Executive Summary
Atmospheric Observations Feasibility Study

Team members reviewed surface and upper air installations near Lake Victoria and the region, spoke with meteorological staffs of the three shore-side countries, and talked with several people supporting the fishery industry at the Lake Victoria Basin Commission. The team considered numerous instrumentation systems both atmospheric and hydrological in the context of the Consolidated Terms of Reference: to evaluate the status and needs for safe use of Lake Victoria, to support the long-term use of its natural resources, and protect the water and air quality over the basin. We also considered infrastructure needs for the fishing industry, shipping, and transportation users of the lake and how they could best receive and use weather information to advert dangerous encounters with the active weather often found over the lake.

During the course of our review, we gave a priority to meteorological systems that could yield a high-value in supplying short-term forecasts (nowcasts) to Lake Victoria users. This was our underlying evaluation. Length of time for implementation, cost, and what the shoreline governments were already considering, also had strong influences in our recommendations. In the final evaluation several systems, due either the low value to the overall goals or the complexity of developing useable results in a short time period, did not make the final list of considerations. Such systems not included are satellite data handling (too costly and little gain from current capability) and new GPS radiosonde systems (to high of a daily operational cost).

In spite of our limited time in the region, we made a number of important findings toward supporting several viable nowcasting processes and risk reducing measures for users on the lake. These findings relate to how the lake is used, the frequencies and locations of storms in the region, the current plans of the coastal countries, and the existing infrastructure to enable a successful weather warning system over a large inland water body. Three key technologies applied across the lake could enhance the safety of operations for all users: 1) navigational aids; 2) cellular warning systems that focus on nowcasting of storm movement and intensity; and 3) radar coverage across the lake.

Navigational aids (lights and beacons) on lake islands and key costal points would support the boat and ship traffic during periods of storm activity. For fishermen in the lighter and smaller boats, enhancing their ability to safely navigate the lake on a stormy night is one of the quickest and least expensive methods of aid. Additionally, knowing where the leeward side of a lake island is could protect the boaters from longer fetch storm driven waves on the lake.

Implementation of cellular warning system similar to the system Uganda is developing is important. Cellular technology already has widespread use in the area and is the least costly technology for implementation. The system needs to move from its current forecast role to a nowcasting role where it can deliver storm location with respect to the lake and project storm movement. Already, Tanzania and Kenya have plans to place radars that can provide nowcasting advances to the boats and ships on the lake. Complete radar coverage across the lake can deliver warnings and information on the timing, movement, and intensity of storm cells on and nearby shore. Current plans only cover about a third of the lake adequately. More radar units will be needed to complete adequate coverage over the lake.

Atmospheric Observations Feasibility Study – Final Report

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I) Introduction

The meteorological agencies in the East African countries issue forecasts to protect the safety of citizens on and around Lake Victoria. These efforts are directly in line with the Lake Victoria Basin Commission's goal to enhance the safety of users of the lake. In our initial project proposal we discussed nowcasts, or short-term forecasts, as a way to achieve these goals. Nowcasts can be used to warn citizens on the lake of approaching storms and give them enough lead-time to take precautionary actions. The ability to nowcast is currently limited by the lack of information about weather conditions directly over the lake. Without sufficient information about current conditions, the forecasters have no opportunity to convert the broader daily forecasts into useable warnings about specific storms. In our proposal we aimed to improve the quantity and quality of weather data collected over and around the lake by recommending new sensors which could be deployed. Our tasks, as outlined in the initial proposal, were threefold:

1) Develop a summary of precipitation characteristics over Lake Victoria
2) Understand how the current observation networks are used operationally to make daily weather forecasts
3) Develop recommendations for new sensors to deploy to improve the nowcasting capabilities of the meteorological services in the region and improve the navigational safety of the users of the lake

These three tasks dealt directly with Consolidated Terms of Reference (CTOR) one, two, and three:

CTOR-1: Develop a plan for skillful guidance for early warning alerts, search and rescue, and continuous post-disaster evaluation (e.g. loses and need assessment), for safety and resource utilization (including severe weather and hazardous marine conditions)

CTOR-2: Develop a plan for the production of hotspot maps of lake hazards & high quality meteorological information and services to support the exploitation of natural resources (e.g. transportation, energy, health, agriculture, tourism, water resources, resource sharing and conflict early warning, etc.).

CTOR-3: Develop a plan for a marine and atmospheric observational network and water/air-quality to support activities in (i) and (ii).

The first two of our tasks served to inform our recommendations in the third task. We could not make meaningful recommendations without learning about the specific challenges the agencies are facing and how they are dealing with them with the data they currently have. To this end, the visits to the meteorological agencies in Kenya, Uganda, and Tanzania were very useful in helping us earn about the state of forecasting in the East African Community. We are deeply indebted to the many individuals who had very open and informative conversations with us during our visit. In this final report, we will first address the nature of precipitation occurring over the lake, including a discussion of specific severe weather threats which directly lead to hazards over the lake. We will then briefly summarize the status of the current observation network and how it is being utilized in each of the three countries. Finally, this report will end with an in depth discussion of our recommendations for improving upon the current observation network.

II) Precipitation Characteristics Over Lake Victoria

A) Methods

In order to analyze the spatial and temporal variability of rainfall that occurs over the Lake Victoria Basin, we have developed a high spatial resolution precipitation climatology utilizing the U.S. National Aeronautic and Space Administration (NASA) Tropical Rainfall Measuring Mission (TRMM) satellite's scanning precipitation radar (PR). The TRMM PR allows us to view precipitation across a large domain using the same instrument, providing a consistent analysis for each of the countries involved. We compiled ten (1998-2007) years of PR data onto a 5 km x 5 km regular grid for the domain spanning 10°S to 10°N and 25°E to 45°E. From the gridded product we are able to assess precipitation frequency and intensity across the diurnal cycle. In addition to radar reflectivity, another measure of storm intensity can be formulated using the TRMM satellite's Lightning Imaging Sensor (LIS) which detects the presence of lightning within storms viewed by the satellite. The presence of lightning is a rough proxy for storm intensity because it often occurs in regions of strong vertical motion within deep tropical convection over land.

B) General Precipitation Climatology

The multi-year climatology demonstrates that the precipitation occurring over the Lake Victoria Basin is dynamically complex and fascinating. Breaking the data into three hour intervals across the diurnal cycle allows us to see the effect of the land-lake breeze which forms as a result of differential heating between the lake and the surrounding continent. During the day, the land heats up faster than the water eventually generating a pressure gradient which forces an onshore wind (from the lake onto the land). At night the pattern is reversed as the land cools much more rapidly and the flow becomes offshore (from the land onto the lake). The diurnal cycle of precipitation frequency, shown in Figure 1, clearly demonstrates that the land-lake breeze interacts with the easterly trade-winds in a predictable, but interesting fashion. During the day, the onshore flow is convergent with the trade winds on the eastern side of the lake, resulting in a lifting mechanism in the convergence zone and enhanced precipitation frequency on the eastern shore. On the western side of the lake the offshore breeze is in the same easterly direction as the trade winds, resulting in divergent motion on the western shore and reduced precipitation frequency there. At night the pattern is reversed and the offshore flow is divergent on the eastern side of the lake and convergent on the western side, resulting in enhanced precipitation over the western portion of the lake.

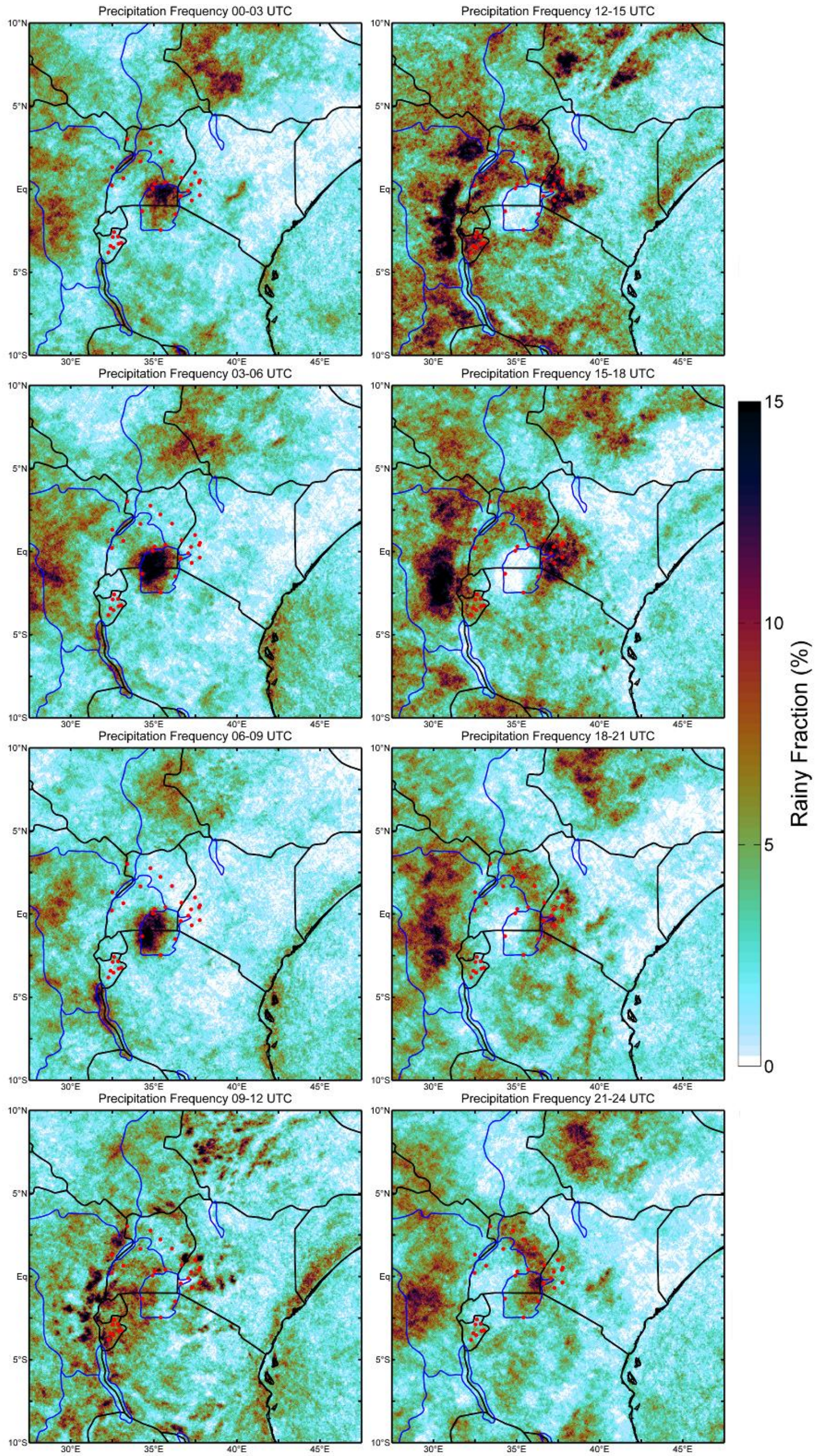

Fig. 1: The distribution of precipitation frequency in three-hour time blocks across the diurnal cycle. The frequency plots are overlaid on a map of the surface observation sites in the East African countries.

This complex interaction between the land-lake breeze and the easterly trade winds seems to be a major controlling factor in the temporal and spatial variability of precipitation over the basin. Combining these simple dynamics with the orographic enhancement of precipitation in the eastern Kenyan highlands yields nearly a complete view of the precipitation mechanisms. The remaining precipitation is likely convection that results from the strong daytime heating on the land. It is our hope that the climatology of precipitation frequency generated in our analysis can be used to validate long term modeling efforts over Lake Victoria. Correctly forecasting the change from onshore to offshore winds is a critical step toward obtaining accurate precipitation forecast for the regions around and over the lake.

C) Specific Severe Weather Threats

In order to improve the nowcasting capabilities of the meteorological agencies protecting the lake, we must first understand their major areas of concern. Analysis of the precipitating storms over the Lake Victoria Basin shows that a large majority of the storms are quite intense. Severe thunderstorms constitute a persistent and important threat to public safety. Typical convective storms are deep (> 6 km) and intense, with the mode of surface reflectivity being greater than 35 dBZ (rain rate > 50 mm hr^{-1}). The distribution of maximum near surface reflectivity observed by the TRMM PR, shown in Figure 2, is evidence of the intensity of precipitation reaching the surface. In Figure 3 we show that the storms occurring around the lake often have reflectivity greater than 40 dBZ at heights well over 6 km. This is a clear indicator that the storms are often producing large graupel or hail.

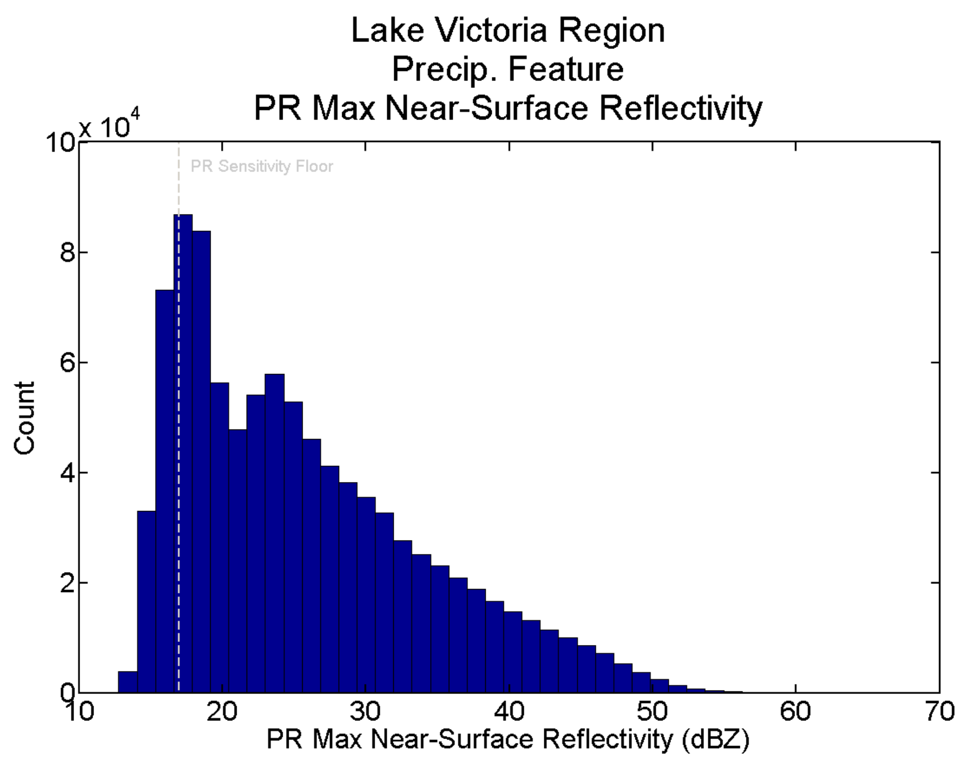

Fig. 2: Distribution of the maximum near surface reflectivity observed by the TRMM PR in the Lake Victoria region.

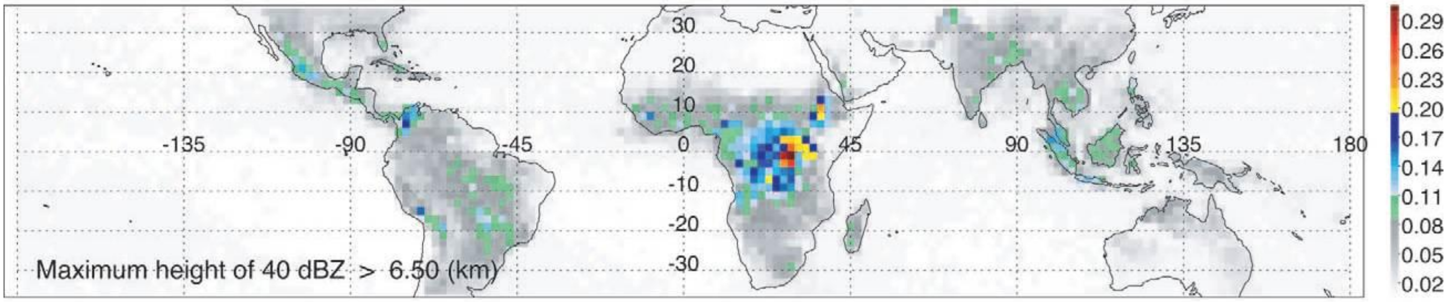

Fig. 3: Frequency of 40 dBZ echoes occurring higher than 6.5 km observed by the TRMM satellite. (From Zipser et al. 2006)

Our analysis also shows that the storms are often fairly small in area and that individual storms are rarely part of a larger synoptically organized disturbance. This systemic disorganization is consistent with weak synoptic forcing throughout the equatorial tropics. Two specific forecasting challenges were discussed in our meetings with the meteorological agencies in the East African Community – flooding in the region immediately east of Lake Victoria as well as the damaging impact of hail on the tea leaf crops that are grown in eastern Kenya. The storms associated with these threats were described as slow moving because of the relatively weak trade winds in the region. As a result, the cumulative rainfall produced during the lifetime of the storm can fall in a very small area and produce flash flooding. Additionally, forecasters are concerned with lightning produced from intense thunderstorms. An analysis of global lightning frequency, shown in Figure 4, shows that the equatorial African region encompassing Lake Victoria has the highest density of lightning in the world. Lightning is a serious threat to life and property, particularly for boaters on the open waters of the lake.

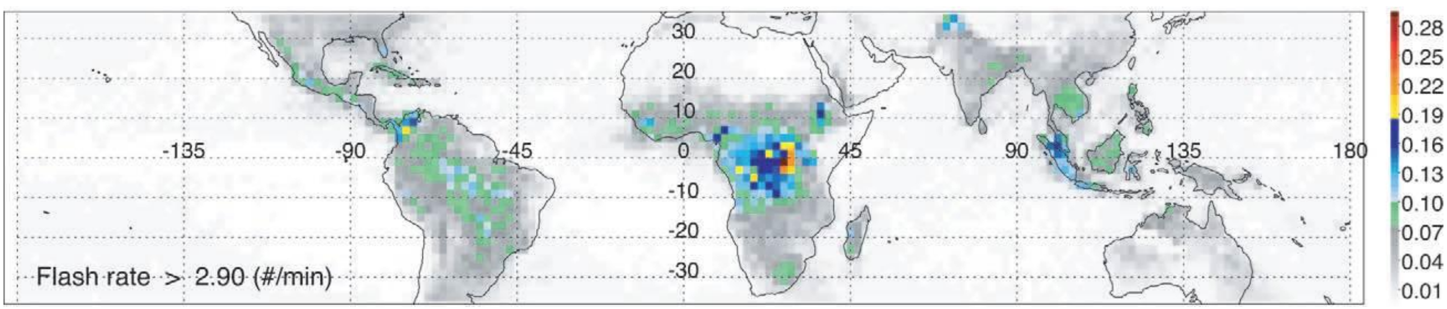

Fig. 4: Global distribution of lightning strikes observed by the TRMM satellite. (From Zipser et al. 2006)

During the stakeholders workshop held in Kisumu, Kenya on July 18th and 19th we had the opportunity to talk in depth with representatives of the fishermen on Lake Victoria about their specific severe weather concerns. First and foremost, they are worried about high winds occurring over the lake which can result in waves large enough to capsize the relatively small fishing boats they use. Most of the severe and threatening instances of high winds over the lake occur in the vicinity of severe thunderstorms. Improving the prediction and training capabilities for severe thunderstorms would thus improve warnings to fishermen that high winds and large waves are more or less likely on a given day.

III) Utilization of the Current Observational Network

A) Atmospheric Observations Currently Collected

The meteorological agencies in each country provided us with detailed information on what types of sensors they have currently operating and how they are used. The locations of individual surface meteorological observation sites are shown below in Figure 5. The stations are plotted on top of a geographic map of elevation in the larger East African Community. Most of the surface sites are able to record temperature, pressure, relative humidity, and precipitation amounts. The observations are transmitted to the central forecasting offices in intervals between fifteen minutes and one hour, meaning that the forecasters have surface observation data available in near real-time. The surface data are shared between countries in real-time providing valuable information about the regional surface characteristics to each individual forecast desk. This is done largely to support aviation forecasting for planes coming into and out of the East African countries. In all of the sites we were able to visit, the data collected were high quality. The instruments were well-maintained and frequently serviced and calibrated by technicians from each of the meteorological agencies.

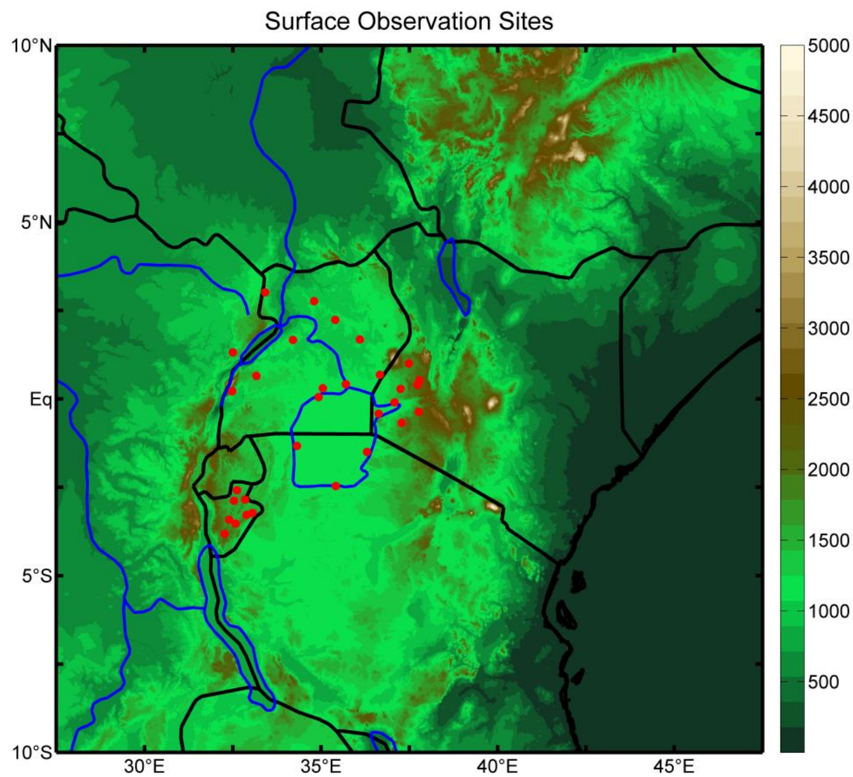

Fig. 5: The location of surface observation sites, indicated by red dots, overlaid on a map of elevation (in meters) for the East African region.

B) Weather Forecasting Using the Current Observational Network

Surface observations are plotted and analyzed by forecasters in each country to identify surface features such as temperature or pressure boundaries. Regions of convergence or divergence, surface instability, and enhanced surface moisture are analyzed throughout the day. The likelihood of severe storms within a given region is then incorporated into the 24-hour and 4-day forecasts made daily by each central office. In addition to being used in a nowcasting or forecasting sense, the surface observations are stored and used to validate the 3-month seasonal forecast products issued for each of the individual countries. Comparisons between observed and predicted rainfall are used to improve future seasonal outlooks. The surface data are archived alongside a large set of volunteer observation data which record 24-hour temperature and precipitation observations. These long-term data sets provide a critical climate data record which will be essential for correctly interpreting future changes to the East African climate system.

The final daily forecast in each country is largely based on the analysis of output from a handful of regional mesoscale models which are run daily in Nairobi and Dar es Salaam. These numerical weather prediction systems are initialized using the analyzed output from global models such as the Global Forecast System (GFS) or the European Centre for Medium-Range Weather Forecasts (ECMWF). Numerical models can provide useful guidance for forecasters concerned with severe storms, but their usefulness is conditioned on their ability to interpret the current weather scenarios and integrate the patterns forward in time. In the future, mesoscale models for the basin region would be well served to utilize the surface data being collected to improve the initial conditions in the model. Additionally, any future radar or buoy data collected could be assimilated into the models to improve their predictive capabilities. We discuss these possibilities in detail in our recommendations section.

In each of the three countries we visited the forecasts are being generated and disseminated once daily, typically in the morning (before noon). In some cases individual forecasts are made for a specific city or generalized region, but on the whole the forecasts are the same for large sections of each country. This could be due in part to the limited amount of new weather information that could be used to fine-tune the daily forecast for a given city. The forecasts are disseminated to the public mainly through common media channels. These include television, radio, and newspapers. Several of the forecasters we talked to discussed that radio was the most likely method by which citizens and end-users of the forecast were able to hear the daily forecasts.

IV) Recommendations to Enhance Safety on Lake Victoria

A) Introduction and Our Primary Recommendations

Our final task was to recommend additional sensors and activities that would aid in improving short term forecasts (nowcasts) over Lake Victoria. In order to provide an accurate nowcast and warnings to lake users, forecasters in each of the countries need three essential pieces of information: the location of severe storms occurring over the lake, the speed and direction that the storms are moving, and an estimate of the intensity of the storms in order to gauge how much risk they pose to citizens on the lake. Once the forecasters have this information they need the capability to communicate these threats to users on the lake in a reasonable amount of time. Below is a list of possible options which we believe would give forecasters these critical pieces of information, positively enhancing current forecast abilities and providing the capability to issue useable nowcasts. In addition to recommending specific instruments, we also make a handful of broad recommendations which we believe will positively enhance the services provided by the meteorological departments around Lake Victoria.

Our overall number one recommendation is that the full support and resources of the Lake Victoria Basin Commission, and any other agencies concerned with safety over Lake Victoria, be directed toward finalizing the installation of the two scanning weather radars in Eldoret, Kenya and Mwanza, Tanzania. Scanning weather radars provide forecasters with a real-time spatially coherent view of storms within their forecast domains. Radar information can be used to determine the size and intensity of storms, which direction they are moving, and whether the storm is strengthening or weakening. Relationships between the radar return and the rain rate at the surface provide estimates of how much rain is falling or has fallen in a particular area. These features make weather radars an extremely valuable tool for forecasters concerned with intense precipitating storms such as those that commonly threaten the safety of fishermen on Lake Victoria. Weather radars can provide real-time areal coverage of developing storms which can cause flash flooding and hail. Areas of intense precipitation and hail can be quickly identified by the radar, allowing the forecasters to issue warnings for where these storms are going with useable lead times.

The East African nations recognize the power of weather radars and have plans to incorporate them into their weather observation networks around Lake Victoria. In Kenya, there are radars in place in Nairobi and Mombasa. While these two radars are no longer operational, the Kenya Meteorological Department is hopeful to bring them back online in the near future. With regards to the Lake Victoria region, the Kenyans have plans to place a S-band scanning weather radar at the Eldoret International Airport, located approximately 100 km northeast of the lake. During our site visit to the proposed Eldoret radar, we were encouraged that the project has been strongly supported by the aviation authority in Eldoret and that they have the infrastructure in place to support such a large investment. The Tanzanian Meteorological Agency is currently running one scanning weather radar in Dar es Salaam, and is in the procurement stage of putting a weather radar in Mwanza, located directly on the south-central shore of Lake Victoria. They have an excellent site already selected which would provide coverage over much of Lake Victoria.

Weather radars would not only provide forecasters with valuable observations over land, but also over the lake itself where observations are sparse. A schematic of the coverage area of the two radars in Eldoret and Mwanza is shown in Figure 6. In this set-up the range rings have a 150 km radius. Operationally, certain radars such as the S-bands currently owned by the Kenyan agency can have ranges closer to 250 km, thus bringing the coverage of the two radars much closer together. For the first time, forecasters would be able to directly track storms that are over the open waters of the lake. This ability would give forecasters the opportunity to utilize a warning system to alert fishermen, ferries, and other lake users of impending dangers from approaching storms. Data collected from radars in Eldoret, Kenya and Mwanza, Tanzania could be shared over the internet in real-time, allowing forecasters in each country to have information about where storms are located over the lake. While weather radars are quite costly and do have their limitations, the addition of radar observations to the forecasting offices in the East African Community would have the highest probability of immediately improving the safety of users of Lake Victoria.

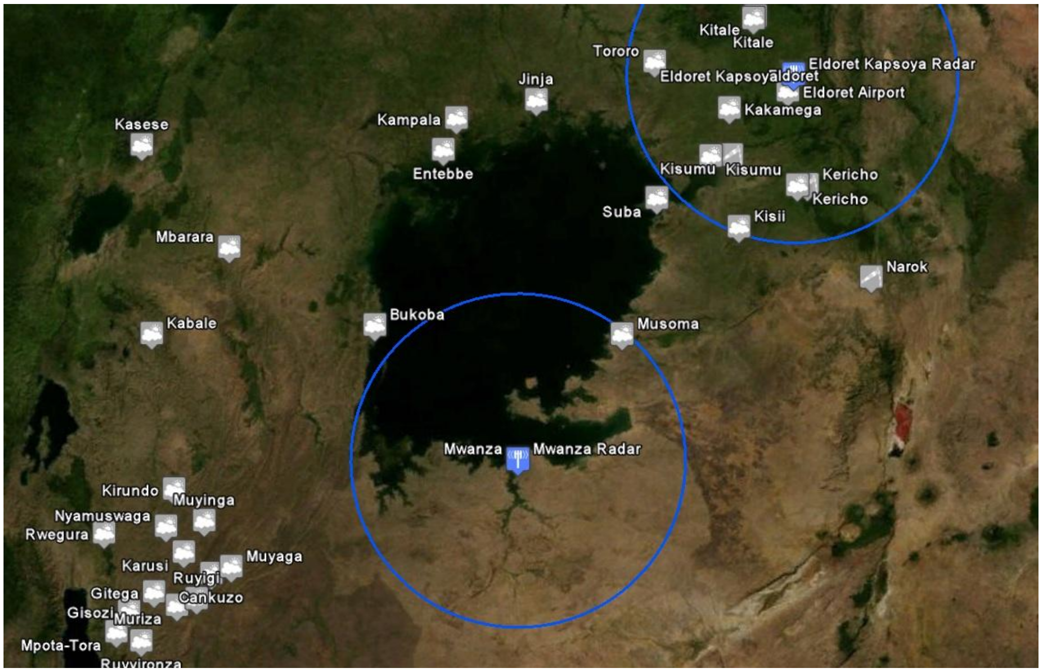

Fig. 6: 150 km range rings for the two proposed S-band radars in Mwanza, Tanzania and Eldoret, Kenya.

A less costly option than radars would be to deploy a system of four to five lightning detection and location sensors around the lake or on an island in the lake. Lightning detection sensors could give forecasters the location of severe storms and could be used to back out estimates of storm motion and intensity. While intensity estimates from lightning are not as clear to interpret as radar data, some degree of information would be provided about storm severity. Because of the high frequency of lightning associated with the deep storms over the lake, lightning detection sensors would likely be able to capture a large majority of the storms which threaten the safety of fishermen and other users of Lake Victoria.

B) Broad Recommendations

In addition to the specific sensors we will recommend, our visits to the meteorological departments in East Africa prompted a list of broader recommendations which we believe will help to improve safety over Lake Victoria. In summary:

1) Issue Evening Forecasts - In addition to the once-a-day forecasts being currently issued in the morning by all of the operational centers, forecasters in each country could take advantage of data being collected during the day to issue an additional evening forecast for fishermen to consult before setting out after sunset. Because most of the fishermen go out on the lake at night, there is a large amount of time between when the forecasts are currently issued in the morning and when they would be used by the fishermen. Issuing an evening forecast, which would include a better understanding of how the weather has changed throughout the day, would result in a more useable forecast product that the fishermen could consult.

2) Aids to Navigation - A series of solar powered lights could be mounted on islands and the shoreline to provide the fishermen with a way to navigate safely even when it is cloudy or dark and stars and landmarks are not visible. At present most of the fishermen use simple dead-reckoning to move about the lake during the night. At the stakeholders meeting in Kisumu, the fishermen discussed the dangers posed by large rocks and other obstacles which could be hidden from view at night or when the lake

levels are high. A light-based navigation system could help the fishermen understand where they are on the lake and help them avoid the lake hazards at night. The fishermen told us about an old system of multicolored lights mounted on the numerous islands close to the shore of the lake. The lights were different colors to indicate whether you were facing the north, south, east, or west side of the island. This light-based navigation system was heavily utilized and appreciated by the fishermen but has fallen into disrepair over the years and is no longer in use. Revitalizing such a system would give the fishermen a useable compass by which to navigate out of the way of impending storms.

3) Mobile Phone Weather Alert Program – The meteorological departments around Lake Victoria could utilize text messages (SMS) sent to the mobile phones of registered users on the lake to disseminate forecasts and warnings. Warnings must be distributed in a timely manner in order to be useful to the recipient. SMS messages are a quick, easy, and affordable method of communicating information. A system for disseminating forecasts via SMS has been pioneered in Uganda as part of the World Meteorological Organization (WMO) severe weather test bed project. Daily forecasts are sent out each morning in multiple languages and can be targeted to select groups of users who may be on a specific part of the lake. Such a powerful system for communicating weather hazards could be very useful for all of the meteorological departments in the East African Community.

4) Use of Local Observations in Regional Models - Efforts to use numerical weather prediction (models) to build a forecast could be aided by utilizing the large amount of surface data currently available throughout the region. Utilizing the high-quality surface data would give more regionally precise initial conditions to the model and would likely result in improved forecasting skill. Until the models begin to utilize regional observations to tune the model initial conditions, the predictive capabilities of numerical models will be limited.

5) Web Sites to Disseminate Observations among Countries - A stronger web presence by each of the meteorological departments would facilitate interaction and cooperation among the different national meteorological agencies. Surface observations, new radar data, and forecasts could be shared over the web in real-time, linking the different agencies together and enhancing their ability to issue spatially coherent and accurate short-term forecasts.

6) Lake Victoria Basin Climate Data Archive - All current and future meteorological data recorded in the region could be collected in a central location and archived for future studies. Data such as surface observations, model output, and radar scans could all serve as important climate data records against which future changes involving the climate of the lake can be assessed. These data could also be used to evaluate the skill of regional climate models (i.e. hindcasting). Regional institutions such as ICPAC (IGAD Climate Prediction and Applications Centre) would be very suitable locations for storing climate data records.

7) Satellite Communication to Make Observations Available in Real-Time - Current and future rural observation systems could take advantage of readily available satellite communication technologies (such as EUMETSAT) to transmit their data to the forecast centers in near real-time. This would give the forecasters an up to the minute view of what is occurring in all parts of their forecast domain and would improve their nowcasting ability.

C) Recommended Meteorological Sensors

We have generated the following list of sensors which we believe would improve the nowcasting capabilities of meteorological departments of the East African Community. The list should not be seen as all inclusive, but rather as a set of approaches which would most likely lead to the most direct improvements in forecasters understanding of the weather over the lake. It is not our recommendation that all of these sensors be utilized, or that the same new sensor or combination of sensors be implemented in every country. These recommendations should be seen as a buffet, with the agencies in each country selecting the tools which they believe they can implement within their budget and would most greatly benefit their office. We first present an overview table that describes all of the instruments before going into details about each individual option. The recommended sensors are listed in order of the value which we think they hold.

Instrument	Cost	Description
Scanning Weather Radars	High	Weather radars provide information on the location of precipitation, storm movement and intensity, rainfall estimates, and wind patterns in and around precipitating storms.
Lightning Detection and Location Sensors	Moderate	A network of 4-5 lightning detection sensors could be deployed around the lake to give forecasters the location and frequency of lightning occurring over and around the lake.
More Automated Surface Observation Sensors around the Lake	Low	Additional surface observation sites could be installed to fill in the gaps of information within the existing network and to enhance the effectiveness of the observation network around the lake.
Fixed Buoys with Surface Weather Observation Sensors in the Lake	Moderate to High	Weather observation instruments, similar to those used over land, can be mounted on top of floating buoys which can be secured at fixed points in the middle of the lake.
Automated Surface Weather Observation Sensors on Islands	Low to Moderate	Surface meteorological stations, similar to those already in place at sites inland, could be installed on some of the numerous islands in the middle of the lake.
GPS Occultation System	Moderate to High	A system of GPS receiving sensors can communicate with each other and, based off of the signal delay time due to differential propagation in moist and dry air, determine the locations of higher or lower moisture concentrations in the atmosphere and produce a moisture profile of the atmosphere.
Lightning Prediction by Radar	Low	A routine can be provided for volume-scanning weather radars to predict the probability of a lightning strike in a certain area approximately 15 minutes before it occurs.
Stream Gauges	Low to Moderate	Installing a denser network of stream gauges on the rivers and streams flowing into Lake Victoria would improve estimates of how much water is flowing into and out of the lake.

1) Scanning Weather Radars

Overview: Weather radars provide information on the location of precipitation, storm movement and intensity, rainfall estimates, and wind patterns in and around precipitating storms.

Cost: High

Benefits:

- Forecasters will know the location, movement, and intensity of severe storms
- Doppler radars can provide estimates of wind speed and direction in and around precipitating storms
- Provides uniform information over a large area (radius of up to 275 km for high-end instruments) over both land and water
- Doppler-derived estimates of wind speed and wind direction, as well as precipitation location, can be fed into numerical models to improve their predictive capabilities
- Data can easily be made available and shared with multiple users in real-time
- Can provide quantitative rainfall estimates, within 150 km of the radar, which would be useful for hydrological purposes.

Limitations:

- Will need a network of 3 radars to provide complete coverage of the lake and its basin
- While one can still detect the presence or absence of storms, data quality is much lower at ranges beyond 150 km (rain rate estimates are unreliable beyond this range) due to beam broadening and the curvature of the Earth
- Radars are expensive instruments that need large amounts of supervision, maintenance, and calibration
- Forecasters would have to be trained in the interpretation of radar data

Specifications:

- An S-band (frequency) radar would provide the largest coverage area and would attenuate the least when observing severe storms
- The radar should have Doppler capabilities
- While dual-polarization radars would provide more accurate precipitation estimates, the benefits do not likely outweigh the cost for installing dual-polarization radars around the lake at this time

2) Lightning Detection and Location Sensors:

Overview: A network of 4-5 lightning detection sensors could be deployed around the lake to give forecasters the location and frequency of lightning occurring over and around the lake.

Cost: Moderate

Benefits:

- Can give the location of storms producing lightning with 2-3 km accuracy
- Will show signs of storm movements (could back out estimates of storm speed and direction)
- Gives information about cloud-to-cloud and cloud-to-ground strikes, can distinguish between positive and negatively charged strikes (positive strikes are usually associated with dying storms)

Limitations:

- Storm intensity estimates from lightning alone are not as clear to interpret as radar observations
- Cannot be used in any meaningful way to improve numerical models

Specifications:

- 4 to 5 sensors deployed around the lake should be able to provide complete coverage of the lake basin
- Should utilize satellite communications in order to get the data to the forecasters soon after the lightning strike occurs
- Would require a strong solar power source as well as a reliable battery backup to avoid interruptions

3) More Automated Surface Weather Observation Sensors around the Lake

Overview: Additional surface observation sites could be installed to fill in the gaps of information within the existing network and to enhance the effectiveness of the observation network around the lake.

Cost: Low

Benefits:

- Would help forecasters to better resolve important atmospheric features (such as the land-lake breeze or the presence of surface boundaries)
- A denser network is more likely to observe severe storms occurring within the network as they are developing and would aid in the calibration of radar derived rain rate estimates
- More sensors would provide better information for drought monitoring and prediction, numerical model forecast verification, and provides more climate data records against which future changes to the climate can be judged
- Increases the amount and reliability of information that can be ingested into numerical models
- Would aid in the forecasting of inland flash floods by providing a more regionally precise analysis of where the rain is falling and how intense it is

Limitations:

- Surface observation sites are only a point measurement and would not provide the same wide spatial coverage as radars
- The true benefit of a surface network is largely dependent on the density of the observation sites – in order to get a marked improvement in forecast capabilities using only a denser surface network an additional 10-20 automated surface observation sites would need to be installed
- Does not provide any new information over the lake

Specifications:

- Should utilize satellite communications in order to get the data to the forecasters in a useable amount of time
- Would require a strong solar power source as well as a reliable battery backup to avoid interruptions

4) Fixed Buoys with Surface Weather Observation Sensors in the Lake

Overview: Weather observation instruments, similar to those used over land, can be mounted on top of floating buoys which can be secured at fixed points in the middle of the lake.

Cost: Moderate to High

Benefits:

- Weather sensors on buoys would provide measurements of temperature, humidity, precipitation, wind speed, and wind direction over the lake
- Data could be transmitted by communication satellites to the forecast offices and be used in near real-time
- Buoy-based atmospheric observations could be ingested into numerical models to provide initial conditions in data sparse regions over the lake
- Provides rainfall estimates over the lake which could be used to validate radar derived rainfall estimates as well as for hydrological and climate monitoring purposes
- Provides wave height information for storm warnings
- Marine forecasters would get information about underwater currents which could be used to improve the coupled lake-atmosphere numerical models (current data could also be useful to aid in search and rescue efforts)
- Users can select the location of the buoys to provide the maximum benefit from fixed point observations

Limitations:
- Fixed buoys only provide a point measurement of the atmosphere and do not provide the same contiguous spatial coverage needed to locate and track severe storms (i.e. information on a storm only if it is directly on top of the buoy)
- The cost to install and maintain the instruments is high and it would require specialized or modified ships and technicians
- The true benefit of a buoy network is largely dependent on the density of the buoy sites – in order to get a marked improvement in forecast capabilities using only a buoy network would require the installation of a large (5-10) number of buoys

Specifications:
- Should utilize satellite communications in order to get the data to the forecasters in a useable amount of time
- Would require a strong solar power source as well as a reliable battery backup to avoid interruptions

5) Automated Surface Weather Observation Sensors on Islands

Overview: Surface meteorological stations, similar to those already in place at sites inland, could be installed on some of the numerous islands in the middle of the lake.

Cost: Low to Moderate

Benefits:
- Would provide atmospheric observations in data sparse regions over the lake
- Data could be transmitted by satellites to the forecast offices and be used in near real-time
- Atmospheric observations could be ingested into numerical models to provide initial conditions in otherwise data sparse regions
- Placing the instruments on islands would be much cheaper than installing buoys

Limitations:
- Because they are on land these observation sites would not provide any information on underwater currents or wave heights
- A technician is needed to visit each of the island sites for required maintenance and calibration
- Data collected on the islands may not represent the true state over the water because of the contamination by the island itself (this is more likely to affect temperature and relative humidity than precipitation, wind speed, or wind direction)
- The location of the instruments would be predetermined by the location of available islands and not user selected (may not get representative, complete, or even coverage over the entire lake)

Specifications:
- Should utilize satellite communications in order to get the data to the forecasters in a useable amount of time
- Would require a strong solar power source as well as a reliable battery backup to avoid interruptions

6) GPS Occultation System

Overview: A system of GPS receiving sensors can communicate with each other and, based off of the signal delay time due to differential propagation in moist and dry air, determine the locations of higher or lower moisture concentrations in the atmosphere and produce a moisture profile of the atmosphere.

Cost: Moderate to High

Benefits:
- Provides location and depth of atmospheric moisture
- Water vapor profiles could be ingested into regional numerical models

- This capability provides similar information to the humidity measurements on upper air soundings but has the advantages of frequent updates and no expensive expendables

Limitations:

- Systems are still in development and testing and thus are not available commercially yet but should be available in a few years

Specifications:

- Rough estimate is that less than ten sensors would provide complete coverage of the lake and its basin
- Should utilize satellite communications in order to get the data to the forecasters in a useable amount of time
- Would require a strong solar power source as well as a reliable battery backup to avoid interruptions

7) Lightning Prediction by Radar

Overview: A routine can be provided for volume-scanning weather radars to predict the probability of a lightning strike in a certain area approximately 15 minutes before it occurs.

Cost: Low (if radars are operational)

Benefits:

- Can provide general area in which a lightning strike is likely to occur in the next 15-20 minutes within a range of 250-300 km for a typical severe storm (accurate distances depend on the size of the storm and the spatial resolution of the radar data)
- Can forecast cloud-to-cloud strikes where a lightning sensor network may not observe these

Limitations:

- Prediction ability is dependent on the radar scan (for example, cannot predict lightning directly over the radar due to the data gap in the cone-of-silence)

8) Stream Gauges

Overview: Installing a denser network of stream gauges on the rivers and streams flowing into Lake Victoria would improve estimates of how much water is flowing into and out of the lake.

Cost: Low to Moderate

Benefits:

- Provides a valuable tool for climate monitoring
- Aids in river flood stage forecasting and could improve flood warning lead-times in eastern Kenya

Limitations:

- Does not provide any improved water estimates of rainfall falling on the lake or entering the lake from the land via run-off
- Should utilize satellite communications in order to get the data to the forecasters in a useable amount of time
- Would require a strong solar power source as well as a reliable battery backup to avoid interruptions