in the CIP.
2. **Government Subsidies/Grants:** During the first five years, the Model reflects a significant level of Government subsidies and grant funding to support the aforementioned level of expenses.
3. **Debt financing:** Three (3) debt financing structures aggregating to US$ 16,013,320 with 10 year tenor. The purpose of the financing is to fund the acquisition of radar equipment and installation in Years 2015, 2017, and 2021.

In this case, the range of the annual funding requirement is between $5.1 million and $15.3 million with the higher levels attributable to the funding for radar procurement and site development. The average annual funding requirement in this forecast is $9.9 million. Over the 15 year forecast, the funding requirement aggregates to $151.6 million, of which $54.2 million is required for the near term (Years 1-5).

Based on the high level of outlays, the Model confirms that there is a need to review the revenue streams to discern their potential impact in reducing the deficit and the level of subsidies, grants, and loans to cover said outlays. The principal revenue stream areas that should be addressed are as follows:

1. **Uganda Civil Aviation Authority**: Domestic and international air traffic activity in Uganda is expected to increase appreciably, particularly as a consequence of continued economic growth, particularly from the anticipated increase in growth arising from oil and gas production activity accelerating around 2016. This aalong with ither sectors will rely on the services provided by the Civil Aviation Authority (CAA.) in which acomponent of these services will be meteorological services provide by UNMA through CAA Consequently, in view of the inadequacy of current payments, anticipated growth in flight movements, and the need to recover relevant UNMA costs from enhanced services arising from the modernization program, there is the need to revisit the cost recovery arrangement between the UNMA and

the CAA that reflects the enhanced services and products that the UNMA will provide to the CAA to support this economic sector. Furthermore, UNMA's cost recovery should be achieved in a manner that is in accordance with Article15 of the Chicago Convention on "Meteorological Services for International Air Navigation."

2. **Private Sector:** The development of envisioned forecasting and other services and products by UNMA and the growth of banks, insurance companies, the oil and gas sector, tourism and other elements of the private sector, could position UNMA to accrue higher private sector revenue streams. Accordingly, further analysis of the private sector revenue potential is warranted. This would entail a market analysis of forecasting and other services and products demanded by the private sector and the fees that these entities have a propensity to pay. This analysis would serve as the basis for developing a marketing strategy that could bring this revenue stream to fruition. Engagement of advisors to assist UNMA to achieve this end could be beneficial.
3. **Government Reimbursements:** The current reimbursement levels in the Model do not reflect the recommended higher level of operating expenses and capital costs. Therefore, there is the need to adjust reimbursements to reflect new expenses. This includes assuring that the Memoranda of Understanding with users for which the Government reimburses UNMA, reflect these expense adjustments.

9.8 SENSITIVITY ANALYSIS

The results from the Financial Model above present a case of implementing the CIP at a level that enables UNMA to develop a meteorological service organization that has a high opportunity to enhance public safety and support the growth and sustainability of the economy. There are many variables in the Model that, when changed, give an indication of their effect. Consequently, this enables UNMA to create alternative scenarios by changing Model inputs, thereby creating the basis for comparing results. The discussion of sensitivity analysis herein discusses three scenarios- Alternative Funding of Major Capital Expenditures, Multilateral Finance Impact, and Changes to Total Expenses. Alternative Funding of Major Capital Expenditures

Radar Financing: The Financial Model above assumed that for the procurement of three radar installations, for which UNMA would be the borrower and responsible for debt servicing. An alternative structure is for the Government of Uganda to serve as the borrower and in turn, make a capital contribution of the financed goods and services to UNMA. The benefit to UNMA's cash flow is shown in Table 9.4.

Table 9.4: Debt service effect of alternative funding for radar finance.

US$ 000s	JUN-2014	JUN-2015	JUN-2016	JUN-2017	JUN-2018	JUN-2019	JUN-2020	JUN-2021	JUN-2022	JUN-2023	JUN-2024	JUN-2025	JUN-2026	JUN-2027	JUN-2028
Interest Expense	-	300	150	300	646	609	549	465	846	763	651	510	387	284	203
Principal Repayment	0	0	0	625	625	1,277	1,277	1,277	1,277	2,002	2,002	1,377	1,377	725	725
Positive Cash Flow Effect	**-**	**300**	**150**	**925**	**1,271**	**1,886**	**1,826**	**1,743**	**2,123**	**2,765**	**2,652**	**1,886**	**1,764**	**1,008**	**927**

This cash flow benefit would allow UNMA to more effectively cover operating and personnel related expenses and places less pressure on the effort to secure additional grant funding. It is envisioned that the debt financing would emanate from export credit agency financing, likely through the support of regional development banks. As a byproduct, this source could assist the Government of Uganda in heightening its profile in the international financial markets and position the Government of Uganda and its agencies for future financings in those markets and such funding could serve as an alternative to donor funding.

9.8.1 MULTILATERAL FINANCE

To determine its impact on the apportionment of funding expenditures, a US$ 25 million equivalent multilateral loan was assumed during the sixth year of operation. Disbursements are assumed to occur over a 5 year period and tenor of the loan was 40 years with a grace period of 10 years. As evidenced on the Equity/Grants line, said financing would also reduce the level of direct subsidy payments that the Government would have to pay in.

Table 9.5: Multilateral finance impact.

Sources of Capital US$ 000s	JUL-2013	JUN-2014	JUN-2015	JUN-2016	JUN-2017	JUN-2018	JUN-2019	JUN-2020	JUN-2021	JUN-2022	JUN-2023	JUN-2024	JUN-2025	JUN-2026	JUN-2027	JUN-2028
Equity/Grants	2,500	4,935	10,374	9,352	9,778	9,287	3,453	3,731	4,197	4,135	4,797	9,662	8,960	9,099	8,528	8,737
Loans	0	0	5,000	0	5,217	0	5,000	5,000	10,796	5,000	5,000	0	0	0	0	0
Sub Total	2,500	4,935	15,374	9,352	14,995	9,287	8,453	8,731	14,993	9,135	9,797	9,662	8,960	9,099	8,528	8,737

The ability to secure long term financing at that stage of the CIP could be critical to project sustainability. This commitment would increase the level of certainty to move forward on the medium term phase of the CIP. Having stated this, the ability to secure this financing will hinge upon UNMA's ability to manage a dynamic process to attain its mandate to become a provider of enhanced meteorological services and products in Uganda.

9.8.2 CHANGES TO TOTAL EXPENSES

The near-term and medium-term investments create high demands on UNMA to secure funding through government investments, grants, and loans. As discussed, Total Expenses relative to the revenue streams are disproportionately higher. To determine its impact on cash flow, the Model assumed a reduction of annual Total Expenses by 20 percent, which has a positive effect on cash flow and UNMA's funding requirements:

Table 9.6: Expense differential table.

US$ 000s	JUN-2014	JUN-2015	JUN-2016	JUN-2017	JUN-2018	JUN-2019	JUN-2020	JUN-2021	JUN-2022	JUN-2023	JUN-2024	JUN-2025	JUN-2026	JUN-2027	JUN-2028
Total Expenses	5,316	6,880	7,691	9,488	9,133	7,821	8,302	8,526	8,696	8,915	9,105	9,360	9,828	10,249	10,796
Total Expenses (20%)	4,252	5,504	6,153	7,591	7,307	6,257	6,642	6,820	6,957	7,132	7,284	7,488	7,862	8,199	8,637
Differential	1,063	1,376	1,538	1,898	1,827	1,564	1,660	1,705	1,739	1,783	1,821	1,872	1,966	2,050	2,159

This 20 percent reduction in expenses could be achieved through consideration to take action such as the following:

1. Deferring capital investment to latter years of the CIP
2. Reducing or deferring the institution of field office staffing

9.9 CONCLUSIONS

The Financial Model has led the MDA Team to the following conclusions and recommendations relating to the financial viability of the Capital Investment Program for UNMA:

- **Revenue Streams**: The Model's demonstration of a high level of annual funding required from government and external sources should motivate a strong effort to identify ways to enhance revenues.
  a. **Private Sector:** Although, many of the key private sector users have been identified in the UNMA Business Plan, the development of a strategy on marketing and providing services to this clientele is considered to be at an early stage. Thus, additional research and analysis is warranted to better discern domestic and international private sector market potential and what the respective segments of the market is willing to pay for UNMA's meteorological services and products. On the international side, it might be prudent to consider a joint venture with US or other foreign entities to market UNMA's service capabilities to non-Ugandan entities. As discussed above, this undertaking would serve as the basis for developing a marketing strategy that could bring this revenue stream to fruition, engagement of advisors to assist UNMA to achieve this end could be beneficial.
  b. **Civil Aviation:** ICAO under Annex 15 encourages member States to maintain accounts for the air navigation services they provide in a manner that ensures that air navigation services charges levied on international civil aviation are properly cost-based. In terms of future UNMA revenue streams, the annual payment from the Civil Aviation Authority can be material. It is therefore critical that with the enhanced services brought about by the modernization program, UNMA is fairly compensated for services that it renders (We note that this appears to be a region-wide phenomenon and thus, EAC Meteorological entities should collectively explore resolution to this matter). Finally, the notion of fair cost recovery applies not only to CAA but to any Government organization contractually agreeing to specific meteorological services and products.
  c. **Government Subsidies:** A cost recovery agreement to reflect revised costs associated with the CIP and to reflect enhanced services rendered to various government entities is a priority. So as to develop certainty of cash flow, UNMA and the Ministry of Finance, the tenor of this agreement should be for a fixed period (e.g. 3 to 5 years). In so doing, this agreement might create interest on the part of financial institutions to consider the provision of financing.

Financial Management: Notwithstanding the economic benefits accrued from investment in meteorological service entities as presented in the discussion of developmental impact, expense levels are significant and constant monitoring of expenditures is warranted. This monitoring might signal actions that should be taken including possible deferral of certain capital outlays until early expenditures are fully absorbed and deemed effectively operational. Additionally, particular attention should be paid to personnel policies and expenses associated with them. As an example, for the strategy on manual weather observations, by taking advantage of automated weather systems, manual observation staff can be deployed to more valuable user services and products that not only increase their level of productivity, but also increase operating revenues, thereby offsetting the expense burden.

Funding Support: As part of its effort to increase the likelihood of multilateral/bilateral support, UNMA should embark on a strategic initiative regarding its approach on applying for assistance in the form of grants and loans, as success in securing commitments early on in the project cycle facilitates the ability to make critical strategic decisions on how best to move forward on project implementation.

Alternative Funding Approaches

  d. **Government of Uganda Borrower:** The alternative funding strategy in which the Government of Uganda borrows directly to finance major capital acquisitions and in turn makes a capital contribution to UNMA not only relieves the UNMA debt servicing effect, but is an effective strategic tool to secure higher levels of funding from international sources including export credit agency financing.
  e. **Multi-regional Approach:** Another means to reduce the burden of capital funding associated with the implementation of the weather radars is to consider collaboration with Kenya and

other EAC members leading to a joint procurement and financing strategy that could involve the participation of regional developmental institutions such as PTA Bank and East African Development Bank. Alternatively, this strategy could have use public private partnerships including an arrangement to build, operate, and maintain radar equipment on a concession basis. Such strategies might dovetail with initiatives that the EAC and COMESA are considering to establish a collective air traffic management system employing the use of ADS-B and other satellite-based navigation technologies.

10 FINANCING OPTIONS

10.1 INTRODUCTION

The discussion herein provides the Department of Meteorology with financing options for the DoM modernization program which could serve as the platform for DoM's transition to the Uganda National Meteorology Authority (UNMA).

The Uganda National Meteorological Authority Bill Legislation enables the creation of the structure of an authority, which is intended to have greater autonomy in carrying out its activities and operations in fulfilling its mandate as the provider of meteorological services in Uganda.

This Bill includes financial provisions that, among others, allow the UNMA to:

- Receive monies appropriated by the Parliament for the purposes of UNMA,
- Receive grants, monies or assets donated to the Authority by the Government or other sources
- "Borrow money", subject to approval by the Minister of Finance

As stated in previous chapters, weather conditions experienced in Uganda support the need to collect real time weather information and data for the purpose of analyzing said information and data for timely dissemination with user-specific forecasts and warnings. These conditions do affect many of Uganda's vital sectors in which information and data in turn can influence decisions made for among others, the general public, the agriculture sector, transport sector, and the financial sector.

After this assessment, the MDA Team then developed a capital investment program that mapped out stages the necessary procurement of equipment and services that reflects the upgrade and expansion required for UNMA to meet its goals and objectives to collect and disseminate information and data to a broader client base. Additionally, in an effort to address complexities of implementing the modernization program alongside managing the day to day activities of UNMA, recommendations for an organization plan was developed to achieve this end. Finally, the financial model looked at various financing options and scenarios that would enable UNMA to effectively achieve these goals and objectives.

With a view toward better understanding how those financing options might evolve and best support the modernization of UNMA, the MDA Team conducted research and held a series of meetings and discussions with financial institutions in Washington, Johannesburg, Nairobi, and Kampala. Additionally, MDA took into account institutions from which DoM had received support in the past. In total, the institutions in this analysis primarily include multilateral and bilateral donor institutions, export credit agencies, regional development banks, commercial banking institutions, and supplier credits. Finally, in order to better understand policy and historical accounting, the MDA Team staff met with representatives from the Ministry of Finance and from the Ministry of Water and the Environment. In this regard, the MDA Team presents its findings and conclusions from these meetings and they serve as the base for recommendations and strategy for securing the requisite financing to invest and sustain the modernization project.

When discussing this project with prospective financiers, the MDA Team also stressed that the Government of Uganda's capital and subsidy funding commitments to UNMA are indicative of the Government's priority to enhance its meteorology capability, which if achieved could increase and diversify UNMA's client base and revenue streams. The more significant and diverse revenue streams could facilitate the evolution of available financing options from one which in the past has been confined to support from the Government and donors to one which has a broader array of options including those as well as regional development banks, export credit agencies, commercial banking sources, and suppliers.

Factoring in among others the UNMA Law, the UNMA Business Plan, the recommended CIP, and various meetings and discussions with financial institutions and Ugandan Government officials, this report covers the following:

The financing plan for the implementation of the UNMA modernization program takes into account the following primary sources:

- Meetings with prospective funding sources including multilateral and bilateral institutions, regional development banks and commercial banks

- Meetings with Ugandan government officials
- The technical, management and operational recommendations presented by the MDA Team for the implementation of the modernization program

These have led to the identification of financing options and recommendations on those best suited to meet the near-, medium- and long-term program implementation requirements

- Report on findings from meetings, discussions, and research on prospective funding sources including multilateral and bilateral institutions, regional development banks, and commercial banking institutions.
- Recommendations on implementation of financing options for the Modernization Program in the Near-Term (Years 1-Year 5) and Medium-Term/Long-Term).

10.2 PROSPECTIVE FUNDING SOURCES

Table 10.1: International aid received during the last five years.

Agency	Aid
German International Cooperation (GIZ)	Automatic Weather Stations, 2 Vehicles, Computer lab for Data digitization
European Union/African Union	Satellite Ground receiving Equipment (PUMA), Staff Training
African Development Bank/Ministry of Agriculture	Automatic Weather Stations
World Food Program	Automatic Weather Stations
Japan International Cooperation Agency (JICA)	Staff training
Korean International Cooperation Agency KOICA)	Staff training
Israel International Cooperation Agency (MASHAV)	Staff training
United States Government/WMO	Staff training
UK Met Office/World Meteorological Organization (WMO)	Pilot projects on Severe Weather Forecasting for Fishermen and Farmers, Staff training
Vaisala-Finland	DigiCora Upper Air Sounding System
United States Trade and Development Agency (USTDA)	Feasibility Study on Modernization of Meteorological Services

10.2.1 MULTILATERAL INSTITUTIONS/BILATERAL DONORS

Multilateral and bilateral donor institutions have been the major source of international funding for social and economic development in Uganda. These institutions have collectively worked closely with Uganda in developing funding programs that are reflective of social and economic goals and objectives established by the Government of Uganda. Based on those goals and objectives, these institutions provide funding directly and through other entities including NGOs for the respective projects that they have developed and agreed to support in both the public sector or to the private sector. In this section, the MDA Team discusses how multilateral and bilateral donor institutions might support this project. The MDA Team does not present the full universe of institutions that could support this project, but it provides UNMA with a framework for approaching the multilateral and bilateral community for financial and technical support.

10.2.2 WORLD BANK GROUP (WBG)

Uganda is a member country that can receive financial assistance offered by the WBG through its International Development Agency (IDA) programs in which the World Bank's places emphasis on assistance based on Poverty Reduction Strategies. In preparing these strategies, the government identifies the country's priorities and targets for reducing poverty over a three to five year period. The WBG and other aid agencies then align their assistance efforts with the country's own strategy - a proven way of boosting aid effectiveness.

The Bank's main vehicle for making strategic choices about the program design and resource allocations for individual countries is its Country Assistance Strategy (CAS). Uganda's current CAS covers the period 2011-2015 and supports the government in promoting the objectives of the Uganda's National Development Plan. Based on these objectives, the World Bank Uganda CAS[1] establishes the objectives to (i) promote inclusive and sustainable economic growth; (ii) enhance public infrastructure; (iii) strengthen human capital development; and (iv) improve good governance and value for money.

The Uganda portfolio comprises 17 IDA-financed operations with a net commitment of US$1.46 billion[2] . Additionally, there are five regional projects in agriculture, health, and trade and transport, of which the Uganda components have net commitments of about US$94 million. IDA recently extended a loan of US$135 million to provide Ugandans with access to potable water and to improved sanitation facilities. These investments are being made by the National Water and Sewerage Corporation and the Directorate of Water Development in the Ministry of Water and Environment, which has purview over DoM and UNMA. Note that IDA financing when compared to conventional commercial loans, have longer tenors and more lengthy grace periods (before repayment commences), thereby easing pressure on cash flow and debt servicing during the early phase of a project such as that of UNMA.

In discussions with the WBG Staff in Kampala, MDA learned that over the next three years, WBG will be considering additional credits for projects within the Ministry of Water and Environment, in which consideration could be given to support UNMA's operations. Additionally, there are other sectors (e.g. energy and transport), which UNMA serves and might be able to receive WBG/IDA support. Finally, given its history of financing regional projects, solicitation of financing for any such projects contemplated with other meteorological service entities in the region could be of interest to WBG.

In this respect, with a view toward providing WBG with a better understanding of UNMA's envisioned operations and capabilities, it is critical that UNMA, in coordination with the Ministry of Finance, begin as early as practicable. The UNMA should present in detail, its goals, objectives and strategy for implementation that includes (i) management, organizational structure, and capacity building requirements; (ii) project specifications; (iii) services and market outlook (government and private sector); (iv) timeline for implementation; (v) near term and long term procurement strategy; and (vi) the near term and long term financing requirements with the WBG staff in Kampala. UNMA should in turn explore with WBG, IDA financing programs and other support that UNMA might avail itself of, including such areas as procurement support, project implementation management, and training. Assuming that there is an accord and in view of the timeline of the WBG project cycle[3], UNMA, in concert with the Ministry of Finance, should expeditiously commence the application process as agreed to between WBG, UNMA, and the Ministry of Finance.

10.2.3 AFRICAN DEVELOPMENT BANK (AFDB)

Uganda is a longstanding regional member country of the African Development Bank (AfDB) and provides financial support through the African Development Fund (ADF), which contributes to the promotion of economic and social development by providing concessional funding for projects and

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[1] http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2010/05/04/000334955_20100504033727/Rendered/PDF/541870CAS0P11610only10IDAR201010116.pdf

[2] http://www.worldbank.org/en/country/uganda/projects

[3] World Bank Project Cycle: http://web.worldbank.org/WBSITE/EXTERNAL/PROJECTS/0,,contentMDK:20120731~menuPK:5068121~pagePK:41367~piPK:51533~theSitePK:40941,00.html

programs, as well as technical assistance for studies and capacity-building activities throughout the African member states.

According to its 2011-2915 Country Strategy Paper for Uganda, ADF's priority actions include (i) improving public sector management and administration; (ii) increasing the quantity and improving the quality of human resources; (iii) increasing the stock and improving the quality of physical infrastructure; (iv) transformation of attitudes, mindset and perception; (v) promoting science and technology and facilitating access and availability to critical production inputs.

AfDB has provided support to DoM through the Ministry of Agriculture to acquire automated weather stations. During recent discussions with AfDB in Kampala, AfDB staff indicated that the Bank is not in a position to currently support the UNMA modernization program. Nevertheless, since a modernized weather service capability in Uganda can play an integral role ADF's priorities for Uganda. In the context of these priorities, UNMA should explore with AfDB through the Ministry of Agriculture and the Ministry of Water and Environment, how it might collectively approach AfDB for consideration of financial support.

10.2.4 UNITED NATIONS DEVELOPMENT PROGRAM (UNDP)

UNDP is the organ of the UN organization that assists developing countries to withstand crisis, and to sustain growth that improves the overall quality of life. The UNDP often times, works with other international organizations including the Global Environmental Facility (GEF) which is the largest public funder of projects to improve the global environment. More specific, GEF provides grants for projects related to biodiversity, climate change, international waters, land degradation, the ozone layer, and persistent organic pollutants.

One of the areas of UNDP focus in Africa is meteorology in which it supports the development of early warning systems through its Least Developed Countries Fund (LDCF) in, among others, Uganda, Rwanda, and Malawi. With regard to Uganda, GEF intends to provide US$4.4 million in grant funding through a UNDP program entitled: Uganda: Strengthening Climate Information and Early Warning Systems in Eastern and Southern Africa. Additionally, the UNDP's Regional Center for East and Southern Africa with country management responsibility for Uganda, has another US$1 million available to support this project.

This project is structured around two broad components:

- Investments in weather and climate monitoring infrastructure, including hydrological and meteorological monitoring stations, radar for monitoring severe weather, upper-air monitoring stations for regional forecasts, and satellite monitoring equipment; and
- Measures to integrate climate information into development plans and early warning systems.

The majority of the funding would be allocated towards the procurement and installation or rehabilitation of equipment and systems, as well as for future efforts in adaptation and disaster risk reduction. Another financing component could be training.

Note that the MDA Team members have has had discussions and have met with UNDP officials in South Africa to discuss the USTDA Study, and exchange ideas regarding the UNMA Modernization strategy and discern how UNDP funding could be utilized for capital investment. During those discussions, it became clear that there has yet to be a determination as to which government body that UNDP funding will be allocated to within Uganda. Further, UNDP indicated that it will discuss with Ugandan Government officials and DoM/UNMA before making its final determination.

Given its mandate as an Authority, UNMA is a logical candidate to fulfill UNDP's early warning system objective. This significant level of $5 million in funding along with the capital support from the federal government would facilitate the procurement of equipment and systems that would accelerate timeline for UNMA developing its capability to enhance the level of weather services envisioned in this Study. Moreover, there are co-financing commitments under consideration by other multilateral and bilateral donor agencies that might become available in the medium term.

Taking this into account, UNMA's success in capturing UNDP funds particularly during the initial phase of the Capital Investment Program could hinge upon establishing a high priority to make a funding proposal to UNDP. As part of this proposal, it will be important to stress how the prescribed UNDP early warning system integrates with UNMA's envisioned operations and services. Additionally, the proposal should describe the applicability to the early warning system, but the applicability, synergies, and economies of scale to other operations and services to be offered by UNMA to other targeted markets.

10.2.5 ARAB BANK FOR ECONOMIC DEVELOPMENT IN AFRICA (BADEA)

The objective of BADEA is to foster economic, financial, and technical cooperation between the African States and the Arab nations. In carrying out this purpose, the Bank shall; (a) assist in financing economic development in African countries; (b) stimulate the contribution of Arab capital to African development; and (c) help to provide the technical assistance required for Africa's development.

BADEA is also a member of the Arab and Regional Coordination Group that provides financing for major development projects and programs. In addition to BADEA, its members include the Arab Fund for Economic and Social Development, Arab Gulf Program for United Nations Development Organizations (AGFUND), the Islamic Development Bank (IsDB) and OPEC Fund for International Development (OFID); and three bilateral intuitions: the Abu Dhabi Fund for Development, the Kuwait Fund for Arab Economic Development, and the Saudi Fund for Development. BADEA also works closely with strategic partners including the African Development Bank, World Bank, and other multilateral and bilateral development agencies.

Over the years, BADEA has provided support to various Ugandan projects those involving infrastructure and agriculture. In 2001, BADEA provided US$300,000 in funding for support to DoM covering the following:

1. Training of a total of 30 weather observers,
2. Acquisition of 10 SSB radios and Solar Panels.
3. Acquisition of Thermometers to equip 10 stations
4. Acquisition of Stevenson screens for 10 stations.
5. Procurement of 3 vehicles for equipment installation and inspection

Based on discussions that the MDA Team consultants have has had with it BADEA in past studies, BADEA it is known that BADEA periodically reviews with African governments, the prospective projects that BADEA the Bank might consider supporting. In view of BADEA's previous support, it is recommended that UNMA approach BADEA, with a strategy of discerning their near term or long term interest in providing financial support to the UNMA Modernization Program. Areas of support include the acquisition of equipment and training.

10.2.6 GIZ

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH is a government entity that supports the German Government in achieving its objectives in the field of international cooperation for sustainable development. GIZ operates in many fields: economic development and employment promotion; governance and democracy; security, reconstruction, peacebuilding and civil conflict transformation; food security, health and basic education; and environmental protection, resource conservation and climate change mitigation.

In 2007 the German Federal Ministry for Economic Cooperation and Development (BMZ) declared Uganda a priority country. The following priority areas were agreed:

- Financial sector
- Water sector
- Energy sector.

GIZ has been supportive of DoM/UNMA modernization by supporting through its water management program, the notion of climate change adaptation and accordingly, GIZ is supplying UNMA with 23 automatic weather stations. GIZ is also actively involved with adequate organizational support to the new UNMA.

10.2.7 USAID

USAID is the US Government's donor agency responsible for foreign aid to developing countries around the world. Aid to these countries reflects the economic goals of an individual country and in Uganda's case, USAID, operating in Uganda since 1963, supports programs in among others, agriculture, education, and health. USAID works as a development partner with other multilaterals and bilateral donors and like other institutions. The USAID's programs reflect the goals and objectives of the Ugandan Government's National Development Plan.

The MDA Team understands that USAID has had some limited interaction with the DoM over the past year. While USAID is not currently supporting the DoM, it is willing to consider targeted support in the future and accordingly, UNMA should commence a dialogue with USAID to discuss the UNMA modernization program including its CIP and possible areas of support might include the following.

10.2.7.1 Agriculture

Since its inception of its operations in Uganda, the agriculture sector has been and continues to be a major area of focus for USAID in Uganda. Programs have included supporting further development of Ugandan crops including coffee, tea, cotton, maize and flowers. As has been discussed throughout this Study, enhanced forecasting capabilities brought about by equipment upgrades could have a bearing on farming techniques affecting among others, planting, harvesting, warehousing, and transport of agro produce. Thus, with a view toward achieving these enhancements and given the importance of Ugandan agro production to sustain self-sufficiency, it is recommended that UNMA pursue with USAID how it might support the UNMA CIP.

Another consideration is to explore the development of specialized forecasting services for Uganda agriculture producers supported by USAID. The benefit here would not only be an incremental source of revenue but also serve as a demonstration project to other prospective clients that have the potential to enhance and diversify revenue streams required to help sustain future UNMA growth.

10.2.7.2 Human Capacity Building

USAID in the past has provided financial support on the educational front in which the agency has sent Ugandans to universities in the United States to pursue studies in agriculture and other disciplines. The United States has numerous universities (e.g. University of Oklahoma), which have first rate undergraduate and advanced degree programs in meteorology and which has accommodated students from around the world. Additionally, USAID has the ability to work with other US government agencies such as the National Weather Service and the private sector in developing specialized training programs designed to improve skill sets of UNMA personnel. In effect, as part of its human capacity building programs to develop its existing and new personnel, support from USAID could serve as an instrumental tool to achieve this end.

10.3 EXPORT CREDIT AGENCIES (ECA):

Export credit agencies (ECA) are financial institutions or agencies that provide trade financing to domestic companies for their international activities. ECAs provide financing services such as guarantees, loans and insurance to these companies in order to promote export of equipment and services in the country of the exporter. The policies of ECAs are based on **Organization for Economic Co-Operation AND Development (OECD)** guidelines[1] covering export finance. Many of these ECAs are members of the Berne Union[2] which work in concert with OECD and multilateral institutions, among others, to actively support international acceptance of sound principles in export credits and foreign investment. This includes public and private ECAs offering primarily OECD guideline, export finance at similar terms and conditions, with a goal to minimize any competitive advantage on the part of an individual ECA. As the ECA programs are similar in nature, the MDA Team is providing information herein on the programs of the Export-Import Bank of the United States (refer to footnote 8 for list of all Berne Union members and link to their respective websites).

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1 http://www.jbic.go.jp/ja/finance/export/oecd/pdf/original.pdf
2 http://www.berneunion.org/bu_profiles.htm

10.3.1 EXPORT IMPORT BANK OF THE UNITED STATES

The Export-Import Bank of the United States (US Ex-Im Bank) established in 1934, is an independent US federal government agency that provides financing support through loan guarantees and direct loans; working capital guarantees to US exporters; and export credit insurance to foreign buyers of US equipment and services.

In FY 2012, the Bank authorized $1.52 billion to support U.S. exports to sub-Saharan Africa – $1.4 billion in loan guarantees, $93 million in export-credit insurance and $38 million in working capital guarantees. This financing surpassed US Ex-Im Bank's previous authorizations in the region by over $100 million. In FY 2012, Ex-Im-supported exports accounted for 7 percent of all U.S. merchandise exports to sub-Saharan Africa.

To facilitate U.S. export growth, Ex-Im Bank maintains strong ties with African based banks including regional banks such as the Eastern and Southern African Trade and Development Bank (PTA Bank), which is the regional financial institution for the Common Market for Eastern and Southern Africa (COMESA).

Per Ex-Im Bank policy, UNMA would be eligible for consideration for financing as both public and private sector entities in Uganda are eligible for short term to long term financing. Most public sector debt medium, term and long term public sector financing would be subject to a sovereign guarantee, but there may be certain circumstances in which financing can be structured with a third party guarantor such as PTA Bank.

The likely financing option utilizing Ex-Im Bank would be its loan guarantee program. The ideal equipment for Ex-Im Bank or other ECA related financing would be the weather radar projects primarily due to its relatively large acquisition and implementation costs. The basic tenets of the financing would be as follows:

- US Ex-Im Bank guarantees up to 85% of the export contract
- The residual 15% comes from internal UNMA resources or from a third party such as a regional development bank, a local commercial bank, or the supplier.
- Tenor of the loan guarantee is a function of types of goods and services to be procured. For weather radar equipment, Ex-Im Bank financing would likely have a tenor of 10 years.
- Ex-Im Bank, on a case by case basis, will provide financing of local coasts, for up to 30% of the US export contract. Note that local costs include such items as site preparation and construction services provided in the importing country and are consistent with OECD guidelines for export credit agencies.

10.4 REGIONAL DEVELOPMENTAL INSTITUTIONS

10.4.1 EASTERN AND SOUTHERN AFRICA TRADE AND DEVELOPMENT BANK (PTA BANK)

PTA Bank, established in 1985, is the regional trade and development for the Common Market for Eastern and Southern Africa (COMESA) to which Uganda is a signatory. The PTA Bank serves Uganda and other COMESA member states through the provision of financial services which, per its website, (www.ptabank.org) include the following:

- Short and long term financing denominated in foreign and local currency for the purpose of trade and capital investment
- Provider of guarantees and other support to export credit agencies and other international financial institution;
- Promote private sector development in its member countries through increased trade and project financing and through the intermediation of foreign direct investment;
- Foster increased regional economic integration through trade and investment

PTA Bank has favorable ratings from international agencies including Global Credit Ratings (GCR), Moody's and Fitch Ratings, thereby enabling the Bank to secure ample medium and long term funding to support the massive capital requirements within the COMESA region. In the past, this included the successful issuance of a USUS$ 300 million in November 2010. Additionally, PTA Bank has been successful in securing facilities from export credit agencies in North America, Europe, and Asia. Examples of PTA Bank utilizing ECA facilities include the Export Import Bank of the United States (Ex-Im Bank) with which PTA Bank has worked since 1994 and has since supported well in excess of US$100 million in financing of US goods and services. This includes recently providing a guarantee to support US$60 million in Ex-Im Bank financing for two (2) Boeing 737-800 aircraft for RwandAir.

PTA Bank has also issued securities in local markets and uses the local currency proceeds from those issues to finance local projects. The advantage of local currency financing is not incurring foreign exchange risk[1]. The constraint here is the capacity of the Ugandan capital markets to enable an institution to augment substantive funding. The other key constraint is that the tenor of financing (approximately 5 to 7 years) tends to be much shorter than accessing financing in US and other broader capital markets, thereby restricting the purpose of financing to equipment and services that have a shorter life cycle.

Approved PTA Bank financing in Uganda during 2011 Uganda totaled US$ 25.4 million or 13% of its total portfolio including commitments to Development Finance Company of Uganda Bank Limited (US$ 5 million), BAMUS Holdings (US$ 1.53 million), UAP Properties Ltd (US$ 15.5 million) and Mercantile Credit Bank Limited (local currency: Ushs 8 billion).

In essence, the consistent generation of favorable earnings and a solid capital position reinforced by continued receipt of capital subscriptions from its member states have enabled PTA Bank to receive favorable agency ratings and in turn, raise substantive financing to play an integral role in supporting capital projects in Uganda and throughout the COMESA region. Moreover, familiarity with local market and the operations of governments and its agencies in Uganda and the region, permit an institution such as PTA Bank to offer financing at terms and conditions that would readily facilitate acquisition of desired equipment. Areas of support are as follows:

1. Hard currency financing including export credit agency financing for significant capital acquisitions such as radar equipment.
2. Local and/or hard currency financing for site development (e.g. radar sites, etc.)
3. Co-financing with other institutions to support capital projects including DFCU and EADB.
4. Financing any regional integration projects contemplated with other meteorological service entities in the region.

10.4.2 EAST AFRICAN DEVELOPMENT BANK

Under its 1980 charter, the EADB's role and mandate is to offer a broad range of financial services to the East African Community member states of Kenya, Uganda, Tanzania and Rwanda with a view toward strengthening socio-economic development and regional integration.

EADB can provide debt and equity finance for technically and financially viable projects in both the public and private sectors of member states' economies. Market focus includes agriculture and agro-processing, industry and mining, tourism, infrastructure, and services.

EADB is primarily owned by the four of the EAC member states including Kenya, Uganda, Tanzania and Rwanda. Other shareholders include the African Development Bank (AfDB), the Netherlands Development Finance Company (FMO), German Investment and Development Company (DEG), SBIC-Africa Holdings, Commercial Bank of Africa, Nairobi, Nordea Bank of Sweden, Standard Chartered Bank, London and Barclays Bank Plc., London.

To enhance its original development objectives, EABD places emphasis on:

- Projects that have regional orientation (cross-border projects)
- Projects with a comparative advantage in the utilization of local raw material in the production of goods for local consumption in the region or for export
- Projects that utilize resources common to the member states

[1]Foreign Exchange Risk in this case, arises when an entity borrows in US dollars or other currencies and its source of cash flow used for repayment is in another currency, thereby making the borrower vulnerable to negative movements of the local currency relative to the currency of the loan.

Additionally, EADB has provided agency services and co-financing through collaboration with multilateral institutions, bilateral donors, and other regional development banks to manage on their behalf funds directed to projects in East Africa.

As at December 31, 2010 (December 31, 2009), EADB's Shareholder Equity was US$ 93.277 million (US$ 87.311 million) with Total Assets at US$ 237.302 million (US$ 224.446 million) and Total Loans Outstanding at US$ 95.823 million (US$ 104.344 million). Approved EADB financing in Uganda includes Kayonaza Tea Factory, Protea Hotel, and Jambo Roses. In effect, the MDA Team feels that its financing capacity and prior financing experience with Uganda make EADB well positioned to support the UNMA's capitalization program. Moreover, EADB has the ability to work with PTA Bank other financial institutions on co-financing arrangements with UNMA. Consequently, UNMA should commence a dialog with EADB regarding among others, the UNMA Bill Legislation; the modernization program including its capital and organizational plans; and its financing requirements.

10.5 COMMERCIAL BANKING INSTITUTIONS

Uganda has a number of commercial banking institutions that are capable of providing account services and that have the capital base to provide local and foreign currency financing. Because UNMA is effectively a startup operation, getting the necessary approval for financing could be a challenge during the initial years of operations. These institutions also play a key role within the Ugandan capital markets, which from a longer term perspective could serve as a source of funding for UNMA. Notwithstanding, it is recommended that UNMA select commercial bank institutions that not only provide account services, but also provide financing and other services vital to UNMA’s growth.

Additionally, in reviewing the activities and operations of commercial banks in Uganda, agro-financing is a major business line and as stated in the UNMA Business Plan, Ugandan commercial banking institutions along with insurance companies, could be major users UNMA’s forecasting services. Thus, in addition to soliciting account and financing services, UNMA with the objective of enhancing revenue streams, should work closely with these institutions in developing forecasting products that best suits their respective needs.

10.5.1 STANBIC UGANDA

Stanbic Bank is part of Africa's leading banking and financial services organization, Standard Bank Group when Standard Bank acquired the majority of the operations of Grindlays Bank in 1993. Stanbic Bank Uganda is the largest bank in Uganda by assets and market capitalization.

In 2011, the Bank’s total assets grew by 13% to UShs 2.7 trillion with the level of loans and advances to customers are at 56.5% of total assets. Shareholders’ equity grew to UShs 295 billion, up 28.2% from UShs 230 billion in 2010. As at December 2011, the Bank’s total capital base was 15.0% (2010: 14.2%) of risk-weighted assets, with primary capital at 11.8% (2010:12.5%).

Stanbic Uganda offers a full range of banking services through two business units; Personal and Business Banking and Corporate and Investment Banking, the latter which is the area where clients such as UNMA are served.

Stanbic’s Corporate and Investment Banking Unit services a broad range of clients including local businesses and corporates, multinational organizations, government parastatal and non-governmental organizations. As a parastatal, UNMA would be served by this Unit whose services offered are as follows:

- Account services: cash management, nternational trade services, online banking
- Debt and equity finance: term lending, asset finance, ECA financing, and project finance
- Trading and risk management: foreign exchange and money markets

10.5.2 CITIBANK

Citibank Uganda Limited was licensed as a commercial bank in Uganda on 27th August, 1999 and the branch was officially opened by the Minister of Finance and Economic Planning on 11th November, 1999. Citibank Uganda is a wholly owned subsidiary of Citicorp, New York. Citi's products and services include the following:

- Cash Management
- Electronic Banking
- Trade Services
- Treasury
- Corporate Finance

As a global bank, Citi has vast experience with the various developmental finance programs of numerous countries. This includes extensive experience with export credit agency programs in among others, United States, Germany, Japan, France, and United Kingdom.

10.5.3 DFCU BANK

DFCU was established in 1964 as a development financial institution. In 2000, the company bought Gold Trust Bank and started commercial banking and renamed it DFCU Bank which provides both personal and commercial banking services.

With regard to commercial services, DFCU Bank is actively involved in a number of key sectors of the Ugandan economy including transport, education, floriculture, agriculture, manufacturing and agro-processing. Its services include the following:

- Current Accounts
- Women in Business program
- Trade Finance
- Loans
- Treasury Services

Additionally, DFCU Bank, with its origin as a developmental institution, has worked with regional developmental banks including PTA Bank and with numerous developmental partners including Kfw Bankengruppe (Germany), International Finance Corporation (IFC), United States Agency for International Development (USAID), and European Investment Bank (EIB). Working through DFCU Bank with these relationships could be an asset to UNMA in its quest to seek financial and other support for the modernization program

10.5.4 SUPPLIERS CREDITS

Supplier credit is an offer of credit that is extended to a buyer by a supplier of equipment and services. This model is prevalent among export circles including suppliers that might sell equipment to UNMA. As is the case with conventional loans from financial institutions, suppliers credits have defined terms and conditions agreed to between the buyer and the seller.

Supplier credit financing might consist all or part of the financing required by the buyer. For example, in export credit agency financing, the requisite 15% down payment requirement often times emanates from the exporter in the form of a supplier credit.

Also, so as to attain political and economic risk protection, suppliers will apply for risk insurance from public, private, or multilateral insurers. Export credit agencies including US Ex-Im Bank, Euler Hermes (Germany), and Nippon Export and Investment Insurance (Japan) all provide such insurance. Additionally, there are insurance programs of multilateral institutions including the programs of the World Bank's Multilateral Insurance Guarantee Agency (MIGA). In effect, this insurance would likely place a premium on the price of equipment, but it gives better assurances to the buyer of the timely delivery of equipment and services.

10.6 RECOMMENDATIONS

The recommendations herein address financing options in the **near term** or the first five (5) years of operations and then options for meeting **medium term** and **long term** needs out to year fifteen (15) of UNMA operations.

10.6.1 NEAR TERM (YEARS 1-5)

The initial five years reflects the implementation of major upgrades of operations of the Department of Meteorology in its transition to the Uganda National Meteorological Authority (UNMA). The Bill creating UNMA allows the new authority to carry out its operations with a certain level of autonomy, which includes a higher level of involvement with the Ministry of Finance, in determining how it finances those operations.

Near term financing options would primarily emanate from multilateral institutions and bilateral donors, with additional financial support from the Government of Uganda. Additionally, there are certain financing structures, if favorably considered, that could lead to receiving financial support from regional development banks and export credit agencies. As local and international markets change, these options could become more attractive than others, and as such, it is critical that UNMA maintain a dialog with the financial community to discern which options are best suited for the financial and operational goals of UNMA during the entire modernization program. This might include engagement of a financial advisor to assist UNMA with steering through consideration of alternative financing structures for implementation.

The UNMA should strongly consider the following options, particularly in the near-term:

United Nations Development Program (UNDP): UNMA, as a high priority, should pursue the **UNDP** commitment, which, through the Global Environment Fund, provides US$4.4 million in grant funding to Uganda, through its *Strengthening Climate Information and Early Warning Systems in Eastern and Southern Africa*. Additionally, the UNDP's Regional Center for East and Southern Africa has another US$1 million available to support this project. The project specifies that funding geared toward developing early warning systems but the equipment and systems have applicability to other capabilities that UNMA seeks. Thus, receiving substantial support for systems, equipment, and training that has multiple applications could create synergies and economies of scale.

PTA Bank (Structured Finance): Developing a financing structure which dedicates part the Ugandan Government's capital commitments to debt servicing could induce regional development banks or export credit agencies to raise debt financing for major capital expenditures (e.g. weather radar). PTA Bank (and to a certain extent, East African Development Bank) can fund loans with their own resources or these banks can work in concert with export agency programs in funding loans. The export credit agencies would include among others, the Export-Import Bank of the United States, the UK's Export Credit Guarantee Department, and Japan's Nippon Export Investment Insurance. Based on discussions with PTA Bank and given its capital base and long standing experience, PTA Bank has expressed interest on its part to explore a viable financing structure. The benefit of this financing structure would be an acceleration of project implementation which could favorably affect UNMA's market and financial outlook. Additionally, ECA support would give UNMA and this project greater visibility in the international markets, something which often times attract greater supplier interest and new financing options.

If such a structure is not viable, consideration should be given to request a sovereign guarantee or UNMA might defer an approach to regional development banks/export credit agencies until early on in the medium term phase when UNMA, as an entity, is more established.

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, the German bilateral donor, is currently providing support through supplying UNMA with 23 automatic weather stations. GIZ is also actively involved with adequate organizational support to the new UNMA. Additionally, in view of their familiarity with UNMA's operations, UNMA should explore with GIZ other areas of support including training.

US Agency for International Development (USAID): Preliminary discussions with USAID staff indicate an interest in working with UNMA in some capacity. Areas of interest could include:

Human Capacity Building: Supporting personnel training programs locally as well as sending designated UNMA personnel abroad for skills enhancement be it advanced degrees at US universities or specialized programs with other US agencies including the National Weather Service and NASA.

Agro-Forecasting: Supporting UNMA in developing crop and yield forecasting models for the agriculture sector, an area where there is a major focus of USAID in Uganda.

UNMA should actively pursue establishing a relationship with USAID and other donor agencies. With respect to the agro-forecasting program, MDA would have interest working with UNMA in approaching USAID in developing such a product.

Stanbic, DFCU Bank, and other commercial banks: It is understood that UNMA will require account facilities with commercial banks. In selecting a bank, it would be ideal if the commercial banking institution not only provides the requisite account services for UNMA's operations, but the institution over time, assist UNMA with meeting its financing requirements. In the near term, institutions such as Stanbic and DFCU will consider overdraft facilities and also, lease or other secured asset based financing for assets that have a shorter life cycle such as computers and telecom equipment.

10.6.2 MEDIUM-TERM/LONG-TERM (YEARS 5-15)

The fifth year is likely to be a major milestone to measure the success of UNMA attaining its operational and financial goals as established at its inception. In this respect and prior to implementing its medium-term/long-term strategy, it is recommended that UNMA undertake an in depth review analysis of its financing strategy to discern if funding is among others, achieving the following:

- Enabling UNMA to meet its procurement strategy,

Affecting profitability and cash flow generation capability;

Increasing financing options available to UNMA.

UNMA should revise its medium-term/long-term financing strategy based on its findings and conclusions from this review analysis. This is another point where the engagement of a financial advisor knowledgeable of the respective markets might be appropriate to assist UNMA with this analysis.

Notwithstanding, the MDA Team, at this juncture, envisions UNMA moving from having sole financial dependency on government and multilateral/bilateral donor sources to an entity having those as well as regional development banks, export credit agencies, and commercial banks. Additionally, there is the prospect of accessing funding from local and regional capital markets.

Prospective sources of financing would include the following:

- **World Bank Group/Multilateral/Bilateral Donors**: In discussions with the WBG Staff in Kampala, the MDA Team learned that over the next three to five years, WBG will be considering additional credits for projects within the Ministry of Water and Environment, in which consideration could be given to support UNMA's operations. Thus, it is recommended that as early as possible that UNMA liaise with appropriate staff at the Ministry of Water and Environment to develop a possible strategy for approaching WBG for project support be it funding support for capital investment or training.

  Another area to explore with the WBG, the African Development Bank, and bilateral donors would be any regional initiatives that it might be considering and if funding is available, UNMA liaise with fellow meteorology services in East African or COMESA in applying for funding.
- **Regional Development Banks/Export Credit Agencies**: Even though the MDA Team recommended pursuit of this these options during the near term phase, this alternative becomes even more viable at this advanced stage of UNMA's development. At this phase, the MDA Team continues to recommend that UNMA work through the regional development banks because they have the ability to provide down payment financing and, particularly PTA Bank, have extensive experience with ECAs in structuring and closing these transactions.

  We also recommend that UNMA liaise with fellow meteorology services in East African or COMESA in applying for funding from regional banks and ECAs. This is particularly the case with weather radars, due their high capital cost. The collaboration would involve Kenya and other

EAC members, and potentially Rwanda, Burundi and the D.R. Congo in developing a joint procurement and financing strategy that could also involve the participation of international financial institutions including ECAs and PTA Bank and East African Development Bank..

- **Stanbic, DFCU Bank, Citibank, and other commercial banks**: During the mid-term long-term phase, UNMA should build on its relationships with the commercial banks that have been providing account services and the lease and other asset based financing. This is achieved by exploring financing structures involving medium-term local currency and foreign currency loans. Additionally, these institutions could be an alternative source in raising financing through export credit agency financing. Note however, because of limited access to foreign currency funding (currently 7 years) the tenor of foreign currency financing from these institutions would be less than that which regional development banks, for example, might consider. Finally, the investment banking functions of these banks could advise UNMA in accessing medium term funding from funding from the capital markets in Uganda.
- **Suppliers**: Suppliers may be induced to provide credits particularly in situations where the potential for growth either in Uganda or within the region for the sale of its equipment and services offers continuing business opportunities. The terms and conditions of the supplier credits will vary but often times reflect those of traditional financing offered by commercial banking institutions. This financing can also comprise the 15% down payment financing typically tied to export credit agency financing from the country of the supplier. In cases where financing has not been arranged, it is recommended that UNMA consider the inclusion of requests for financing as part of the tender package. This financing might include direct financing from commercial banks, regional development banks, export credit agency banks, and from suppliers.

10.7 CONCLUSIONS

The process of managing financing after disbursement is not only confined to assurances that any repayments are made on a timely basis and that agreed to covenants are met, it is also critical that as part of the process of managing all aspects of financing, the executive and financial management teams review these financing structures to assure that they fulfill the purpose and intent of the projects financed.

Taking this into account, the MDA Team recommended in the working paper for Task 7 Organization Requirements, that the Finance and Administration unit have the resources to effectively manage all aspects of the financing process. This includes remaining current on the financial markets, particularly trends that are relevant meeting the respective needs of UNMA. In this respect, it is important that UNMA financial staff maintain a dialog with key players in the financial sector including among others, multilateral and donor institutions, local and regional financial institutions, suppliers and financial regulators. This also includes having a clear understanding of the institutions policies and procedures, thereby facilitating the decision making process and better assuring that UNMA receive the type of financing required to meet a respective project's needs.

In closing, the MDA Team stresses the importance of the project financing strategy being developed concurrent with overall project conceptualization and development. This is critical in the sense that project approval by virtually all institutions considering financing proposals is based on the following:

- Project Concept and Market Outlook
- Management and Staff Capacity
- Technical Viability
- Financial Viability
- Governance Principles

The process of securing support from prospective sources of financing should include the following action steps:

- Review financing requirement and develop a strategy to target alternative financing sources, including a clear understanding of their policies, terms, and conditions in the context of financing the initial phase of the CIP.
- Review financing strategy with the Ministry of Finance
- Meet with prospective financiers to discuss financing requirements

- Prepare financing application if there is interest on the part of the financier
- Meet with targeted financing sources to discuss application and as necessary, be available for follow on discussions.
- If application is approved, negotiate terms and conditions
- Closing and disbursement after meeting conditions precedent.

11 IMPLEMENTATION PLAN

11.1 INTRODUCTION

The discussion herein provides the Uganda National Meteorological Authority (hereinafter referred to as UNMA with a “game Plan” for modernizing the UNMA. Uganda has made significant strides in the growth and development of the economy in the last 20 years. Two important elements of this growth are improvements in the support and capacity for international aviation and agriculture exports. Those two elements often support each other as, for example; regularly scheduled flights from Uganda to Europe are a critical element in the logistical chain of the Uganda cut flower industry. However, the growth of the aviation and agriculture sectors is very weather sensitive, with conditions such as microbursts and wind shear affecting aviation safety, and flood or drought affecting agricultural production. The MDA Team also found that the general population of Uganda is threatened by many types of extreme weather events, including severe thunderstorms and the attendant hazards of lightning, hail and flash floods. Because of these extreme events, it is incumbent on UNMA to modernize their meteorological observing, warning and forecasting technology and expand their services in order to continue effectively achieving their mission.

During the MDA Team’s fact finding trips across Uganda, a common theme emerged. Staffs were well trained to make observations and were equipped with thermometers and manual rain gauges. Forecasters were valiantly trying to do a good job. However, more sophisticated equipment was generally in poor state of disrepair or inoperable due to a lack of supplies. The team also found telephone communications were poorly funded, many radios were inoperable, and no stations outside of Entebbe had access to Internet, There were no other means of obtaining information on conditions beyond their immediate view. Radiosondes have not been launched in Uganda for five years and the radar at Entebbe has not functioned in a similar period.

Many station facilities and offices are provided by other government organs and tenure is not assured. Perhaps because local governments get little in the way of forecast services from the local stations, working relations are not sufficiently close to allow for support of UNMA goals. Neither the general population nor the Agriculture or Civil Aviation authorities have had full confidence in the weather forecasting skill of DoM. The run down facilities are certainly not in shape to accept a modernized UNMA. The forecast facility at Entebbe lacks proper tools to do their job and as a result the SIGMET program to support international and domestic aviation is non-existent. The forecasts for upcountry areas are simply a city forecast with little or no detail and certainly not indicative of any hazard that may arise. High speed data access to help create a viable warning and forecast program is only a dream. The lack of capital investment has prevented UNMA from providing their personnel with the requisite physical and information tools and resources. UNMA will need to implement rapid improvements in maintenance, repair, material supplies, security and record-keeping of its current system and a capital investment program for the future if it is to earn the confidence required to obtain the financial support of potential lending institutions.

Therefore, the mission of this MDA Team study is to develop a capital investment and procurement strategy that will enable the UNMA to move forward out of the morass of the many years of neglect and become the pearl of the East African Community with respect to weather services.

11.2 MODERNIZATION PLAN NARRATIVE

Near Term Years (1-5): The initial five years reflects the implementation of major upgrades of operations of the Department of Meteorology in its transition to the full-fledged Uganda National Meteorological Authority (UNMA). The following actions are required to be implemented in order for the modernization to take place.

Of highest importance is the establishment of a Wide Area Network (WAN) backbone which is essential for the establishment of Uganda-wide communications for UNMA. This would involve installation of hardwired internet connections with bandwidth of at least 2 mbps at NMC and Headquarters, and at each radar facility. This is to be followed quickly by or done in parallel with establishment of a high speed Local Area Network (LAN) both within upcountry UNMA offices and in the Kampala/Entebbe corridor. The modernization of the UNMA Internet, both Inter and Intra, is necessary for showcasing the modernization to the Ugandan government and its citizens, including placing weather warnings, advisories and forecasts in an easily accessible fashion. Internal communication to UNMA employees using the Intranet capability will be extremely important so that everyone in the organization is on the same page and knows the next steps in the modernization. Establishment of the latest technologies to allow distribution of warnings and forecast over cell phones is essential. A request reply system must be in place. Part of the WAN should include connectivity to the Ugandan military. More detailed actions to be accomplished can be found in the section on ICT Infrastructure.

The establishment of a lightning detection network is a crucial early step that will provide real-time awareness of most severe weather activity over all of Uganda. As a first step, in 2013, two or three detectors compatible with the World Wide Lightning Location Network should be installed at locations in Uganda with existing hard-wired internet connections and dependable power. These might be located at NMC, at the University of Gulu, and at the Institute for Tropical Forecast Conservation. By 2014, a total lightning detection network should be purchased and installed. If funds are short, an initial 4-sensor network using Boltek equipment and Astrogenic software could be installed for ~$30,000. The Capital Investment Program assumes a $1,000,000 installation using equipment from more established companies such as Vaisala or Earth Networks.

To go hand in hand with the communication upgrade, the facility infrastructures must also be upgraded. This would include conditioned space, raised floors, improved electrical connectivity, redundancy, backup power, and security. A new headquarters building that would accommodate the transitioned National Meteorological Center (NMC), Training Center, Quality Data Center, Radar Operations Center (ROC), Calibration Laboratory and new headquarters Directorates must be built within the first five years so that the transition ongoing in the remainder of Uganda can take place in an orderly and coherent fashion.

Land acquisition and new office construction with security at Soroti, Kasese, Gulu, Aura, Kidepo, and Pakuba are necessary. The offices at Soroti, Kasese and Gulu need to have the extra room built in to house the regional centers that will require staff and be able to store equipment. Redesign and modification of the space at the Entebbe location of the current NMC will be essential for the initial upgrade in communications. Security fencing is a must at those locations where new observation equipment is to be established and indeed security arrangements at all offices must be strengthened to protect employees and equipment. The MDA team recommends that the initial radar for UNMA be collocated with the new headquarters building. If this is not possible, then a site will need to be identified and the attendant roads, electricity, internet, and security will need to be prepared.

Personnel decisions are also important to the modernization in the first five years. An executive Director must the selected and after his selection, a modernization Program Manager will be his first appointment. The Program Manager will ensure the implementation plan stays on schedule and milestones are reached. The new Directorates of the UNMA headquarters will be created and staffing will begin.

As new automated observational equipment is added at the airports at Jinja, Tororo, and Kabale, a test will be run for 36 months to ensure the equipment is functioning while manual observations continue. After this test and calibration period the offices will be closed and personnel who meet the required qualifications and experience demanded by the new positions in the UNMA will be redeployed to those offices remaining open to help with the burden of new forecasting and watch/warning tasks that will be heavy in the first five years.

Reincorporation of the National Meteorological Training School should include a search for a PhD-level meteorologist to review and improve the curriculum to train staff on new equipment operation and maintenance and interpretation of new data streams from lightning detection and radar. Funding for scholarships to support additional students training in Meteorology at Makerere should be found. In addition, an international internship program to bring recent Meteorology master's degree recipients to Uganda to server for one or two years in forecast and observer positions could be explored. This

The Chief of the Climate Prediction Center (CPC) should be hired and his staff should be filled out. The Chief of the Quality Data Center should be hired and his staff should be filled out. The Chief of the Radar Operations Center should be hired commiserate with the installation of the first radar and his staff should be filled out.

It has been established that the equipment needs are numerous as the modernization moves forward. During the first year; soil moisture, soil temperature and evapotranspiration sensors should be added to the existing synoptic stations and should be part of all future Mesonet installations. All GIZ stations should be installed with output brought onto the UNMA WAN. An additional nine AWS stations should be bought and installed in the first five years with the first three to go to Jinja, Tororo and Kabale. This Mesonet network will eventually be built out to a 50 station AWC network, as discussed in Section 5, and shown in Figure 5.1.

Eight air pollution stations will be installed during the first five years of the modernization. These will be installed at Kampala, Kabale, Mt. Elgon, Gulu, Mbarara, Kasese, Jinja, and Apoka. In concert with the Uganda CAA airport classifications, AWOS-3PT stations will be installed at Soroti, followed by installations at Gulu, Kasese and Aura.

The first radar installation in Uganda is a major milestone. As indicated above, the MDA Team recommends the first installation be collocated with the new UNMA headquarters. A number of computer workstations and servers are to be installed in the first five years. The implementation plan assumes that 50 new workstations will be purchased and installed in the first year. The second year the plan assumes servers will be purchased that are adequate to take over operation of the data archive/multi model ensemble forecast task provided by the NOAA office of International Programs. The MDA Team recommends that the number of radiosondes purchased be increased in year three of the modernization and that UNMA begin taking two soundings a day.

The MDA Team ascertained that a very robust Hydrological network was being operated in Uganda by the Department of Water. UNMA should move quickly to provide connectivity to that network, ingest through the Quality Data Center and make it available for use by the NMC and CPC forecasters and for display on the UNMA web site.

It has been demonstrated that Lightning is also an important tool to not only help the warning and forecast program but aid in the saving of lives. UNMA should move quickly to purchase a basic system in the first year of the modernization. The installation will require hookup to adequate power and available Internet. There should be an evaluation during the first year to determine system performance. The evaluation will include among other things; up time and detection efficiency. If the system performance is not capable of detecting 95% of lightning producing storms and to rank storms correctly by intensity of lightning production, then a Request for Proposals (RFP) for a more advanced system should be released.

Medium-Term/Long-Term (Years 5-15): By the fifth year the MDA Team assumes that adequate communications have been established throughout Uganda, a new Headquarters building has been built with the attendant startups such as the ROC, the Quality Data Center, the Training Center, the move of the non-aviation part of NMC has been accomplished and the Headquarters Directorates are up and running. Radar has been installed and the UNMA web site is mature enough to become a major player in the distribution of warnings and forecasts in the modernized UNMA. All equipment as listed in the previous section has been installed and the field structure is beginning to mature.

However, there is still work to be accomplished. The MDA Team proposes that two additional radars be procured and installed to more adequately cover the Republic of Uganda. Two additional AWOS-3PTs are to be installed one each, at Kidepo and Pakuba. Eighteen additional AWS stations need to be acquired and installed. These would go to replace aging Agrometeorological states and fill out the rest of the Ugandan Mesonet. Consideration should be given to Adjumani, Achol Pii, Ankole Tea, Bugungu, Bugambe and Bundibugyo.

The following sections contain additional details of the various parts of the implementation.

11.3 ICT INFRASTRUCTURE

The wealth of data gathered by observing systems and produced by numerical models does not have value unless the users can access it in a timely and efficient manner. UNMA operational and research personnel must have the ability to retrieve, analyze, display, and archive digital information systematically and with minimal effort so that they can focus their attention on generating their local products and transmitting the same as well as on decision making and research. This implies that establishing the ICT infrastructure including the Wide Area Network (WAN) and the Local Area Networks (LANS) must have the highest priority within the modernization of UNMA.

The UNMA should systematically organize data, software, hardware, networking, protocols, and procedures to serve UNMA personnel and ultimately the stake holders and end users. The system organization should be well documented and communicated to all users. All shared devices (e.g., printers, modem banks) should be considered in the system organization. ICT development and operational activities must be separated so that no developers can accidently cause an operational IT component to cease working.

The UNMA network and hardware infrastructures over all Uganda offices must operate 24 hours per day year round. Because of the critical nature of UNMA observations during hazardous events, the UNMA ICT infrastructure must provide enough redundancy and failover capacity to continue operations if UNMA Headquarters or the other forecast and warning offices were inoperable. In addition, because the UNMA retains all historical climate records for Uganda, all UNMA observations and other important data, products, or information must be archived both on-site and off-site. Procedures for backup of servers, databases, and personal computers should be routinely done in the ICT system background daily.

Adequate power conditioning and climate control must be provided in all network and server rooms. These rooms must be physically secure, with access controlled to appropriate ICT personnel and senior managers. Firewalls must separate publicly accessible information from the UNMA ICT system including processing and storage.

Sufficient security must exist to ensure that forecast operations during hazardous weather continue uninterrupted by accidental or intentional ICT breaches. Sensitive personnel information must be password protected and access limited to selected authorized users.

Primary ICT system components such as servers, backup devices, and network switches should be associated with specific tasks (e.g., data collection, ftp services, database services, statistical and graphical analyses, archive of research model output) and be designated as either operational, test, or research (e.g., operational servers would not be used for test or research purposes).

Sufficient online storage should be available for the following data sets:

- All real-time and historical station observations,
- the most recent 10 days of all other observations (e.g., radar, lightning),
- the most recent 10 days of satellite images from EUMETSAT,
- Output from the most recent 10 days of NWP model raw data and products,
- Output of current (active) research programs.
- All station or locally generated products for the most recent 10 days.

Offline storage should include all officially disseminated forecast, alert, and advisory products. Offline storage (e.g., tape drives) may include all historical data and output from previous research projects.

Equipment and robust software along with attendant policies and procedures must be established to reduce the vulnerability of UNMA to data loss. Backup capability also should be available to the model development team in order to effectively manage spinning-disk resources. For all data that the UNMA has collected in the past, there must be provision for routine on-site and off-site backups of the files and databases, including metadata.

Backup capability should include an expandable, robust, automated state-of-the-art backup technology. Provision should be made for regular frequent backups of all UNMA collected data in perpetuity.

UNMA-generated numerical weather forecast model data should be archived for a sufficient time to develop and report seasonal and yearly statistics of numerical model performance versus observations. In addition, sufficient quantities of all observations received in real-time at UNMA and global and regional boundary model data (e.g. from ECMWF and GFS) should be archived so that retrospective case studies can be performed for purposes of testing analysis improvements and model development.

Computer resources, software, and networking infrastructure should allow ingest, retrieval, and display of products on forecaster workstations with minimal latency. Computing resources must be sufficient to achieve the following:

- Automated QC of all incoming and locally generated UNMA observation data within one minute of its reception or generation at UNMA Headquarters,
- Disseminate to the network and all stake holders of the full suite of real-time products within one minute of obtaining quality controlled data,

- Complete all forecast model runs (model data and output) before 1/20 of the forecast length has expired (e.g., a 72-hour forecast must be generated in less than 3-6 hours).

In addition, computer resources should be sufficient to run operationally a WRF mesoscale model at storm scale (1 to 3 km) resolution.

Data from UNMA and other agency observing systems as well as locally generated forecast products should be transmitted to the Quality Data Center for ingest, processing, and dissemination. For critical observations, such as radar and synoptic data, as well as locally generated forecast products the UNMA should ensure backup communications. A dedicated line between the forecast offices and the Ugandan military should be established for routine and emergency operations.

Secure high-bandwidth connections must exist between the Quality Data Center and the following:

- All Doppler radar sites,
- All UNMA forecast and meteorological observatory offices,
- The UNMA Headquarters offices including the Climate Prediction Center and the high speed link to Nairobi.

Real-time observations automatically transmitted over low bandwidth connections should arrive at the central data hub within 5 minutes of the observation, including during inclement weather.

Within the UNMA, network infrastructure should be connected via the latest reliable technology (e.g., fiber optics). Secure wireless access should be provided throughout UNMA facilities. Connections to personal computers must be at a speed necessary for efficient work using the latest technologies.

A robust Web Site should be one of the early-on developments in the modernization of the UNMA, since one of the dissemination methods must include the UNMA web site for external access and data queries for internal access. Other methods should include the latest technologies including distribution of warnings and forecasts over cell phones. A request reply system is essential.

The UNMA web site should be organized in a structured manner so that users can find and interpret products easily. Sections of the web site may be focused on a specific customer group. Interpretation guides should be linked to any product that may be difficult to understand. Critical, time-sensitive information (e.g., warnings, advisories) should be displayed or linked directly on the UNMA home page.

Internal to the UNMA, publications, news, reusable code and scripts, policies, catalogs, and other information should be shared electronically through a centralized system.

11.4 FACILITIES

Simply stated, the UNMA cannot modernize without a complete overhaul of their headquarters. The MDA Team proposes and strongly advocates the relocation of the UNMA Headquarters to a new, modern facility somewhere in the general Kampala Entebbe area.

It is of the utmost importance that there is an implementation of critical recommendations of this report, most notably those dealing with IT infrastructure. To implement the IT infrastructure requires and relies completely on a modern new facility.

In addition, the physical facilities of the various offices including the aviation facility at Entebbe and new offices in the upcountry of Uganda must be must be renovated substantially, or the offices must move to new modern facilities, so that the recommendations of the MDA Team can be implemented.

It is paramount that UNMA employees work in safe facilities with emergency exits, fire restriction and suppression equipment, adequate ventilation, backup and emergency power, redundant communications links, and adequate space for employees, handicap access, and a well-planned and secure IT infrastructure.

UNMA headquarters should include the following facilities: calibration laboratories, machine shop, equipment storage, library, several conference rooms (different sizes), Training Center, lunch room (i.e., kitchenette with several tables), garage, secure parking for UNMA owned vehicles, computer server room, forecast operations center, Quality Data Center, Radar Operations Center, media interview and broadcast room, and employee offices.

The upcountry forecast offices including the aviation facility at Entebbe should include the following facilities: conditioned space, raised flooring, adequate electrical infrastructure to support modern workstations and servers, break room, conference room, computer server room and employee offices, microwaves, and drinking water, conference room, computer server room, forecast operations center, and employee offices.

The Study Team strongly recommends a smoke free environment for all UNMA facilities, not only for the health of UNMA personnel but to increase the lifetime of sensors, computers, and other expensive equipment. All IT facilities, including server rooms, network closets, and data storage areas, must be smoke free to ensure the integrity of the systems and the data. The fire threat will be appreciably diminished.

11.5 LEADERSHIP

As the State Authority, the UNMA should assume a leadership role coordinating information about and data from other environmental networks or stations within Uganda. Coordinating activities may include the following:

- Creating an inventory of what observing systems exist, what they do, how data can be accessed, and under what conditions,
- Differentiating national observation networks that provide data for public use from user networks that help solve a particular technological or security problem,
- Providing advice on measurement techniques, availability of measurements, and data access from other agency networks,
- Participating in planning activities for other observing networks,
- Centralizing the Quality Assurance (QA) and archival of atmospheric, terrestrial, marine, and environmental observations.

The UNMA also should help ensure seamless decision making, coordination of responsibilities, and data flow among agencies and organizations involved in crisis management during natural or manmade hazards. As the UNMA is modernized, it should invest in marketing and public awareness campaigns that increase the visibility of the Authority and its new products and services. Materials developed should focus on the benefits of the modernized UNMA to the public and other users.

11.5.1 FINANCING IMPLEMENTATION STRATEGY

Near Term (Years 1-5): As discussed in the Section 10, Financing Options, the initial five years reflects the implementation of major upgrades of operations of the Department of Meteorology in its transition to the Uganda National Meteorological Authority (UNMA). Near term financing options would primarily emanate from grant assistance from multilateral institutions and bilateral donors, with additional financial support from the Government of Uganda.

Additionally, there are certain financing structures, if favorably considered, that could lead to receiving financial support from regional development banks and export credit agencies. As local and international markets change, these options could become more attractive than others, and as such, it is critical that UNMA maintain a dialog with the financial community to discern which options are best suited for the financial and operational goals of UNMA during the entire modernization program. This might include engagement of a financial advisor to assist UNMA with steering through consideration of alternative financing structures for implementation.

Recommendations regarding those institutions that UNMA should target are discussed in detail in Section 10, but they include the following:

1. United Nations Development Program (grant assistance)
2. PTA Bank (ECA and Structured Finance)
3. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH (grant assistance)
4. US Agency for International Development (USAID)grant assistance)
5. Stanbic, DFCU Bank, and other commercial banks (banking services/overdraft facilities)

Medium-Term/Long-Term (Years 6-15): As discussed in Task 10, the fifth year is likely to be a major milestone to measure the success of UNMA attaining its operational and financial goals as established at its inception. In this respect and prior to implementing its medium-term/long-term strategy, it is recommended that UNMA undertake an in depth review analysis of its financing strategy to discern if funding is among others, achieving the following:

1. Enabling UNMA to meet its procurement strategy,
2. Affecting profitability and cash flow generation capability;
3. Increasing financing options available to UNMA.

UNMA should revise its medium-term/long-term financing strategy based on its findings and conclusions from this review analysis. This is another point where the engagement of a financial advisor knowledgeable of the respective markets might be appropriate to assist UNMA with this analysis. Notwithstanding, the MDA Team, at this juncture, envisions UNMA moving from having sole financial dependency on government and multilateral/bilateral donor sources to an entity having those as well as regional development banks, export credit agencies, and commercial banks. Additionally, there is the prospect of accessing funding from local and regional capital markets.

While discussed in greater detail in Task 10, the prospective sources of medium-term/long-term financing would in broad terms, include the following:

1. World Bank Group/Multilateral/Bilateral Donors
2. Regional Development Banks/Export Credit Agencies
3. Stanbic, DFCU Bank, Citibank, and other commercial banks
4. Suppliers

11.5.2 IMPLEMENTATION OF RECOMMENDATIONS

To ensure consistency and compatibility with all aspects of UNMA modernization, the MDA Team recommends that, with UNMA oversight, the Ugandan Government solicit bids from interested and qualified firms or individuals to assist in the full modernization of the UNMA. The winning firm may provide the full solution themselves or may subcontract to one or more individuals or organizations to provide the full solution. In either case, the winning firm shall be responsible for ensuring that equipment, software, networking, and communications form an integrated system that can be maintained by UNMA personnel.

Preparation of the proposal solicitation should rely heavily on the guidelines itemized in this report, though the MDA Team acknowledges that the UNMA may have future needs that are unmet by these recommendations. The proposal solicitation should address training, maintenance, warranties, hardware and software documentation, and other follow-up support to ensure the longevity of the system.

Individual proposals should be evaluated by a selection committee that consists of representatives from the UNMA. Offers should use the following criteria:

- Firm’s or team’s past experience and current work plan;
- Quality of the firm’s or teams previous work;
- Proposed budget; and
- Firm’s or team’s familiarity with the existing UNMA, its needs, legislation, and responsibilities.

The MDA Team advises the selection committee to consider the quality of the firm’s or teams previous work carefully. In this manner, the lowest cost bidder may not be the highest ranked proposal. Clearly, the lowest bidder may not be the best valued bid.

In addition to the solicitation, evaluation, and selection of a firm or team to implement the new technologies and methods of a modernized UNMA, full implementation of the recommendations will require the reduction or elimination of some components of the current DoM. The Study Team recommends that the UNMA be proactive to remove Personnel from the DoM organization by the end of 2016. Personnel who meet the required qualifications and experience demanded by the new positions should transition to work for the new and modernized UNMA.

In particular, as the automation of surface observing systems is implemented and manned stations are reduced, UNMA personnel who currently work at the manned stations should assume other duties within the UNMA. E.g., the digitizing of copious amounts of historic data and metadata will require devoted time of people who care deeply about observations and their integrity or other observing stations where they might be needed.

The new data, products, and services of a modernized UNMA will be valuable assets to the Republic of Uganda and its citizens as long as undue restrictions are not placed on their distribution and use. The MDA Team strongly encourages the UNMA to plan strategically how to best control and release control of its information components. In particular, the MDA Team recommends that all quality-assured UNMA observations be made freely available in real-time. Cost-recovery fees, priced reasonably, may be assessed on organizations that profit financially from the UNMA data feed.

To encourage economic growth, it is important to recognize, appreciate, and strengthen the role of the private sector. Similarly, for growth of the private sector and its resultant boon to economic development, domestic and foreign companies must be assured that the personnel and infrastructure of the UNMA is well supported, both financially and politically, by the Republic of Uganda.

Hence, the MDA Team strongly encourages the Republic of Uganda to provide adequate and stable funding to the UNMA annually for operations, development, and research.

11.5.3 ADDITIONAL SERVICES NEEDED TO AID THE IMPLEMENTATION

The MDA Team believes that UNMA will benefit from professional services to provide assistance during some phases of the modernization. Consulting services should provide technical assistance on Change Management across the board—top senior management, middle management and technical staff. Listed below are the kinds of services and duties that would be performed to aid in the implementation.

Consultants would provide staff training on new observation systems (radar, lightning detection, automated weather systems), and on state-of-the-art interpretation of existing satellite observation products. Consultants could be retained to:

- Assist in setting up a continuously updated data base that would include the last month's forecasts, at multiple lead times, from all publically available global weather forecast models, as well as updated observations from Uganda's automated station network and volunteer observer network. The consultant would also assist UNMA in setting up an **automated forecast system** that, using this database, removes forecasts biases, ranks models according to their skill, and generates skill-weighted ensemble mean forecasts for temperature, precipitation, insolation, evaporation, and any other variables of interest.
- Assist in setting up **limited-area numerical weather prediction** modeling for Uganda using WRF or another mesoscale model.
- Provide technical assistance in setting up a **watch and warning system** for UNMA. The watch warning system is very much a change in paradigm and needs a strong experienced consultant. Staff selection and training will be an initial key to its success as will its design, organization, and leadership.
- Provide technical assistance in improving communications with **traditional and new media**. This task would include assistance in setting up a state-of-the-art web site for UNMA, in setting up SMS text message alerts, and in preparing forecasts for traditional media outlets that maximize clarity and usefulness of forecasts.
- Provide technical assistance in establishing a **radar network** in Uganda. The MDA Team believes UNMA needs a consultant to write an RFP for radars. This same consultant needs to put together a team to evaluate industry proposals, select the winner, establish sites and help to do initial training or help to organize it. The consultant will need to heavily influence the overall radar program and the ROC design and staffing and the Radar Hot Line.
- Provide technical assistance in **agricultural forecasting**. This would involve technology transfer to UNMA that would allow useful forecasts of crop yield for all major crops in Uganda using a combination of observed weather data to date and long-term forecasts from global models.

- Provide technical assistance in **fee-based provision of specialized forecasts**. This would involve assistance in setting up a marketing department for fee-based services, in setting up a web-based to advertise and accept payment for these services and in market and scientific research to define products that will be of value to economic interests in Uganda.
- Establish the NMC **training** center. The consultant would identify qualified lecturers
- Provide **financial advice and grant-writing assistance** during the implementation. A financial advisor could assist UNMA with steering through consideration of alternative financing structures for implementation. Engagement of a financial advisor knowledgeable of the respective markets might be appropriate to assist UNMA with the analysis of revision of its medium-term/long-term financing strategy.

12 Preliminary Environmental Impact Assessment

Environmental impacts from Uganda Department of Meteorology Modernization will on the whole be positive. The ability to predict heavy rainfall in particular and effective dissemination of these predictions to the general public will enable Ugandans to avoid agricultural and construction activities that might cause damage to hill slopes and result in loss of topsoil and contamination of streams with large amounts of soil and agricultural waste. Observation of air pollution will make possible effective regulations to limit such pollution.

However, certain activities associated with this modernization plan will require assessment and possibly mitigation of local environmental impacts. Schedule 3 of the Uganda National Environmental Act (http://www.ulii.org/ug/legislation/consolidated-act/153) specifies that an environmental impact assessment may be required for "any structure of a scale not in keeping with its surroundings," for "all roads in scenic, wooded or mountainous areas," "electrical transmission lines" and "electricity generating stations". It seems likely that construction of radar facilities (which will need to be sited on hills, remote from obstructing views) will require new roads, electrical connections and small back-up generating stations) will trigger the requirement under Part V, section 19 of this act for the submission of a project brief to the National Environmental Management Authority. Similarly, the establishment of air pollution and climatological observing stations in National Parks, as recommended herein will probably trigger this requirement, since these might require some minor road construction within in mountainous areas.

Because these impacts are expected to be minor and able to be "minimized by the application of mitigation measures" (such as constructing roads in ways that minimize soil loss or damage to hill slopes or forests), we expect them to fall under "Category 2" of the African Development Banks environmental impacts screening procedures (http://www.afdb.org/fileadmin/uploads/afdb/Documents/Policy-Documents/ENVIRONMENTAL%20AND%20SOCIAL%20ASSESSMENT%20PROCEDURES.pdf). Should African Development Bank funding be requested for this project, this would result in the need for an "Environmental and Social Management Plan."

The Modernization will likely fall into Category C of the World Bank's environmental impact screening procedure (see Chapter 1 of their Environmental Assessment Sourcebook http://siteresources.worldbank.org/INTSAFEPOL/1142947-1116495579739/20507372/Chapter1TheEnvironmentalReviewProcess.pdf), requiring no Environmental Analysis, since from the perspective of the World Bank, the project will likely be seen as having no "significant" environmental impacts. Category C projects "may not be entirely devoid of environmental impacts," as long as the impacts are mitigated within the design.

The elements of the modernization plan that will require careful environmental analysis include:

- Back-up power generation facilities, which must be constructed in such a way that any leaks during fueling do not result in spills, and which should conform to high standards of air pollution control so that the project can be presented in its entirety as a model of more general efforts to reduce air pollution in Uganda.
- Any road construction required for radar facilities or new observation stations, particularly in forested areas, mountainous areas or national parks.
- Construction of new buildings that appear out of scale with surrounding buildings.
- Construction of any new electrical transmission lines (likely to be required for radar installations).

In writing this section, we were aided by the work of Kakuru et al. (2001), who describe the environmental impact assessment processes in Uganda in detail.

13 DEVELOPMENTAL IMPACT ASSESSMENT

13.1 BACKGROUND

The provision of public weather services in Uganda during the last thirty years presented a number of formidable challenges to DoM but it also now presents an array of exciting opportunities to the UNMA. While the provision of adequate resources must be expected to remain a major impediment, it is becoming increasingly clear that the provision of state-of-the-art public weather services has the potential of translating into a cost-effective investment for UNMA. In order to secure government recognition of the value of this investment, one of the important steps is for UNMA to demonstrate the economic benefits accruing to the nation as a result of the meteorological services it provides.

The operating environment for UNMA is likely to be influenced by four key factors. Advancements in science and technology, upon which the provision of meteorological service depends heavily, are continuing to evolve at a rapid pace in many parts of the world. This is coupled with an increasingly sophisticated public and private sector clientele who continue to demand more and better quality services with improved level of accuracy and usefulness. There is also a growing demand for more rigorous determination of the economic value of meteorological services and a growing involvement of financial markets in relation to the meteorological services through products such as weather derivatives.

At present, the provision of meteorological services in Uganda is subject to ongoing budgetary pressure and scrutiny and yet the value and benefits of meteorological services are not fully understood or recognized. There is also an increasing requirement for UNMA to generate revenue from cost recovery and commercial activities. Key areas that UNMA should focus its resources were determined in a survey (WMO 2001) on the role and operation of NMHSs. The survey identified thirty key service areas and the analysis further showed that the top ten key economic areas are aviation, agriculture, disaster management, water resource management, environmental protection, mass media, construction, energy generation and supply, marine transportation, and tourism.

Given this changing operating environment, it is desirable to have a more widely understood economic framework through which to assess the benefits and the costs of meteorological service provision at the national level.

13.2 FRAMEWORK FOR CATEGORIZING METEOROLOGICAL SERVICES

In order to establish a methodology for evaluating the economic benefits of meteorological services, it is important to appreciate the distinction that economists draw between two extreme categories of goods and services (Samuelson 1954 and Gunasekera 2004). Private (or market) goods are those which are both rival (one person's consumption makes them unavailable for others) and excludable (those who will not pay can be excluded from consumption); and public goods which are both non-rival (one person's consumption does not reduce the amount available to others) and non-excludable (it is impossible or extremely expensive to exclude from benefit a person who will not pay); and the existence of a range of intermediate ("mixed") goods that may be rival but not excludable or non-rival but excludable. These two characteristics (rivalry and excludability) lead to the categorization of three broad types of goods or services – public, private and mixed goods; and they are depicted in Figure 13.1 below.

Rivalry of C	Non-Rival	MIXED GOODS	PUBLIC GOODS

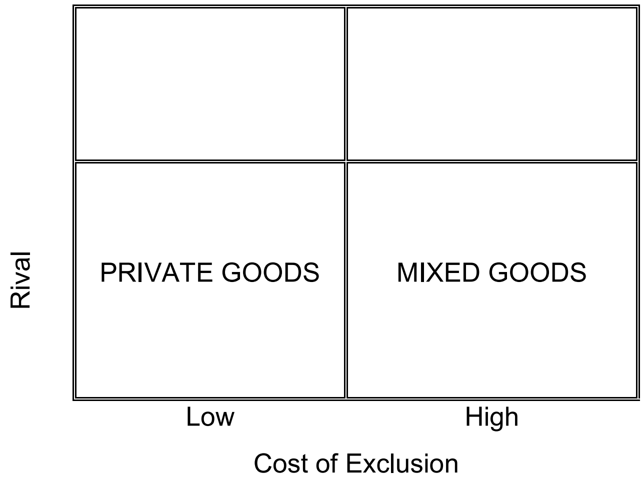

Figure 13.1: Categories of meteorological services

While most of the important social benefits of public meteorological services defy valuation in strictly economic terms, many public good services and virtually all those services which are of the nature of private or mixed goods serve as input to decisions which have direct or indirect financial impacts on different levels of the national economy and may thus be valued in money terms through the normal techniques of economic analysis. See, for example, Katz and Murphy (1997).

13.3 ASSESSMENT OF THE ECONOMIC VALUE OF METEOROLOGICAL SERVICES

A number of approaches have been developed to estimate the economic benefits of meteorological services. These include the use of market prices to measure the benefits of specialized meteorological services when treated as private goods; normative or prescriptive decision-making models; descriptive behavioral response studies (including user surveys and regression models); contingent valuation models; and conjoint analysis.

Market-based approaches. Market prices can be used as a measure of the marginal benefits to users of meteorological information, which have private good characteristics. An advantage of market prices is that they explicitly reveal the value users place on and are willing to pay for particular categories of meteorological information. However, the wide-scale applicability of market prices is limited by the public good characteristics of much of the meteorological information provided by NMS.

Normative or prescriptive decision-making models. The approach in these models is to view meteorological information as a factor in the decision-making process that can be used by decision makers to reduce uncertainty. This approach is based on the Bayesian decision theory. The meteorological information acquired by decision-makers provides a basis for revising or updating the probabilities attached to each stage of meteorological event. Values of additional or new meteorological information are based on the expected payoff from the more informed decision as compared to the expected payoff without the information. In general, to estimate the economic value of meteorological information such as current improved forecasts using this approach requires: (i) information about the quality of current and improved forecasts and baseline “state of the atmosphere or nature” conditions; (ii) a model of how users incorporate forecasts into decisions (the process of maximizing expected net benefits); and (iii) a model of how economic outcomes (prices of goods and services, level of consumption and economic welfare) are determined by users’ decisions and subsequent states of the atmosphere or nature.

Descriptive behavioral response methods. Descriptive behavioral response methods are based on the notion that the value of meteorological information depends on the influence it has on decision making by users engaged in meteorologically sensitive activities. Descriptive studies are divided into several groups, including case studies and user surveys. Case studies involve a more systematic study of the use of meteorological information and provide a useful way of representing a decision process in a simplified manner in order to develop tractable models. User surveys are essentially marketing studies and have limited use in helping to derive realistic estimates of the value of meteorological information.

Contingent valuation method. The contingent valuation method is a non-market valuation method used by some analysts in relation to public good meteorological information. There are two key implicit assumptions in contingent valuation studies. First, respondents are assumed to be able to assign values to the non-market goods concerned. The second assumption is that these values can be captured through the hypothetical markets of the contingent valuation method. The disadvantage of contingent valuation method is that the absence of real financial transactions introduces substantial possibilities for bias. Thus, reliable results require considerable care in the structuring of questionnaires so that subjects understand the full implications of the provision of whatever goods they are being asked to evaluate.

Conjoint analysis. Conjoint analysis is a method that is similar to contingent valuation in that it also uses a hypothetical context in a survey format involving the users of meteorological information. The survey questions in conjoint analysis are designed as choices between and/or ranking of preferences for alternatives with multiple attributes. Therefore, this method requires survey respondents to rank or rate multiple alternatives where each alternative is characterized by multiple attributes.

To assess the benefits resulting from utilization of hydro-meteorological information, several things should be taken into account:

- Identification of economic losses caused by weather and climate;
- Benefits coming from current information;
- Definition of ideal services for various sectors;
- Estimation of the potential reduction of losses resulting from different levels of improved information;
- Estimation of potential improvement in operations coming from different levels of improved information.

13.4 ECONOMIC BENEFITS OF METEOROLOGICAL SERVICES

Several studies have been undertaken in recent years to estimate the economic benefits of selected meteorological services and products (for example, Katz and Murphy 1997). Although results have shown consistently that the economic value of weather forecasts is significant, one major outstanding problem is that most studies only examine the economic impact of weather-related events on some part of an industry or sector and therefore fail to systematically integrate the assessments of value at a national level.

The most comprehensive and quantitative assessments of economic benefits of meteorological services have been carried out in the key sectors of *agriculture* where, for example, crop losses can be avoided through protective action in the face of threatening weather; *aviation*, especially national and international regular public transport, where major operating cost savings have been realized; and *disaster reduction* where, in addition to the enormous social benefits associated with the minimization of injury and loss of life, effective meteorological services permit major cost savings to individuals, organization and governments.

These assessments and other studies conducted in sectors such as tourism, mining, water resources management and off-shore operations, confirm the existence of actual or potential economic benefits far in excess of the total cost of operation of the NMHS system, often even from a single sector alone. Benefit-cost ratios for individual services range from the order of 2:1 up to 100s:1 (Katz and Murphy, 1997).

Many of the studies referred to above have been conducted in the western bloc countries (USA, UK, Germany, France, Nordic countries, Australia, etc) and recently in China, Eastern Europe, Russia, and Central Asia countries. In contrast, very few cost-benefit studies have been conducted in Africa. In the East African region, Aura 2009 reported, during a WMO sponsored workshop, that a pilot study on evaluating the socio-economic benefits of meteorological information and services in Kenya had commenced. In view of the paucity of case studies in the East African region, inference will be drawn from findings of studies done by the WMO, the World Bank and China Meteorological Agency.

In a review of cost-benefit studies, WMO 1995 found that a rough approximation of the ratio of economic benefits to an NMS budget would typically be in the range of 5 - 10:1. And given that the global budget for NMSs at that time was about US$4 billion, it was concluded that the global economic benefits were in the range of US$20 – 40 billion. Related to this, Michel Jarraud, WMO Secretary-General 2007, indicated that 1€ spent on weather, climate and water-preparedness can prevent 7€ from being spent in disaster-related economic costs, and this is indeed a very considerable return on investments. Traditionally, the overall benefits accrued from investment made in the meteorological and hydrological infrastructures were estimated to be, in several countries, in order of 10:1 and this ratio differs from one eco-geographical zone to another, depending on the relative vulnerability of a specific locality, its socio-economic development and its susceptibility to weather and climate and parameters used in calculations.

In 2003, Roshydromet (the NMHS of Russia) initiated the National Hydromet Modernization Project to assess the potential benefits of improving Roshydromet's services and products as part of making the case for large-scale modernization. Due to time and resource constraints, a sector-specific assessment approach was selected, i.e., to estimate and then generalize the direct weather-related losses for weather-dependent industries and sectors of the economy. Study results reported in 2004 indicated a likely reduction of 8.5% in weather-related losses as a result of forecasting improvements. Total returns to investment in the modernization project were estimated in the range of 400 - 800% over the period of project implementation. The results of the study were well received by the Russian Government, which decided to enhance the modernization package from the original US$80 million to about US$133 million. In another study by the World Bank 2008, a cost benefit analysis of the proposed modernization programs in three Central Asia countries showed that the benefit-cost ratios for Belarus, Georgia, and Kazakhstan were 3.3, 5.7, and 3.1 respectively.

According to a recent study by Xu 2007, the ratio of average annual costs to the overall yearly economic benefits of meteorological service for China Meteorological Agency (CMA) is 1:69. It was found in an earlier survey in 1994, using similar approaches, that the ratio between the input and benefit was in the range 1:35 - 40, implying that the benefits of meteorological services have considerably increased as China has accelerated its economic development and social growth as well as the development of meteorological service.

13.5 EXAMPLES OF ECONOMIC BENEFITS OF MET SERVICES RELEVANT TO UGANDA

How and to what extent does investment in meteorological service impact on the national economy? If a significant return on investment were to be achieved (in the medium- to long-term time frame), it would imply that better services would be provided by UNMA which would translate to more added value to the various sectors of the economy. When that happens, the economy would be expected to grow in the medium- to long-term when the full effect of the modernized meteorological service would be felt. Strictly, this is a difficult question to answer quantitatively because current studies have not been able to devise a mechanism for integrating the assessments into the overall national economy and therefore the growth can only be characterized qualitatively. The main qualitative benefits of services provided by NHMSs are shown in Table 13.1 below.

Table 13.1: The main qualitative benefits of services provided by NHMSs

Economic	Agriculture: avoidance of crop losses from frost, hail, drought, flood or extreme temperatures; timing of crop protection, planting & harvesting; increased farm production and sales; more efficient scheduling of the use of agricultural machinery; minimization of drought relief costs. Air transport: Reduced fuel consumption through route planning; improved scheduling of flight arrivals and departures; minimization of airline costs from aircraft diversions; minimization of search and rescue costs; reduction of accidents and emissions; savings in passenger times, materials and working times (airport maintenance) Maritime transport: reduction of accidents and environmental damages, fuel savings, more efficient rescue operations. Oil prospecting: avoidance of unnecessary shutdown of offshore oil and gas operations; more efficient planning of energy production and delivery. Energy: prediction of power demands, power failure reduction, savings in material and working times (maintenance), energy savings. Construction: potential to eliminate serious construction problems *a priori* (risk control system). Flood protection: savings in human lives and property, more efficient rescue operations.
Social	Protection of life and property: Avoidance of loss of life and property from natural disasters. Research: Improved information and data to the scientific community. Leisure: Contribution to the day-to-day safety, comfort, enjoyment, and general convenience of citizens, including recreation, travel/ commuting and other direct and indirect forms of societal benefits.
Environmental	Air quality monitoring and warnings: reducing adverse health impacts; saving human lives in possible environmental accidents (evacuations); minimization of release of toxic substances and other pollutants; management of local environmental quality.

14 Summary of Recommendations

Here we present detailed technical requirements for some of the elements of our proposed modernization plan. Recommendations are numbered so as to coincide with the section of the report in which they are discussed more generally.

#	Recommendation	Comment	Priority
5.1	National Sensor Network Please refer to WMO CIMO Guide, 7th edition, available here: http://www.wmo.int/pages/prog/gcos/documents/gruanmanuals/CIMO/CIMO_Guide-7th_Edition-2008.pdf		
5.1.2	Automated weather station requirements		
5.1.2.1	Number of stations > 25	Coverage of all major climate and agricultural zones, proximity to all population centers, all airports.	High
5.1.2.2	Frequency of observations: 5 minutes, 24 hours/day	Ability to detect rapid changes in weather makes possible more accurate warnings and watches. High frequency variability of wind and rain are important climate variables.	High
5.1.2.3	Wind speed measured at 10 m height above ground, with accuracy of ± 1 m/s or 5%, whichever is greater	Sufficient to detect climate trends, resolve high frequency weather changes	High
5.1.2.4	Wind direction measured at 10 m height above ground, with accuracy of ± 5°	As above	High
5.1.2.5	Temperature accuracy of ± 0.2 °C	As above	High
5.1.2.6	Dew point accuracy of ±2 °C	As above	High
5.1.2.7	Barometric pressure (two systems for cross check and verification) accuracy of ± 0.5 mb	As above	High
5.1.2.8	Cloud Ceiling (at airports) with accuracy of ±50 m	Sufficient for navigation	High
5.1.2.9	Cloud Cover (using last 30 minutes of cloud ceiling)	Sufficient for navigation and climate trend, weather change detection	High
5.1.2.10	Visibility measured above 3 m, with accuracy of ± 2 km.	As above, also important for air pollution sensing.	High
5.1.2.11	Present weather (type precipitation)	Hail detection important for agricultural warning.	High
5.1.2.12	Lightning from local or national detection system, detection rate for CG flashes > 90%	Sufficient for issuance of thunderstorm warnings.	High
5.1.2.13	Insolation with accuracy of ±10 W m^{-2}	Sufficient to build reliable solar energy potential maps and detect climate trends in insolation.	High
5.1.2.14	Precipitation accuracy of ±.0.5 mm	Sufficient to detect climate trends and resolve high frequency weather changes	High
5.1.2.15	Manual station network		
5.1.2.16	Daily precipitation observations by volunteer	Resolve structure of	High

	observers at hundreds of stations, distributed over all sub-counties in Uganda with accuracy of ±0.5 mm. Daily observations at all AWS stations, to maintain calibration.	precipitation anomalies to aid in crop yield prediction and hydrological prediction for flood prediction and hydropower prediction.	
5.1.2.16	Daily maximum, minimum temperatures with 0.2 °C accuracy at all Agromet, Hydromet stations. 2x daily observations at all Synoptic stations to maintain calibration of AWS stations		Medium
5.1.4	Upper Air Observations: 2x/day at Entebbe	Improved forecasting of near-term convection, plus improved initialization of global and regional numerical weather prediction models. Knowledge of upper-air winds for Aviation.	High

#	Recommendation	Comment	Priority
5.2	Air Pollution Observations		
5.2.1	Visibility (see 2.1.10)	Cheapest means of detecting aerosol pollution, but very non-specific.	High
5.2.2	Particulate pollution: pm2.5	Direct health threat	High
5.2.3	Ozone (O_3)	Direct health threat	High
5.2.4	Carbon monoxide (CO)	Good tracer of biomass burning	Medium
5.2.5	NO_x (NO, NO_2)	Direct combustion product, good measure of local pollution source size	Medium
5.2.6	NO_y (NO_x + HNO_3 + HONO + peroxyl acetyl nitrate, etc.)	Precursors to ozone, particulates	Medium
5.2.7	Sulfur dioxide (SO_2)	Particulate producer, acid rain producer	Low
5.2.8	Particulate pollution: pm10	Direct health threat	Medium

#	Requirement	Comment	Priority
5.3	Radar		High
5.3.1	Radar Equipment Requirements		High
5.3.1.1	Able to rotate 360 degrees continuously.	Complete view of surrounding area	High
5.3.1.2	Able to perform a vertical scan from 0 to 90 degrees in range/height indicator mode.	Allows volume scans of storms in close proximity to radar	High
5.3.1.3	Radar antenna pedestal shall support continuous rotation in the azimuth plane and movement from -2 degrees to +90 degrees in the elevation plane.	Allows rapid repeats of scans to give forecasts up-to-date data.	High
5.3.1.4	Radar antenna pedestal shall be able to be steered independently by azimuth and elevation.	Flexibility in scans: plan position indicator, range height indicator, or volume scans.	High
5.3.1.5	Support for dual pulse repetition frequency (PRF) sampling	Unambiguous determination of range and velocity of radar echoes.	High

5.3.1.6	Support for simultaneous transmission and reception of horizontally and vertically polarized beams.	Unambiguous detection of hail.	High
5.3.1.7	Operator can control the antenna pedestal operational parameters in real time. Operator can select the parameters for volume and sector scans (in real-time and pre-scheduled modes).	Flexibility in scan choice in response to changing storm structure or position with respect to vulnerable populations or infrastructure.	High
5.3.1.8	Processing units of the radar system shall implement standard Internet protocols.		High
5.3.1.9	The radar signal processor shall be able to process time series (in-phase and quadrature) data using pulse pair processing, discrete Fourier transform, and fast Fourier transform processing.		High
5.3.1.10	The radar system should support an override mode to permit maintenance personnel to gain local control of the radar system.		High
5.3.1.11	The radar transmitter shall operate at a tunable frequency range of 2700 to 3000 MHz.	Avoids interference from communication frequencies.	High
5.3.1.12	The radar antenna shall have a two-way 3-decibel (dB) beam width less than 1.0 degree.	Resolution of individual cells distant from the radar facility.	High
5.3.1.13	The radar receiver bandwidth shall be no less than five MHz.		High
5.3.1.14	The radar system shall support a maximum unambiguous range of at least 500 km for reflectivity and at least 250 km for velocity.	Maximum areal coverage, subject to the earth's curvature.	High
5.3.1.15	The radar system should be able to collect information on radar performance in real-time.	Faults in radar equipment can be taken into account in making use of radar images.	High
5.3.1.16	The radar system shall be able to report the antenna position (azimuth and elevation), azimuth scan rate, elevation scan rate, reflectivity, velocity, spectrum width, and polarimetric moments to the local display system and the data delivery system (for transfer of data to the UNMA IT system in real-time.	Eases transfer of radar imagery into GIS systems and precipitation modeling software.	High
5.3.1.17	Output data from the radar signal processor should include, at a minimum, the following elements or parameters during simultaneous/horizontal/vertical transmission modes: corrected reflectivity, uncorrected reflectivity, unfolded radial velocity, spectrum width, cross correlation coefficient, differential phase, specific differential phase, and differential reflectivity.		High
5.3.1.18	The radar signal processor shall run data quality algorithms for rain attenuation correction, range normalization, gas attenuation correction, reflectivity speckle removal, and velocity speckle removal.		High
5.3.1.19	The radar system shall transmit its base moment data to the IT system in real time on a radar radial basis.		High
5.3.1.20	The radar signal processor shall output base moment data in a standard, open-source data format.		High

5.3.1.21	The radar transmitter should support a changeable operating pulse width with no less than four presets.		High
5.3.1.22	The radar system shall have a built-in calibration mechanism.		High
5.3.1.23	The radar antenna shall be protected by a radome that covers the entire antenna/pedestal assembly. The radome shall be no less than 1.25 times the diameter of the radar reflector to ensure that maintenance personnel can perform their duties.		High
5.3.1.24	The radar system should be protected against unexpected power surges from either the main power source or lightning strikes.		High
5.3.1.25	The radar system shall protect critical components in the event of a failure in the environmental conditioning equipment.		High
5.3.1.26	The radar system shall contain safety devices, interlocks, and protocols that protect personnel from accidental exposure to unhealthy levels of electromagnetic radiation and from life-threatening power surges or mechanical injuries.		High
5.3.1.27	The radar system should minimize radio frequency (RF) interference between system components.		High
5.3.1.28	The radar system should support high-speed, time-series (in-phase and quadrature) data transmission across its rotational interfaces.		High
5.3.1.29	Spare parts for the radar system shall be available for the projected lifetime of the radar system.		High
5.3.1.30	Test equipment shall be available to verify the proper operation of the radar system after installation.		High
5.3.1.31	Two red signal lamps shall be located on top of the radome for aviation security.		High
5.3.1.32	The radar system shall provide visual display of the status of and functional commands for the transmitter, antenna, receiver, and signal processor in separate “windows” that can be viewed simultaneously.		High
5.3.1.33	The transmitter, receiver, signal processor, and pedestal shall have built-in test and diagnostic equipment capable of monitoring full system functionality.		High
5.3.1.34	The radar software shall have the capability to archive and playback data.	Users can view storm history and trajectory, improving near-term forecasts.	High
5.3.1.35	The radar system shall be able to archive all base moments and products continuously, and have a mechanism to transfer them to external recording media/archive storage.		High
5.3.1.36	The radar system software shall support standard data formats and application programming interfaces (APIs) to allow output radar data and derived products to be integrated with the IT system and the analysis and display system.		High

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5.3.1.37	Software of the radar system shall use modular design practices to facilitate future expansion of capabilities.		High
5.3.1.38	Radar system software shall be maintainable with open-system software tools to facilitate software maintenance and inter-operation with the IT system.		High
5.3.1.39	The radar system shall provide one or more stand-alone visual interfaces to conduct the following functions: radar transmitter/receiver control; radar antenna control; radar signal processor control; scan task scheduling; radar product generation; export to standard image and animation formats; level II product archiving and retrieval; flexible product generation and display; versatile network and data communications capability; and diagnostic and maintenance functions.		High
5.3.1.40	The radar system shall be able to output the following derived moments by automated or manual commands: total rain rate, corrected rain rate, liquid water content, radial shear, azimuthal shear, combined shear, and hourly or N-hourly rainfall accumulation.		High
5.3.1.41	The radar system shall be able to ingest environmental data (e.g., observations from rain gauges, sounding thermodynamic and wind information) necessary for various algorithms.		High
5.3.1.42	The radar system shall produce the radar-estimated precipitation products using a scientifically sound approach that adapts to seasonal and topographic effects.		High
5.3.2	Performance Requirements		
5.3.2.1	The radar system shall support PRFs from 250 to 2000 pulses per second.	Low PRF allows long range scans. High PRF allows high time resolution volume scans.	High
5.3.2.2	The radar system shall have an overall clutter rejection capability of > 45 dB.		High
5.3.2.3	The radar transmitter should provide a minimum of 350 kW peak RF power at the shortest (no greater than 0.4 microseconds) and longest (no less than 1.6 microseconds) pulse width.		High
5.3.2.4	The radar transmitter should provide no less than 750 kW peak RF power.		High
5.3.2.5	The radar system shall be able to operate continuously at least 98% of the time over a 10-year period.		High
5.3.2.6	The radar antenna shall have side lobe levels at least 27 dB lower than the main lobe with radome.		High
5.3.2.7	The pointing accuracy of the radar antenna shall be ±0.1 degrees or better in both azimuth and elevation.	Accurate geolocation of precipitation and wind.	High
5.3.2.8	The radar system shall isolate sidelobes resulting from horizontal and vertical polarization such that the cross-pole isolation is at least 26 dB.	Avoid spurious side-lobe echoes.	High
5.3.2.9	The radome shall have a cross-polarization isolation no less than 40 dB and a signal loss no		High

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	greater than 0.5 dB.		
5.3.2.10	The pedestal shall be able to rotate no less than 25 degrees per second in azimuth and elevation.	High time resolution in PPIs and volume scans	High
5.3.2.11	The radar system shall complete a full volume scan within 5 minutes. [Note: Full volume scan is defined as a complete sequence of successive antenna elevations (tilts) covering a three dimensional (3-D) volume].	High time resolution in 3 dimensional storm structure and retrieved winds form Doppler radar.	High
5.3.2.12	The radar system shall have a buffer of in-phase and quadrature time series data for the latest two hours continuously.		High
5.3.2.13	The radar structure shall be designed to withstand sustained winds of 60 m s–1 and wind gusts of 75 m s–1.	Maximizes facility lifetime.	High
5.3.2.14	The radar antenna system shall be designed to withstand the effects of random vibration on each of three perpendicular axes when in the stowed and secured position.		High
5.3.2.15	The radar structure shall be resistant to damage produced by exposure to salt in the atmosphere.	Longer equipment lifetime.	High
5.3.2.16	After exposure to heterotrophic plants in a warm, humid atmosphere, the radar antenna system shall operate as specified.		High
5.3.2.17	The transmitter shall be able to handle a duty cycle of 0.1%.		High
5.3.2.18	The radar transmitter should operate from single-phase 220 volts and three phase 208 V of alternating current (VAC) ±10% input power cycling at 50 or 60 Hz ±10%. It should also support a 200 amp and 100 amp service panel.		High
5.3.2.19	Operational outdoor equipment of the radar system shall function in ambient air temperatures of -15°C to +50°C and humidity of 10% to 100%.		Low
5.3.2.20	Non-operating outdoor equipment of the radar system shall function in ambient air temperatures of -15°C to +60°C and humidity of 10% to 100%.		Low
5.3.2.21	Operational indoor equipment of the radar system shall function in air temperatures of +5°C to +35°C) and humidity of 10% to 90%.		High
5.3.2.22	Non-operating indoor equipment of the radar system shall function in air temperatures of -15°C to +60°C and humidity of 10% to 90%.		Low
5.3.2.23	The radar system shall be warranted for at least two years after the final acceptance date of the system installation.		High
5.3.2.24	The radar system shall be protected from surges up to 2000 V and power spikes of 300% during one second. The UMD shall develop and follow procedures to ensure that the radar system is installed and maintained according to the system requirements.		High
5.3.2.25	The UNMA and the radar manufacturer shall conduct at least one complete survey of each radar's local electromagnetic environment to locate optimum radar operational frequency windows (i.e., ±10 MHz window) wherein the radar transmission and receiver frequency interference can be minimized while maintaining the system performance.		High

5.3.2.26	The UNMA shall obtain licenses for any software necessary to operate and maintain the radar system.		High
5.3.2.27	The UNMA shall ensure that radar system operators and maintenance personnel are trained properly before they are allowed to operate or maintain the system without supervision.		High
5.3.2.28	The UNMA shall ensure sufficient qualified manpower for maintaining the radar system.		High
5.3.2.29	The UNMA shall ensure that each radar tower and radome are inspected, cleaned, and/or painted at least once every 14 months.		High
5.3.2.30	The UNMA shall request sufficient funding to sustain, maintain, and continue to upgrade the radar system.		High
5.3.2.31	The UNMA shall obtain all documentation (e.g., drawings, technical documents, user guides) for hardware and software necessary to operate and maintain the radar system.		High
5.3.2.32	The UNMA shall establish a Data Quality Committee composed or radar engineers and radar meteorologist to monitor, maintain, and upgrade data quality. This committee shall meet no less often than four times a month.		High
5.3.2.33	The UNMA shall establish a Radar Operations Facility that will service each radar by maintaining configuration management, retrofit and upgrade system hardware and software as needed, to site each radar, and assure system maintenance. Other activities may be designated.		High
5.3.2.34	A radar system Hot Line shall be maintained 24/7 by the UNMA to assist meteorologist or engineers in the field with system malfunctions or unusual system detections or behavior.		Medium

#	Requirement	Comment	Priority
7	Organizational Recommendations		
7.2.1	Reorganize headquarters to promote efficient communications between engineering staff and observational and forecast staff so that maintenance needs are met swiftly, forecast and archive data is easily available to all staff, and forecasts are transmitted efficiently to the public.		
7.2.2	Set up hybrid national/regional forecast operations, with national operations at NMC supplemented by regional forecast offices in Soroti and Kasese with responsibility for particular forecast needs in their regions.		
7.2.2.5	Automate observations at all stations. Observer to shift their function from manual observations to calibration of instrumentation and analysis of observations.		

#	Requirement	Comment	Priority
8.1	Calibrated Model-Based Forecasting		
8.1.1	Automate system to acquire global NWP model forecasts grids for Uganda, and interpolate to synoptic and aws locations		
8.1.2	Automate system to compare interpolated model forecasts with ground truth, and generated calibrated forecasts		
8.2	Numerical Weather Prediction		
8.2.1	Computer system with at least 8 processor cores running at 3.5 GHz, 32 GB of memory, 5 TB storage	Ability to run WRF at better than 5 km resolution 72 hours into the future, 4x daily	Medium
8.2.2	Acquire WRF or other modeling software including data assimilation module, and training to implement model		

#	Requirement	Comment	Priority
8.4	Meteorological Workstations		
8.4.1	Interface		
8.4.1.1	Interface seamlessly with the UNMA Telecommunication System and the forecast system.		High
8.4.1.2	Functions that enable the user to view, explore, and print any of the systems data.		Medium
8.4.1.3	Allow personnel to access and integrate the following real-time and archived data sets: satellite, upper air, surface observations, marine data (Lake Victoria), NWP model data and output, geospatial data, volumetric radar base data, lightning data, and related products.		High
8.4.1.4	Automatically review, archive, and display any new or updated geospatial data sets as updates to data sets become available.		High
8.4.1.5	Automatically generate and disseminate products with all desired formatting, including the UNMA logo and other branding.		Medium
8.4.1.6	Support user-defined workspaces, including menus, color maps, macros, products, and tools.		High
8.4.1.7	Support Unicode for display of interfaces and graphics in different languages.		Medium
8.4.1.8	Display its menus, graphics, and interfaces on every computer on the UNMA network.		High
8.4.1.9	Able to integrate data from similar observing systems into a composite product.		High
8.4.1.10	Support more than 1 monitor.		Medium
8.4.1.11	Able to access any environmental data and products that reside in the UNMA Telecommunication System within five seconds for communications bandwidths of 100 megabit or greater and within 10 seconds for communications bandwidths of 10 megabit		High

	or greater.		
8.4.1.12	Able to export any product to the UNMA Telecommunication System within five seconds of issuance by UNMA personnel.		High
8.4.2	Display		
8.4.2.1	Display geo-referenced raster images, vector data (e.g., shape file).		High
8.4.2.2	Display in one, two, or three spatial dimensions and one time dimension.		High
8.4.2.3	Display symbols, including standard WMO/ICAO weather symbols.		High
8.4.2.4	Access and display data without compressing or filtering the data in a way that reduces accuracy or resolution.		High
8.4.2.5	Plot text, vectors, station models, lines, line contours, polygons, and color-filled, color-shaded, and grayscale gradients, maps, meteograms (e.g., time series of weather data), graphs with user-defined or default axes, vertical cross sections and time cross sections of any gridded data available in two or more dimensions, thermodynamic soundings of data from multiple sources, including model, satellite, and upper air data, one or more hodographs from data from multiple sources, including model, radar, and upper air data.		High
8.4.2.6	Display of user-customizable graphical elements, including annotation of maps and graphs.		High
8.4.2.7	Support automated boundary detection to display kinematic features, storm outflows, and other boundaries.		Medium
8.4.2.8	Support user-defined formats for displaying the date and time (e.g., YYYY-DD-MM, MM/DD/YYYY, and HH:MM:SS).		High
8.4.2.9	Support a display window for system status updates (e.g., to display data loading, issuance of products).		High
8.4.2.10	Able to display geographic overlays such as political boundaries, topography, bathymetry (Lake Victoria), land use, transportation networks, populated areas, hydrological features, and significant facilities.		High
8.4.2.11	Able to display legends, including time, units, a scale bar, and a compass.		High
8.4.2.12	Display time trends of algorithm output for a given thunderstorm.		High
8.4.2.13	Support the simultaneous display of the full volume scan (i.e., all tilts) of radar data.		
8.4.3	User Defined Functions		
8.4.3.1	Fill closed regions with colors, textures, or patterns (e.g., hatching).		Medium
8.4.3.2	Allow observational data to be viewed in tabular form using database queries.		Medium
8.4.3.3	Transform between coordinate systems (i.e., display different map projections with associated datum).		High
8.4.3.4	Able to animate sequences in time.		High
8.4.3.5	Overlay data from multiple sources on a single,		High

	layered map.		
8.4.3.6	Select products by point location, station name, geographical area, variable(s), time, and range of times.		High
8.4.3.7	Able to generate derived fields and products.		High
8.4.3.8	Support interactive, user-defined display functions such as zoom in, zoom out, zoom to an area of interest, and pan.		High
8.4.3.9	Support visual and auditory alerts based on user-defined criteria (e.g., exceedance of threshold).		High
8.4.3.10	Support layer-defined transparency (opacity).		
8.4.3.11	Support user-defined layering with reordering.		
8.4.3.12	Support hiding/showing (toggling on/off) one or more graphic layers.		High
8.4.3.13	Support user-defined progressive disclosure of data (e.g., more observations appear as the user zooms in).		High
8.4.3.14	Allow the user to change the shape and type of boundaries created by the automated boundary detection routine.		Medium
8.4.3.15	Support user-customizable color palettes and both user-customizable and default palettes and symbols.		
8.4.3.16	Permit the user to adjust font sizes or text magnification settings.		
8.4.3.17	Support user-defined default display settings.		Medium
8.4.3.18	Able to be customized to display user-defined ranges of data (e.g., minimum thresholds of decibels of reflectivity [dBZ] to be displayed on radar data).		
8.4.3.19	Support multiple, linked panels (e.g., four-panel display with a cursor tracking consistently in all four panels) within a single window.		
8.4.4	Algorithm Support		
8.4.4.1	Able to compute and display standard severe weather parameters associated with upper air data (e.g., Total Totals, Severe Weather Threat [SWEAT], Showalter and K indices, convective available potential energy [CAPE], convective inhibition [CIN]).		High
8.4.4.2	Able to compute and display newer severe weather parameters including 0 to 1 km shear and helicity, 3 km shear and helicity, deep layer shear, energy helicity (EHI) index, Maximum parcel CAPE, Mixed layer CAPE, Surface based CAPE, deformation, and frontogenesis when necessary.		High
8.4.4.3	Support BUFKIT analysis.		Medium
8.4.4.4	Allow the user to manually adjust environmental data and calculate new values of standard severe weather parameters (e.g., Total Totals, SWEAT, Showalter and K indices, CAPE, CIN).		High
8.4.4.5	UMADS shall be able to convert units of all variables between metric International System of Units (SI), and other systems of measurement.		

8.4.4.6	Able to automatically compare two sets of point data representing a single variable (e.g., rainfall observations compared to flash flood guidance).		High
8.4.4.7	Able to objectively analyze data using different objective analysis techniques, including, at a minimum, Barnes, Cressman, optimal interpolation, and kriging with user-defined coefficients.		High
8.4.4.8	Able to aggregate radar precipitation estimates at various basin scales and compare (e.g., ratio and difference) of these QPEs to a human-produced flash flood guidance product.		High
8.4.5	System		
8.4.5.1	Able to remain operable when the amount of Random access memory (RAM) or disk space is exceeded.		High
8.4.5.2	Support the automatic generation of products on a schedule.		High
8.4.5.3	Display warnings to the user when available RAM or disk space becomes insufficient to continue normal operations.		High
8.4.5.4	Able to prioritize layers for closure to prevent the system crashing.		High
8.4.5.5	Automatically recall lost data and products after a crash.		High
8.4.5.6	Able to confine a layer to a shape (e.g., clip color gradient to country border).		Medium
8.4.5.7	Able to export images and animations in multiple formats, including web-ready formats.		High
8.4.5.8	Upgradable without major inconvenience or downtime to the user.		High
8.4.5.9	Able to save current user-created data sets and layers active for future use.		Medium
8.4.5.10	Able to generate and display a custom graphic within 20 seconds.		Medium
8.4.5.11	Support a minimum of 8-bit color and 8-bit grayscale.		High
8.4.5.12	Support 32-bit color and 32-bit grayscale with an alpha channel.		High
8.4.5.13	Support a minimum of six windows on a single screen.		Medium
8.4.5.14	Support an unlimited number of windows.		Medium
8.4.5.15	Require no more than 16 GB RAM to operate.		High
8.4.5.16	Require no more than 2 each 12 MB video dynamic Random access memory (VRAM) to operate.		High
8.4.5.17	Require no more than a 2.50 15MB GHz processor to operate.		Medium
8.4.5.18	Compatible with Unix-based and Windows-based platforms.		High
8.4.6	UNMA Requirements for operating and managing the UMADS		
8.4.6.1			
8.4.6.2	Provide its meteorological, climatological, research, and supervisory personnel with computer resources necessary to use UMADS according to its performance requirements.		High
8.4.6.3	Ensure that upgrades to UMADS do not		High

	compromise the 24x7x52 operations of the forecast offices.		
8.4.6.4	Obtain licenses for any software if necessary to operate and maintain UMADS.		Medium
8.4.6.5	Obtain all documentation (e.g., drawings, technical documents, user guides) for hardware and software necessary to operate and maintain UMADS.		High
8.4.6.6	Request sufficient funding to sustain and continue to upgrade UMADS.		High
8.4.6.7	Provide its personnel with the training necessary to use UMADS according to its functional requirements.		High

#	Requirement	Comment	Priority
8.5	Telecommunications		
8.5.1	Acquire optical fiber connectivity from leading data service providers (e.g. Orange, MTN) and install at UNMA HQ, all radar sites, Entebbe NMC, Entebbe Airforce Base, Gulu, and Soroti		High
8.5.2	In collaboration with Water Resource Management Department (WRMD), extend optical fiber connectivity from Entebbe Airport to WRMD to facilitate sharing of weather data including radar data for flood forecasting functions on real-time basis		High
8.5.3	Acquire 3G internet connectivity from leading data service providers (e.g. Orange, MTN) and install at all MET locations and collaborating institutions		High
8.5.4	Secure clean electricity supply at all MET locations		High
8.6	Physical Plant		
8.6.1	Land and Building		
8.6.2	Acquire land and construct new offices for UNMA HQ in Kampala or Entebbe -- to house administration, climate prediction center, public weather, agro-meteorological services, hydro-meteorological services, disaster management and IT infrastructure		High
8.6.3	Rehabilitate NMC, Pilot Briefing office, and the synoptic station at Entebbe Airport		High
8.6.4	Rehabilitate the forecast office at Soroti		Medium
8.6.5	Construct new offices at all synoptic stations and at the upper air station at Entebbe Old Airport, with the exception of Soroti and Entebbe Airport where rehabilitation is preferred		Medium
8.6.6	Acquire land and construct new offices, accommodation for staff, security, and access		High

	roads at all radar sites		
8.6.7	Acquire land and construct new offices, accommodation for staff, and access roads at all hydro- meteorological stations (second phase)		Medium
8.6.8	In collaboration with host institutions, rehabilitate offices, accommodation for staff, and access roads at all agro-meteorological stations		Medium

15 CONCLUSION

In this document we have laid out our recommendations for the modernization of the Uganda Department of Meteorology during and after its transition to the Uganda National Meteorological Authority, including improvements to its observing system infrastructure, its forecast methodologies and equipment, its computational resources, its communications capacities and its physical plant.

The Uganda Department of Meteorology has a long and distinguished history. From 1967 to 1977, weather forecasting and climate data services in Uganda were provided by the East African Meteorological Department. During that time, relatively strong investment in meteorological services supported a staff of about 300, and the maintenance a modern system synoptic observation systems, including radiosonde observations and weather radar at Entebbe. The Uganda Department of Meteorology was founded in 1977 after the break-up of the first East African Community. During three tumultuous decades of Ugandan history, many meteorological staff heroically maintained the integrity of the observational records, and the performance of forecasting observations despite extremely challenging circumstances of war, unrest and disease. However, budgets available during this period did not allow for the investments required to maintain the infrastructure necessary for these functions, or to maintain the size and training levels of staff to perform them.

In recent years, the Department has worked hard to re-establish itself as a modern meteorological service. It has commissioned this study, and, through passage of the Meteorology Law of 2012, the government of Uganda has recognized the need for increased autonomy and regular funding for a new Uganda National Meteorological Authority. In our travels through Uganda, the MDA team was continuously impressed by the dedication and skill of Department of Meteorology staff, whose hard work and talent are the prerequisite for the success of the new Authority. We expect that access to improved electronic communication within Uganda to between Uganda and the rest of the world will, as a first step, provide immediate benefits as meteorological staff are able to apply their skill to a much fuller array of data resources. We are convinced that investment by the Government of Uganda and the international community in improved communications, in remote sensing by lightning detection and radar, in computational power and in advanced staff training will be paid back multiple times in economic and social benefits for the people of Uganda.

16 REFERENCES

J. G. Acker and G. Leptoukh, 2007: Online Analysis Enhances Use of NASA Earth Science Data. *Eos,* Trans. AGU, **Vol. 88, No. 2** (9 January 2007), pp. 14 and 17.

Allen, D. J., and K. E. Pickering, Evaluation of lightning flash rate parameterizations for use in a global chemical transport model, *J. Geophys. Res.*, *107*(D23), 4711, doi:10.1029/2002JD002066, 2002.

Aura, S., 2009: Pilot Project on Evaluation of Socio-Economic Benefits of Meteorological Information and Services in Kenya - The Agriculture Sector. Presented at the International Workshop on Assessment of Socio-Economic Benefits of Meteorological & Hydrological Services, Nanjing China, 21 - 28 September 2009.

Chakraborty, Arindam, 2010: The Skill of ECMWF Medium-Range Forecasts during the Year of Tropical Convection 2008. *Mon. Wea. Rev.*, **138**:3787–3805.
doi: http://dx.doi.org/10.1175/2010MWR3217.1

DoM Staff, 2012: Business Plan for Uganda National Meteorological Authority (UNMA), Ministry of Water and Environment, Kampala, Uganda, 28 pp.

Douglas, M., J. Mejia, R. Orozco, J. Murillo, 2008: Suggestions for upgrading the pilot balloon network in West Africa and elsewhere in the tropics. NOAA National Severe Storms Laboratory. http://www.nssl.noaa.gov/projects/pacs/web/PREPRINTS/2008_TECO_pibalafrica.pdf

Faccani, C., and Coauthors, 2009: The Impacts of AMMA Radiosonde Data on the French Global Assimilation and Forecast System. *Wea. Forecasting*, **24**:1268–1286.
doi: http://dx.doi.org/10.1175/2009WAF2222237.1

Freebairn, J.W. and J.W. Zillman, 2002: Economic benefits of meteorological services. Meteorol. Appl., 9, 33-44.Funk, C., Rowland, J., Eilerts, G., and White, L., 2012a: A Climate Trend Analysis of Uganda, U.S. Geological Survey Fact Sheet 2012–3062, 4 p.

Funk, C, Michaelsen, J., and Marshall, M., 2012b: Mapping recent decadal climate variations in precipitation and temperature across eastern Africa and the Sahel, chap. 14 *of* Remote Sensing of Drought: Innovative Monitoring Approaches, *ftp://chg.geog. ucsb.edu/pub/pubs/mapping_decadal_variations.pdf.*

Gatlin, P.N., and S.J. Goodman, 2010: A total lightning trending algorithm to identify severe thunderstorms. *J. Atmos. Ocean. Tech.,* 27:3. DOI: 10.1175/2009JTECHA1286.1

Gunasekera, D., 2003: Measuring the Economic Value of Meteorological Information. WMO Bulletin 52(4):366 - 73.

Gunasekera, D., 2004: Economic Issues Relating to Meteorological Services Provision. BMRC Research Report No. 102, Bureau of Meteorology, Australia.

Kakuru, K., R.O. Musoke, I. Kyajuwaire, 2001: A guide to the environmental impact assessment process in Uganda. *Greenwatch, Sustainable Development Series No. 1.* http://www.greenwatch.or.ug/pdf/news/publications/Guide_to_the_Environment_Impact_Assessment_Process-Issue1.pdf

NEMA, 2011: NEMA News, **10:**1, September 2011, available at http://www.nemaug.org/newsletter/newsletter_Sept_2011.pdf

ICAO, 2001: AFI Air Navigation Plan: Volume 1, Basic Air Navigation Plan (ANP), Document 7474, ICAO, Montreal, Canada.

ICAO, 2001: AFI Air Navigation Plan: Volume 2, Facilities and Services Implementation Document (FASID), Document 7474, ICAO, Montreal, Canada.

ICAO, 2010: Annex 3 to the Convention on International Civil Aviation: Meteorological Service for International Air Navigation (Seventeenth Edition) ICAO, Montreal, Canada, loose-leaf.

ICAO, 2005: Annex 9 to the Convention on International Civil Aviation: Facilitation (Twelfth Edition), ICAO, Montreal, Canada, loose-leaf.

ICAO, 2004: Annex 15 to the Convention on International Civil Aviation: Aeronautical Information Services (Twelfth Edition), ICAO, Montreal, Canada, loose-leaf.

ICAO, 2004: Handbook on the International Airways Volcano Watch (IAVW): Operational Procedures and Contact List (2nd Edition), DOC 9766-AN/968, Montreal, Canada, 98 pp.

IPCC, 2007: Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning,

Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

ICAO, 2010: Meteorological Services for International Air Navigation. 17th Edn., Part I and II.

Jarraud, M., 2007: Statement at the Opening of the international conference, "Secure and Sustainable Living: Social and Economic Benefits of Weather, Climate and Water Resources," Madrid, March 19 - 22.

Katz, R.W. and A.H. Murphy (Ed.), 1997: Economic Value of Weather and Climate Forecasts. Cambridge University Press, 217 pp.

Lin, S., S. Vasic, A. Kilambi, B. Turner, I. Zawadzki, 2005: Precipitation forecast skill of numerical weather prediction models and radar nowcasts. *Geophys. Res. Lets.,* **32**:L14801.

Mary, A.K., and C. Gomes, 2012: Lightning accidents in Uganda. *Lightning Protection (ICLP), 2012 International Conference on,* doi:10.1109/ICLP.2012.6344235

Luganda, P., 2012: SMS weather alerts boost safety for Lake Victoria boatmen. AlertNet, http://www.trust.org/alertnet/news/sms-weather-alerts-boost-safety-for-lake-victoria-boatmen .

Muchinda M., 2005: Report on the COMESA DRAFT STRATEGIC METEOROLOGICAL PRORAMME, COMESA Technical Report, Nairobi, Kenya, 44 pp.

Edyegu, D., and P. Watala, 2012: Bududa landslide: Hope of finding survivors fades. *New Vision,* June 27, 2012. http://www.newvision.co.ug/news/632386-bududa-landslide-hope-of-finding-survivors-fades.html .

Odong, J. and F. Osujo, 2012: Floods: Soroti-Mbale road close. *New Vision,* Sept. 3, 2012. http://www.newvision.co.ug/news/634841-Floods--Soroti-Mbale-road-closed.html .

Peel, M. C., Finlayson, B. L., and McMahon, T. A., 2007: Updated world map of the Köppen-Geiger climate classification, *Hydrol. Earth Syst. Sci.*, **11**:1633-1644, doi:10.5194/hess-11-1633-2007 .

Pope, C.A., M. Ezzati, D.W. Dockery, 2009: Fine-particulate air pollution and life-expectancy in the United States. *N. Engl. J. Med.,* **360**:376-386.

Regional Association I (Africa), Fifteenth session, Marrakech, 1–8 November 2010, Abridged final report with resolutions, WMO-No. 1068.

Samuelson P.A., 1954: The Pure Theory of Public Expenditure, The Review of Economics and Statistics, Vol. 36, No. 4. (Nov., 1954), pp. 387 - 389.

Shively, G.E. and J. Hao, 2012: A review of agriculture, food security and human nutrition issues in Uganda. Working paper #12-3, Purdue University Department of Agricultural Economics. Available at http://purl.umn.edu/135134

Stark, J., 2011, Climate change and conflict in Uganda: The cattle corridor and Karamoja: USAID Office of Conflict Management and Mitigation, Discussion paper No. 3. Accessed September 10, 2011, available at http://www.fess-global.org/Publications/Other/Climate_Change_and_Conflic_%20in_Uganda.pdf .

Weiher, R., L. Houston, and R. Adams, 2007: Socio-Economic Benefits of Climatological Services. Contribution to WMO Working Group Meeting on Socio-Economic Benefits of Climatological Services.

World Meteorological Organization, 1993: Technical Regulations (WMO–No 49), Volume I: General Meteorological Standards and Recommended Practices (1988 Edition, Supplements through 1993), WMO, Geneva, Switzerland, loose leaf.

WMO (World Meteorological Organization), 1995: The Socio-economic benefits of Climate Forecasts: Literature Review and Recommendations. WMO/TD-No. 674, prepared by GCOS Working Group on Socio-economic Benefits.

World Meteorological Organization, 1996: Guide to Meteorological Instruments and Methods of Observations (WMO–No 8, Sixth Edition), WMO, Geneva, Switzerland, loose leaf.

World Meteorological Organization, 2001: Technical Regulations (WMO–No 49), Volume II: Meteorological Service for International Air Navigation (2001 Edition), WMO, Geneva, Switzerland, loose leaf.

World Meteorological Organization, 2002: Guide to the GCOS Surface and Upper-air Networks: GSN and GUAN, GCOS-73 (WMO/TD No. 1106), WMO, Geneva

World Meteorological Organization, 2001, No. 258, Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology Volume 1: Meteorology, WMO Geneva, Switzerland, 121 pp.

WMO (World Meteorological Organization), 2001b: Responses to the Questionnaire on the Role and Operation of NMSs. Preliminary Analysis.

World Meteorological Organization, 2008: Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8., Seventh edition.

World Bank, 2008: World Bank Working Paper No. 151, Weather and Climate Services in Europe and Central Asia - A Regional Review.

World Meteorological Organization, 2012: Final Report, Workshop on Aircraft Observing System Data Management. Geneva, Switzerland, 2012. Available at: http://www.wmo.int/amdar/Reports/Aircraft_Observations_Data_Management_Workshop_June_2012_Final_Report.pdf

Xu X., 2007: Report on Surveying and Evaluating Benefits of China's Meteorological Service. China Meteorological Administration, Beijing, China.

Zillman, J.W. and J.W. Freebairn, 2001: Economic framework for the provision of meteorological services. WMO Bulletin, 50, 206-215.

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