

Intermediate Field Campaign Report

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Executive Summary

This intermediate report on the HIGH impact Weather LAke sYstem (HIGHWAY) Field Campaign summarizes the observations and data archived during the campaign's first two Enhanced Observation Periods (EOPs) from 1 March to 30 September 2019. This report was requested by the World Meteorological Organization (WMO) who are providing oversight of the HIGHWAY project that is funded by the United Kingdom Department for International Development (DFID). The motivation for this report is to provide a status of ongoing data collection efforts, assessment of storm evolution over the lake, and to inform the HIGHWAY partners of types of observations and instrumentation that are needed in the region for long term sustainability in the detection, prediction, and early warning of high impact weather over Lake Victoria Basin (LVB) in East Africa.

In collaboration with the partners, as much operational data as possible was collected and archived at NCAR. As new datasets became available, these data were archived. The NCAR CIDD display system was the primary tool used by the authors for displaying this data. All data have been examined in varying levels of detail, dependent on what datasets were actually available on any given day, to understand the evolution of weather each day over the lake. The Mwanza radar data has opened up exciting new opportunities to understand severe storm initiation and evolution and as a foundation for producing precise 1-2 hour time and space nowcasts of severe storms. The recent soundings from the Nairobi Upper Air Station provide crucial information for characterizing the atmospheric environment in the region. Examination of the Field Campaign data sets and subsequent scientific findings have been used by the authors to produce the following recommendations. These recommendations are all essential steps, but not necessarily in priority order, toward a sustainable EWS. Additional discussion on these recommendations can be found in section 4.0 of the report, along with recommendations of lesser priority that are not provided in this Executive Summary. Following the end of the FC, a final report will be produced summarizing the scientific understanding of storm evolution and severe weather over LVB gained from the three EOPS, along with pertinent updates to this list of recommendations.

Recommendation 1: Sustainability of an Early Warning System

Obtain long term funding to maintain all observational platforms. This funding needs to support a repository of necessary spare parts and consumables, a data archival system, and support technicians, engineers and scientists to maintain these instruments and utilize these observations.

Long term sustainability of observations is the single most important component of a reliable early warning system. Sustainability is not obtained just by purchasing observational platforms. Sustainability is achieved by dedicated long term funding for continuous maintenance and quality assessment of the equipment by technicians, engineers and scientists who use these observations. An early warning system requires real-time, continuously updated observations transmitted to a centralized location for optimal use by forecasters and end-users. Delays experienced when component systems fail, when there is a lack of routine maintenance, and no spare parts are on-hand to quickly resolve the problem substantially reduces the quantity of information, spatial coverage, and utility of an EWS. Data archiving is one of the

required activities for a sustainable Early Warning System. It will always be necessary to examine past data when investigating boating accidents and for developing improved nowcasting capabilities.

Recommendation 2: Radar Coverage over LVB

It is recommended that a radar be installed in Kenya near the northeast coast of Lake Victoria. This will complement the Mwanza, Tanzania radar and the Entebbe, Uganda radar to complete high-resolution radar coverage for Lake Victoria Basin. Radar coverage over LVB provides the foundation for detection and nowcasting of severe weather needed by the NMHSs to provide accurate, timely warnings for the marine zones.

Observations with the Mwanza polarimetric radar have been very effective in observing the location, movement and intensity of convective storms over Lake Victoria and surrounding land areas due to the high spatial and temporal resolution of the radar measurements. Dual-polarimetric radars provide detail within the storms including the precipitation rate and precipitation type (rain, hail, graupel, ice crystals). This microphysical information can be used to characterize storm severity. Particularly noteworthy is the radar's ability to detect lines of converging air motion near the lake surface that are frequently forerunners to thunderstorm initiation. This makes possible precise spatial and temporal nowcasting of new storms that can be used to provide advanced warning to lake users. Shearing instabilities (rotations) that form along these convergence lines also have the potential to evolve into waterspouts when stretched vertically by developing storm updrafts. In addition, radar Doppler velocities can provide warnings of high winds associated with thunderstorms. However, the precise nowcasting of these low-level features is limited by radar range coverage. While the new radar at Entebbe will improve the coverage for the north and northwestern part of the lake, the northeastern quadrant of the lake and surrounding land is not well covered. Thus, a radar is needed along Kenya's shoreline which will extend the severe storm nowcasting capability to the entire lake and surrounding land area.

Recommendation 3: Regional High-Resolution Lightning Network

Obtain data from a high resolution, regional lightning network for detection, evolution, and movement of thunderstorms over Lake Victoria Basin.

Access to high resolution lightning networks are currently available in the region at a cost. With the launch of the EUMETSAT's Meteosat Third Generation (MTG) satellite in late 2021, the new MTG-Flexible Combined Imager (FCI), Infrared Sounder (IRS) and Lightning Imager (LI) will serve as additional data sources to diagnose and characterize the pre-convective environment and monitor storm evolution over the region. This data should become available through the suite of EUMETSAT products. However, in the short-term it is recommended that funds be made available to obtain lightning data from a regional lightning network and make this data routinely available to forecasters in real-time for monitoring storm evolution and intensification arising from a higher frequency of lightning strokes. These observations will also help them prepare for the MTG era when improved spatial and temporal satellite and lightning observations become available.

Recommendation 4: Lake Victoria Measurements

Obtain and install fixed buoy stations in the different marine zones of the lake and a GPS-TPW vertical profiling system on one or more islands in the lake to obtain in-situ water and near-surface air measurements and water vapor profiles directly over the lake.

There is a scarcity of observations on Lake Victoria. No buoy stations are currently available to provide important information on changes in wind speed and direction over the lake, changes in temperature and temperature gradients near the surface of the lake, and measurements of wave height on the lake. Measurements of these variables are needed for scientific understanding of the role they play in storm development and evolution and for real-time monitoring of conditions on the lake. In the future, these measurements can be included in location-specific nowcasts of new thunderstorm development and thunderstorm severity, and for verification of NWP forecasts of wind strength and wave heights on the lake. In addition, observations supplemental to the conventional UAS profiles are needed directly over the lake to provide continuous automatic reports of total precipitable water (TPW) measurements of the atmosphere and to monitor variations in moisture depth critical to storm initiation over the lake.

Recommendation 5: Integrated Displays and Nowcasting Algorithms for EWS

Install dedicated data communication systems and software protocol for transmission of real-time observations from the LVB region to the forecast office. Ingest these data into an integrated display for real-time viewing by the forecaster and review of historic cases. Archive and ingest these data into nowcast algorithms (for example, TITAN storm tracker and NWCSAF RDT) running in the forecaster's EWS.

Timely detection and short-term prediction (in the 0-2 hour timeframe) of severe weather over LVB requires that observations from all observational platforms (soundings, satellite, radar, lightning, surface station, buoy, and vertical profile systems) be transmitted in real-time to a centralized location for ingest into an integrated display system. An integrated display system like NCAR's CIDD enables forecasters to view all concurrent observations and have a clear picture of high impact weather occurring over LVB. Existing nowcast algorithms such as the TITAN storm tracker are available for free to download onto NMHS systems. Nowcast tools such as radar mosaics and radar and satellite tracking products produced by NCAR TITAN and the NWCSAF Rapidly Developing Thunderstorm (RDT) can provide the forecaster with guidance on nowcasting and issuing severe weather warnings for an EWS.

Preface

The Lake Victoria HIGH impact Weather LAke sYstem (HIGHWAY) Field Campaign is part of the planned activities under Output 2 of the HIGHWAY project. The Field Campaign is designed to maximize the use of existing observations along with modest enhancement of the observations where possible, to improve scientific understanding of the weather over Lake Victoria Basin (LVB) in East Africa (Roberts et al 2018). This Field Campaign differs from more traditional field campaigns in that it focuses on the use of existing observational systems rather than deploying a number of temporary observation or mobile platforms, such as radars, research aircraft, profiling systems, and disdrometers during the campaign. It also relies on the resurrection and refurbishment of NMHS upper air stations and Automated Weather Stations (AWSs) and transmission of these data to the WMO Global Telecommunications System (GTS). A successful field campaign involves the sharing of data amongst the participants. Only with data sharing is it possible to build a set of severe weather case studies that can be used for scientific understanding, training of forecasters, verification of NWP forecasts, and development of products for a regional Early Warning System (EWS).

1 Overview of Field Campaign

Prior to the start of the FC, two Enhanced Observation Periods (EOPs) were planned, the first (EOP-1) during the rainy season (Mar-May 2019) for a three month period and the second (EOP-2) during the dry season (Jun-Aug 2019) for a one month period centered during July and August. A planning spreadsheet of the instrumentation and observations expected to be available, along with organizations responsible for the instrumentation, data transmission and data archival was created (see Table A1 in Appendix 1) prior to the start of the FC with input from HIGHWAY participants.

The HIGHWAY Field Campaign (FC) officially began on 1 March 2019. Ingest and archival of EUMETSAT MSG-11 satellite, the EarthNetworks commercial lightning data, the Trans-African Hydro-Meteorological Observatory (TAHMO) surface stations, and selected NMHS Automatic Weather Stations (AWS and 3D-Printer AWS (3D-PAWS) began as well. Most AWS transmissions to the GTS were only every 3 hours. Data converters were written to display these first datasets in NCAR's CIDD display system and images from CIDD were posted on the HIGHWAY Field Catalog (<http://catalog.eol.ucar.edu/highway>) set up by NCAR for quick-look viewing of all available FC data. As additional datasets became available, data were ingested, reformatted, and images produced for the Field Catalog. Due to significant delays in the resurrection of NMHS upper air stations and the delivery of sounding equipment and consumables, no upper air soundings were launched during EOP-1.

After the start date of the FC additional observations became available with the installation of new instrumentation. In late June the UNMA C-Band radar was installed. The first upper air operational sounding was released by KMD at the Nairobi upper air station site on 5 August. Figure 1 shows the location of all ground-based instrumentation available by the end of September 2019, with the exception of the lightning sensors.

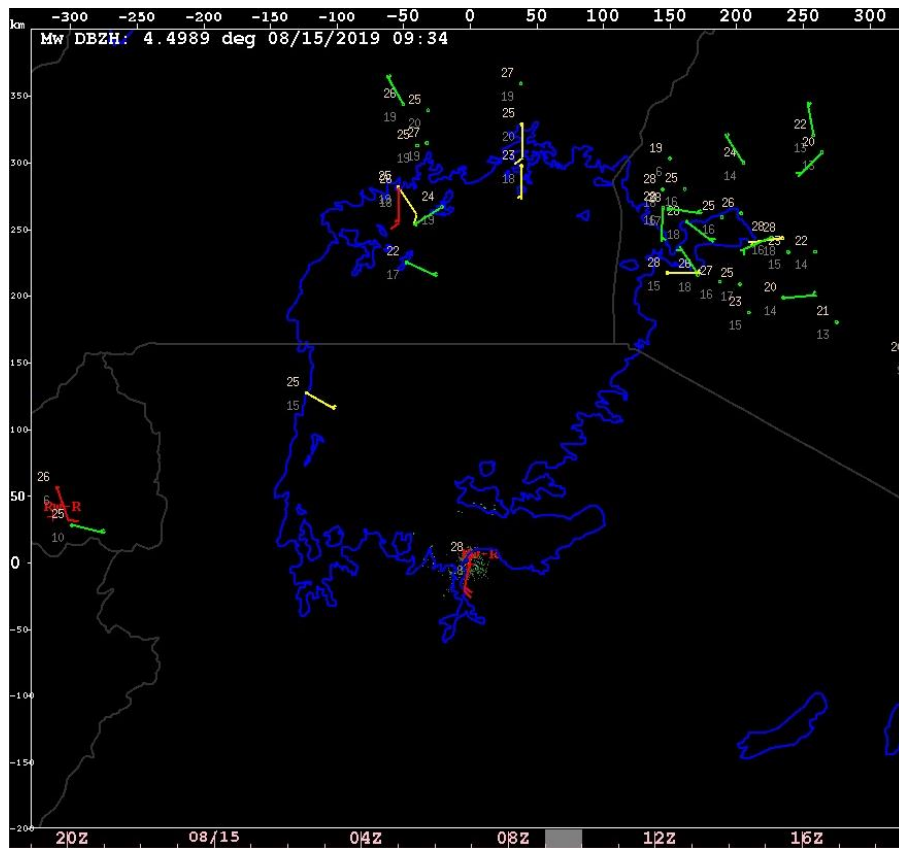


Figure 2. CIDD Cartesian display of surface stations reporting during the Field Campaign. Plotted here are temperature, dewpoint temperature and winds barbs. Winds are direction from and wind speeds are 0-2 kts (no wind barb) 3-5 kts (green barbs), 5-10 kts (yellow barbs) and > 10 kts (red barbs).

AWS

Transmission and archival of all available NMHS AWS stations located within the LVB was requested for the Field Campaign. Each NMHS provided the WMO with a list of existing stations in the region, identifying those stations that required refurbishment and those that needed upgrades to the software for transmission to the GTS, and identifying potential locations for installing new AWS stations.

The activity of resurrecting the stations and repairing sensors has been an ongoing activity through the Field Campaign. Only a limited number of additional stations have been added to the GTS and the FC archival system since the start of the FC. Several of the stations reporting to the GTS provide only 3 hourly surface station data. However, hourly data is being collected by several stations and to obtain this higher frequency data, one must request this data directly from each of the NMHS offices.

TAHMO

The Trans-Hydro-Meteorological Observatory (TAHMO) program was initiated to install a dense network of hydro-meteorological monitoring stations in sub-Saharan Africa. TAHMO stations are installed in Kenya, Uganda, Tanzania and Rwanda. Twenty-seven stations available to HIGHWAY are shown in Fig. 1. Under an agreement with the WMO, the TAHMO station data is provided to the HIGHWAY partners for free for

scientific (peer-reviewed research) purposes and includes collaboration with the WMO to put the data into GTS format.

A TAHMO data server was made available to NCAR and other partners to provide access to the data starting in January 2019. NCAR has been archiving the data from 27 TAHMO stations in Kenya and Uganda. The following variables are recorded: temperature, dew point temperature, wind speed, wind direction and rain. The observation frequency is every 5 min. The surface station data available on this server has some initial data quality analysis and control applied to the data. Sensor measurements outside of acceptable ranges of values are flagged. Data is being made available for the duration of the FC, i.e., through the end of year (31 December 2019). Routine archival of this data at NCAR began on 1 February 2019 and currently extends through 30 September, with only an occasional, random station report missing.

3D-PAWS

The 3D-Printer Automatic Weather Stations (3D-PAWS) and technology developed at UCAR falls under an initiative that is focused on improving weather observations for environmental monitoring and early warning alert systems on a regional to global scale. Instrumentation that has been developed use innovative new technologies such as 3D printers, Raspberry Pi computing systems, and wireless communications. The configuration of 3D-PAWS deployed for HIGHWAY was setup to measure pressure, temperature, relative humidity, wind speed, wind direction, precipitation, and visible/infrared/UV light.

The stations were deployed in Uganda and Kenya from 12 February to 04 March 2019 in preparation for the FC. Seven stations were deployed in Uganda and seven station deployed in Kenya. The locations of the Uganda stations are shown in Fig. 3 and the site information is presented in Table 1. The locations of the Kenya stations are shown in Fig. 4 and the site information is presented in Table 2.

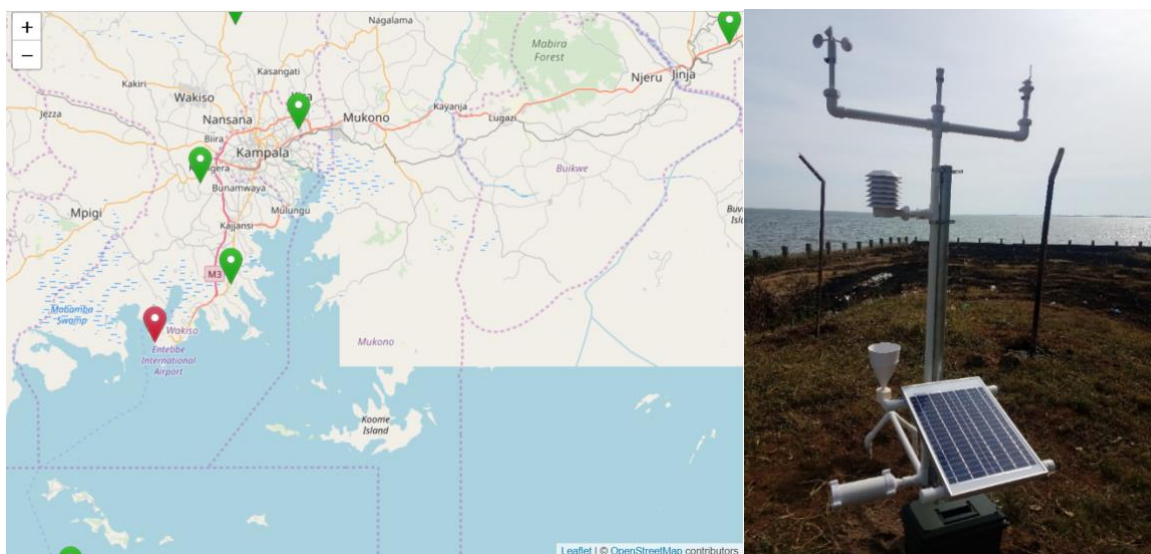


Figure 3. Map of 3D-PAWS HIGHWAY sites in Uganda (left panel) and photo of 3D-PAWS instrumented site (right panel) at Merryland High School located near Entebbe. All seven sites listed in Table 1 are shown on the map, but the southern-most site location located on an island is partially cut-off in the figure.

Table 1: Locations of 3D-PAWS HIGHWAY sites in Uganda.

| Site Name | Location | Latitude | Longitude | Altitude (m) |
|----------------|----------------------------|-----------|-----------|--------------|
| WMO_HIGHWAY_01 | St. Mary's College | 0.120992 | 32.533193 | 1186 |
| WMO_HIGHWAY_02 | YMCA Campus | 0.505700 | 32.539529 | 1170 |
| WMO_HIGHWAY_03 | Budo Junior School | 0.270780 | 32.487661 | 1225 |
| WMO_HIGHWAY_04 | Merryland High School | 0.034475 | 32.420585 | 1123 |
| WMO_HIGHWAY_05 | Kyambogo College School | 0.350501 | 32.633353 | 1211 |
| WMO_HIGHWAY_06 | Ssesse Farm Institute | -0.321667 | 32.296111 | 1264 |
| WMO_HIGHWAY_07 | Muljibhai Madhivan College | 0.476944 | 33.272500 | 1228 |

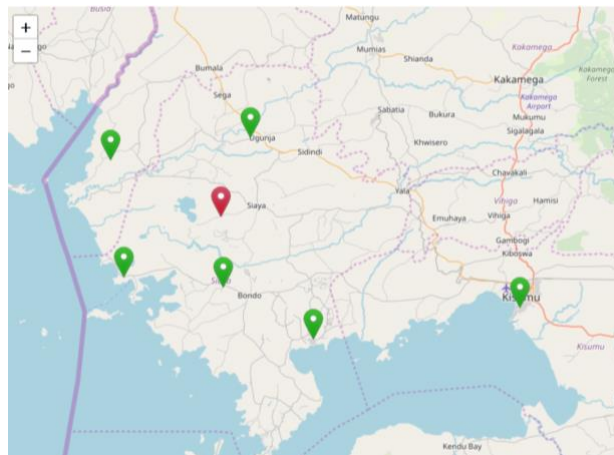


Figure 4. Map of 3D-PAWS HIGHWAY sites in Kenya.

Table 2: Locations of 3D-PAWS HIGHWAY sites in Kenya.

| Site Name | Location | Latitude | Longitude | Altitude (m) |
|----------------|--|-----------|-----------|--------------|
| WMO_HIGHWAY_08 | St. Vincent Raliew Secondary School | -0.178584 | 34.386103 | 1145 |
| WMO_HIGHWAY_09 | Maranda High School | -0.086153 | 34.226904 | 1276 |
| WMO_HIGHWAY_10 | Usenge High School | -0.069331 | 34.051377 | 1144 |
| WMO_HIGHWAY_11 | Joel Omino Mixed Secondary School | -0.12224 | 34.751654 | 1112 |
| WMO_HIGHWAY_12 | St. Benedict's High School – Budalangi | 0.138501 | 34.027495 | 1144 |
| WMO_HIGHWAY_13 | Ambira High School | 0.177893 | 34.274331 | 1235 |
| WMO_HIGHWAY_14 | St. Paul's Obambo Mixed High School | 0.038552 | 34.222893 | 1175 |

The stations have been recording and sending data in 1-min intervals when the network is present since deployment. The number of total records received to NCAR since deployment to the end of August 2019 is shown in Table 3. The number of records received has a large variation mainly due to the quality of the GSM mobile network in the region. However, the data are also being stored on the Raspberry Pi data logger for future retrieval. Note that all the Uganda transmission of data ended in August due to the service expiring on the network. The service is being renewed and the site should be online by October. The 3D-PAWS team (Paul Kucera and Martin Steinson) are planning a trip to Kenya and Uganda at the end of HIGHWAY to retrieve all the data from each site so that the complete record can be included in the database.

Preliminary analysis shows that the data are of good quality and will be useful for the experiment. A separate inter-comparison was conducted by KMD and NCAR in August for the site located at KMD in Nairobi. These results are presented in a separate report (see Appendix 2b).

Table 3: Number of records received at NCAR during the HIGHWAY field campaign.

| Site Name | # of Records | Period |
|----------------|--------------|----------------------|
| WMO_HIGHWAY_01 | 768250 | 12 Feb – 14 Aug 2019 |
| WMO_HIGHWAY_02 | 709740 | 15 Feb – 14 Aug 2019 |
| WMO_HIGHWAY_03 | 532809 | 16 Feb – 27 Jun 2019 |
| WMO_HIGHWAY_04 | 560521 | 17 Feb – 14 Aug 2019 |
| WMO_HIGHWAY_05 | 425709 | 19 Feb – 19 Aug 2019 |
| WMO_HIGHWAY_06 | 256834 | 20 Feb – 15 Jun 2019 |
| WMO_HIGHWAY_07 | 12767580* | 21 Feb – 19 Aug 2019 |
| WMO_HIGHWAY_08 | 163705 | 27 Feb – 27 Aug 2019 |
| WMO_HIGHWAY_09 | 168323 | 28 Feb – 27 Aug 2019 |
| WMO_HIGHWAY_10 | 106111 | 28 Feb – 26 May 2019 |
| WMO_HIGHWAY_11 | 140706 | 02 Mar – 27 Aug 2019 |
| WMO_HIGHWAY_12 | 110501 | 01 Mar – 27 Aug 2019 |
| WMO_HIGHWAY_13 | 77819 | 04 Mar – 23 Aug 2019 |
| WMO_HIGHWAY_14 | 184257 | 04 Mar – 25 Aug 2019 |

*WMO_HIGHWAY_07 was accidentally configured to send information every second instead of minute.

[AWS, TAHMO, 3D-PAWs Inter-comparison Workshop](#)

An inter-comparison workshop, hosted by KMD, was held in Nairobi from 6-8 August 2019 (Fig. 5) for the purpose of comparing data collected by TAHMO and 3D-PAWS station co-located with a KMD manual surface weather station at Dagoretti Corner in Nairobi. Surface station data from 2016-2018 was used for the inter-comparison. Insufficient information exists from all three stations during the FC so no data was used from this period. Summary comments from the workshop report (Appendix 2b, Aura et al 2019) state that *“the various weather parameters compared very well between the three stations. However, there are some features that need to be investigated further.”*



Figure 5. KMD and UCAR/NCAR participants in the surface station inter-comparison workshop, 6-8 August 2019.

2.2 Upper Air Stations

Visits were made by Tim Oakley (WMO) to KMD, TMA and UNMA headquarters prior to the FC to discuss the status of upper air stations that at one time were operable in the region (Fig. 6). Based on these meetings HIGHWAY partners agreed on task timelines, procurements and training at each upper air site.

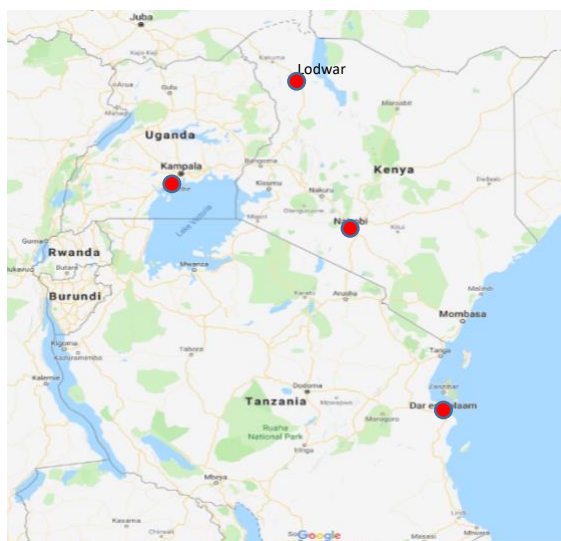


Figure 6. Location (red dots) of upper air stations in the region.

KMD Nairobi and Lodwar stations

The first site to become operational is the KMD Nairobi upper air station (63741). Following the repair of the roof of the Hydrogen Generator System (HGS) building at this KMD site, the HGS was installed in the

building on 29 July. Meteorological balloons (800) for use by KMD arrived in Nairobi from the PAWAN company in India. A new radiosonde system for Lodwar along with 800 radiosonde units for use by KMD were delivered to KMD in mid-April. KMD observers, technicians and line managers including Lodwar engineer received hands-on training on UAS systems installation, configuration and operations by WMO expert in early August. The first upper air operational sounding was released by KMD at the Nairobi upper air station site on 5 August (Fig. 7).



Figure 7. KMD and WMO preparation and launch of upper air balloon and sounding package in Nairobi, Kenya on 5 August.

Twice daily soundings are taken at 12 UTC and 00 UTC with routine transmission of mandatory and occasionally the significant levels of the soundings sent to the GTS. Sounding data at higher resolution in BUFR¹ format is also being transmitted to the GTS. NCAR is ingesting both data formats and Skew-T sounding plots are posted to the Field Catalog web site for viewing. As of 17 September, the Nairobi UAS has been fully compliant with WMO requirements with twice daily soundings with high-resolution BUFR reports being produced. The soundings from 18 September at 11-12 UTC and 23-00 UTC are shown in Fig. 8. Skew-T plots from 9 August – 1 October are stored on the Field Catalog (see Table A3, Appendix 3).

On 17 October, KMD launched the first sounding from the Lodwar UAS site. The TEMP and BUFR formatted files were transmitted to the GTS and the data was plotted (Fig. 9).

¹ Binary Universal Form for the Representation of meteorological data (BUFR) is a binary data format maintained by the WMO.

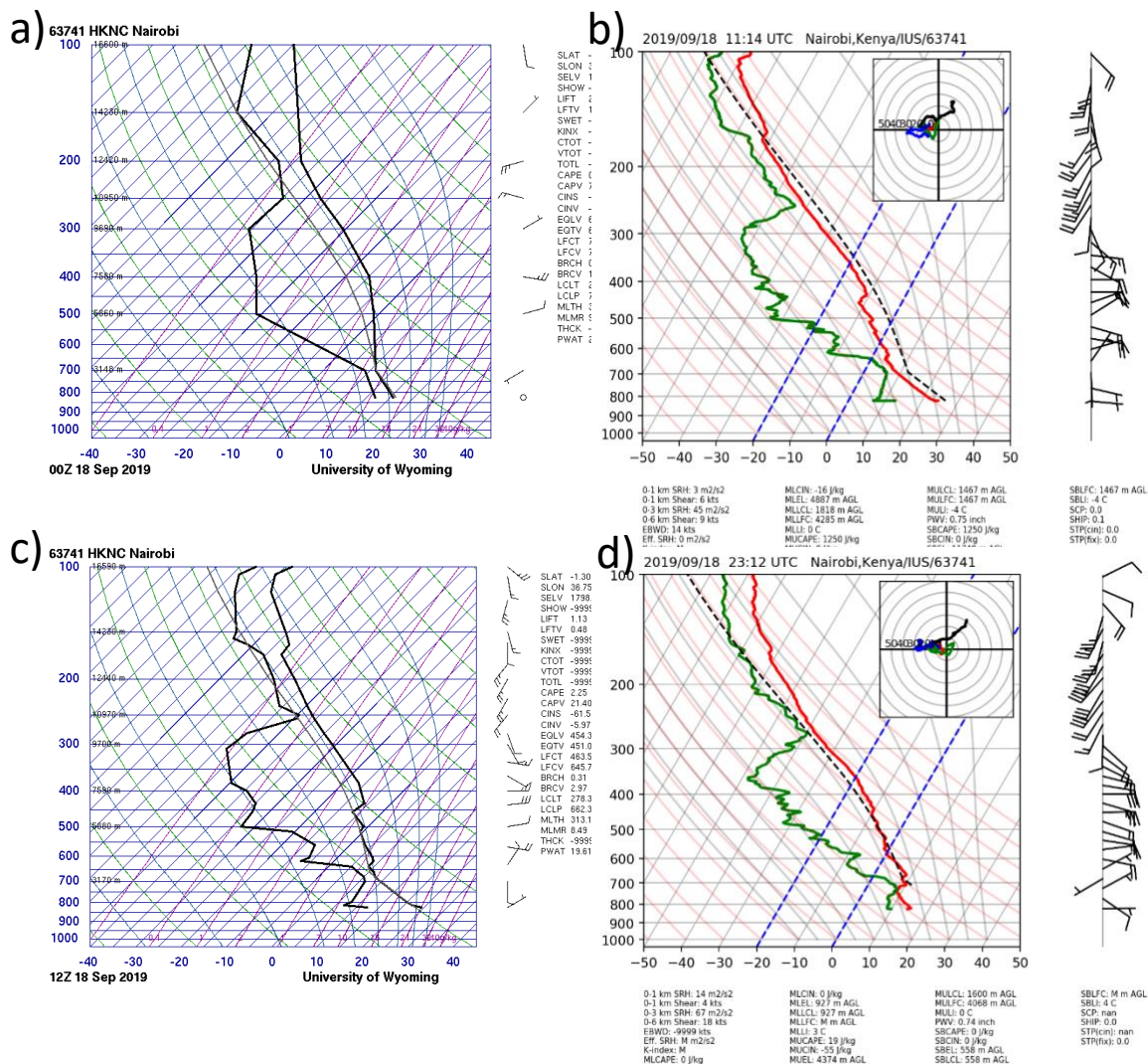


Figure 8. KMD Nairobi (63741) Skew-T plots from 18 September 2019 at 11-12 UTC (a,b) and 23-00 UTC (c,d). Lower resolution sounding data are plotted in (a) and (c). Higher resolution data are plotted in (b) and (d) from the BUFR files. Wind profiles are shown on the right-hand side of the plots. All plots are posted on the HIGHWAY Field Catalog.

UNMA Entebbe station

Several problems associated with the UNMA Entebbe UAS are being addressed but no issues were resolved during EOP-1 and EOP-2 time periods. The installation of the communications link from Entebbe radiosonde station building to the forecasting center was delayed by ongoing governmental administration procedures. The GPS clock drift timing of the Vaisala UAS system was addressed but not resolved. Data for internet was acquired and restoration of UAS has begun. Civil work for replacement of the hydrogen storage tank has begun. Resumption of the launching of twice daily soundings at Entebbe is anticipated to happen in October.

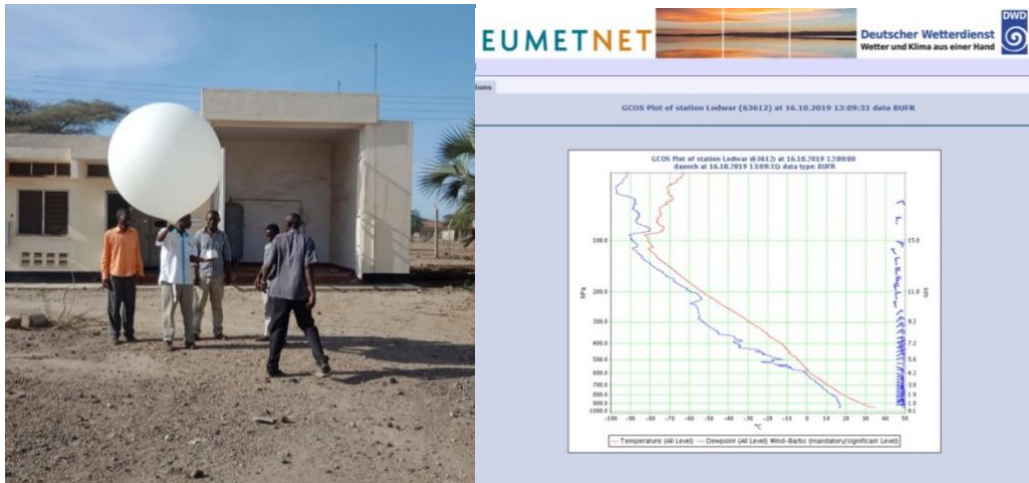


Figure 9. KMD prepares launch of radiosonde at the Lodwar UAS site on 17 October 2019. The sounding plot is shown on the right.

TMA Dar es Salaam GUAN station

The TMA Dar es Salaam UAS is likely to be the last UAS resurrected for the HIGHWAY project due to the long-time consignment of the HGS unit. Purchase orders for radiosondes (MODEM, France) and balloons (PAWAN, India) were issued in May with a shipment planned for Oct-November timeframe. TMA needs to specify and cost out the work on the HGS infrastructure and repair of the AWS system. The HGS unit is expected to be available for shipping at the earliest in mid-October. Installation, testing and training on the UAS system is expected to occur at the end of November. TMA plans to conduct a feasibility study in October for additional UAS sites in Mwanza and Kagera.

2.3 Satellite

The EUMETSAT Meteosat Second Generation (MSG) 11 (Meteosat-11) operates over Europe, Africa and the Indian Ocean. Data files collected by this satellite are being archived at NCAR and displayed in the CIDD system for direct comparison and analysis with radar and lightning data. Satellite imagery is updated every 15 min. A continuous archival of the Meteosat-11 channels in netCDF format from 1 March – 30 September 2019 is stored at NCAR. Specific channel images and Red-Green-Blue (RGB) derived satellite products (see Table 4) are available for viewing on the HIGHWAY Field Catalog (<http://catalog.eol.ucar.edu/highway/satellite>). Satellite images with EarthNetworks 15 min and 5 min strike accumulations are also posted on the field catalog website. Examples of these images are shown in Fig. 10 from 14 September 2019. These images at 0500 UTC show deep convective storms over the lake. Substantial lightning was associated with these storms (Fig. 10d). The RGB products also illustrate the convective nature of the storms and provide information on the microphysical composition of the storms (Fig. 11). The RGB products have been posted on the field catalog starting on 10 September. All satellite images on the catalog can be animated.

Table 4. List of data and imagery being archived during the Field Campaign.

| Meteosat-11 Channels | Meteosat-11 RGB Products |
|------------------------------------|--------------------------|
| Channel 4, near IR | RGB Convection |
| Channel 5, Upper-level water vapor | RGB Dust |
| Channel 6, Lower-level water vapor | RGB Microphysics |
| Channel 9, thermal IR | RGB NaturalColorEnhanced |
| Channel 10, Dirty thermal IR | RGB TropicalAirmass |
| Channel 12, Visible | |

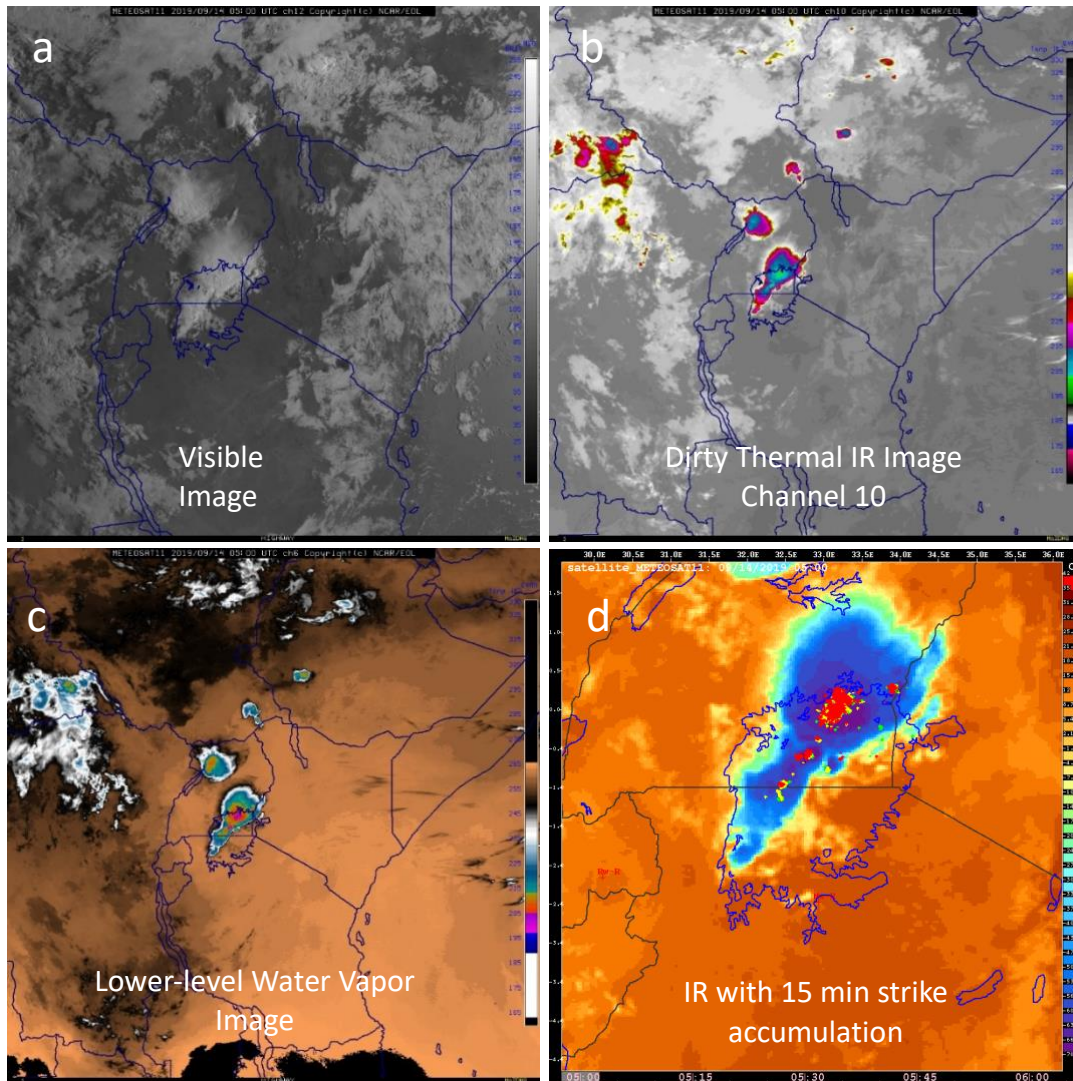


Figure 10. Imagery from the EUMETSAT Meteosat-11 satellite on 14 September 2019 at 0500 UTC. (a)-(c) Images from channels 12, 10 and 6 centered on East Africa. (d) Color-coded IR image magnified over Lake Victoria with EarthNetworks 15 min strike accumulations overlaid. Lake Victoria is outlined in all figures.

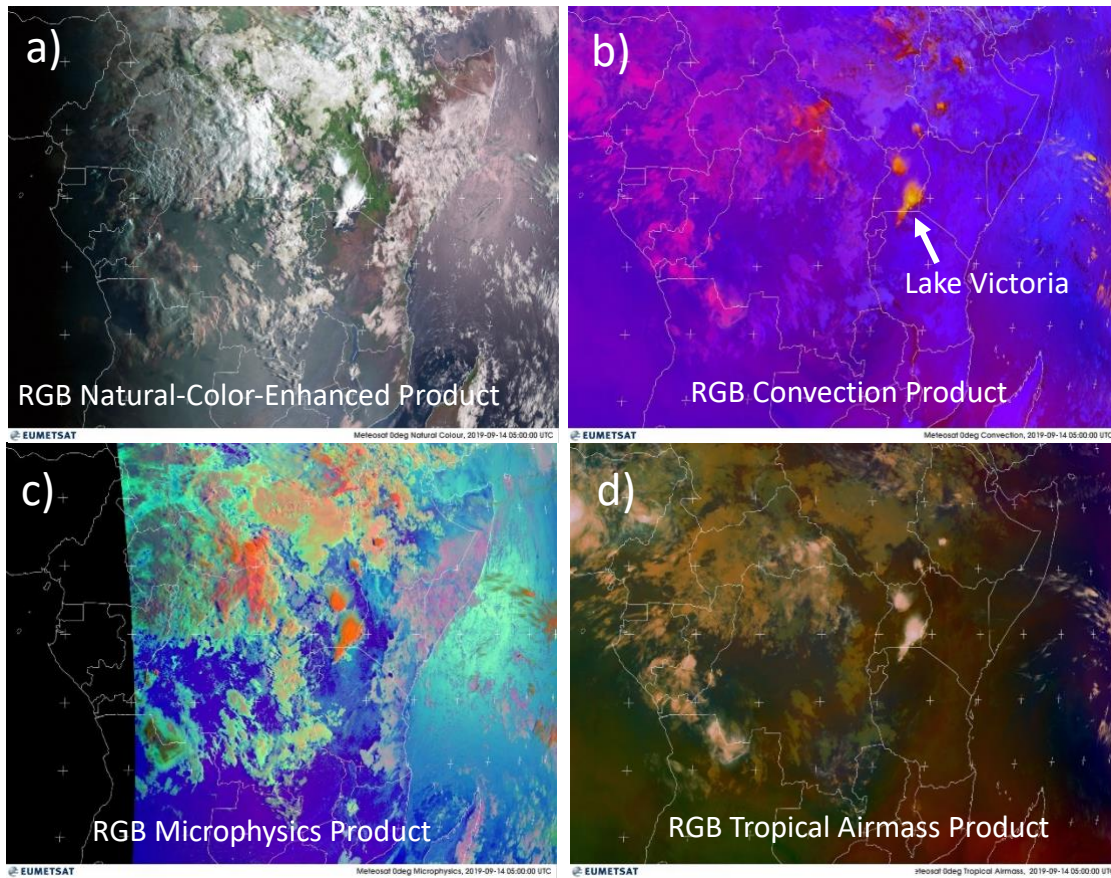


Figure 11. RGB product images from EUMETSAT Meteosat-11 data on 14 September 2019 at 0500UTC. Images include Central and East Africa regions. Lake Victoria is not outlined but is located at the confluence of Uganda, Kenya and Tanzania (see panel b).

2.4 Radars

TMA Radar

The Tanzania Meteorological Agency (TMA) purchased in 2015 a weather radar from EEC. The polarimetric radar is a state-of-the-art radar with a wavelength of 10 cm (S-band) and a one-degree beam-width (Waniha et al 2019). The radar is located in Mwanza on the south shore of Lake Victoria on a hill-top 136 m above the lake. In December 2017 NCAR radar meteorologists Rita Roberts and Jim Wilson traveled to Mwanza to work with Augustino Nduganda, the director of the TMA office in Mwanza and the radar engineer Benedicto Katole to develop radar scanning and data archiving procedures. These procedures were specifically designed to maximize the means for monitoring storm evolution over Lake Victoria and its basin. This included observing clear-air wind convergence features that precede storm initiation. The radar is able to cover the entire lake when running a low Pulse Repetition Frequency (PRF) scan although only the tops of tall storms are detected at farther ranges. Figure 12 is an example of a low PRF radar reflectivity scan on 27 March 2019 showing storms observed over Lake Victoria. At a higher PRF, the radar scans approximately half of the lake to the north of its location and collects full volumetric data within the storms. The present scanning strategy is shown in Table 5, which takes a total of 10 min to complete.

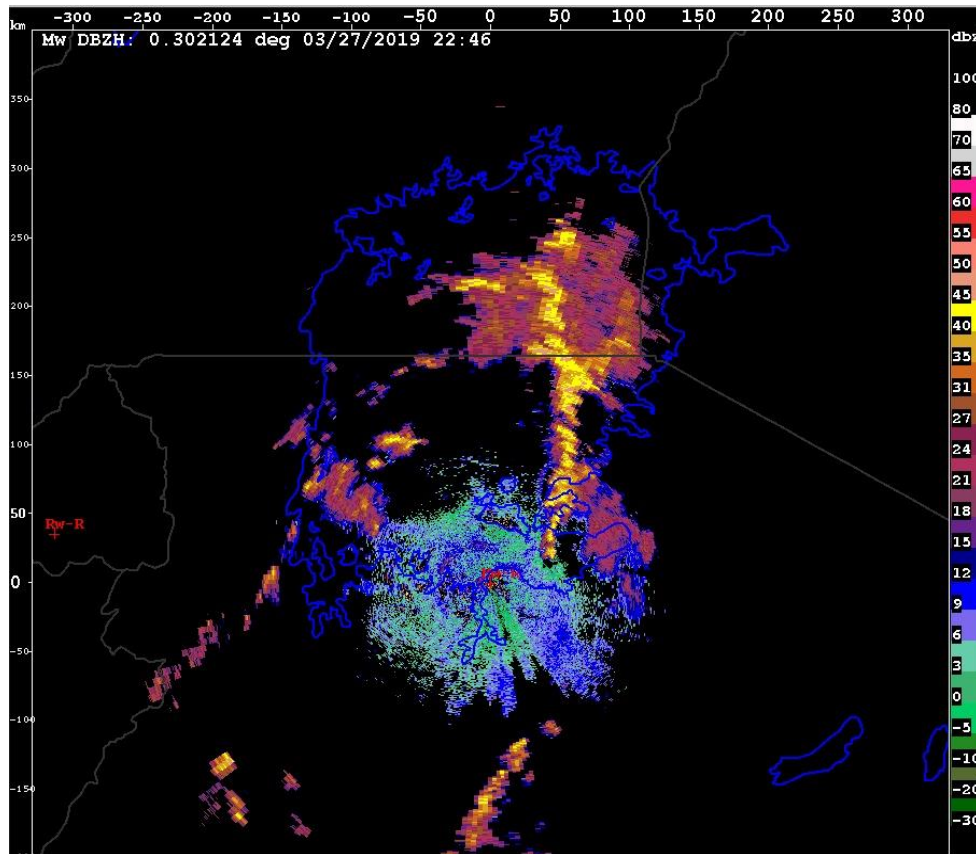


Figure 12. Low PRF radar reflectivity scan from the Mwanza radar on 27 March 2019 showing a N-S line of storms over Lake Victoria. The bluish echo around the radar is back-scattering from insects that are useful for obtaining clear air wind velocities and convergence lines.

Table 5. Scanning strategy of the TMA radar at Mwanza.

| Pulse Repetition Frequency (PRF) | Elevation angles (°) |
|----------------------------------|---|
| 400 | 0.3, 0.8, 1.5, 2.3, 3.3, 4.5 |
| 1000 | 0.3, 1.0, 1.7, 2.7, 3.7, 4.7, 7.0, 11.0, 18.0 |

Just prior to the start of the FC, on 12 February 2019, there was a health checkup by EEC at which time the velocity sign was fixed, and the clutter filters turned on. Also, the low and high PRFs were modified to perform correctly. There were generator and data archiving problems that persisted until 24 March. Additional data archiving problems continued until an EEC maintenance visit occurred on 4 July that resolved the issues. The Mwanza radar fiber optic link installation was completed during the 3rd week of June. However, the ability to transmit the radar data in real-time from the radar to the Dar es Salaam forecast office is still not fully functional at the time of this report. TMA is still working on the VPN data link tunneling between the Mwanza radar site and Forecasting office in Dar es Salaam.

For the HIGHWAY FC, the radar data is initially written to disk on the computer at the radar site and then on an approximately monthly basis, that data are copied to an external disk and mailed to NCAR for

archival and display in CIDD. Radar reflectivity, Doppler velocity and dual-polarimetric fields are being archived. Table A4 in Appendix 4 shows the complete list of radar data archived at NCAR. Low PRF radar reflectivity images are available for perusal in the HIGHWAY field catalog (<http://catalog.eol.ucar.edu/highway/radar>).

Figure 13 is an example of a north-south oriented squall line moving westward across the lake and adjoining land. The maximum radar reflectivities are 40-45 dBZ indicating heavy rain. Maximum Doppler velocities are 15-20 ms^{-1} with evidence of small rotational features along the squall line that might be waterspouts. This type of high impact weather could likely have affected fishermen on the lake that evening, although there are no reported accidents or fatalities that occurred that evening.

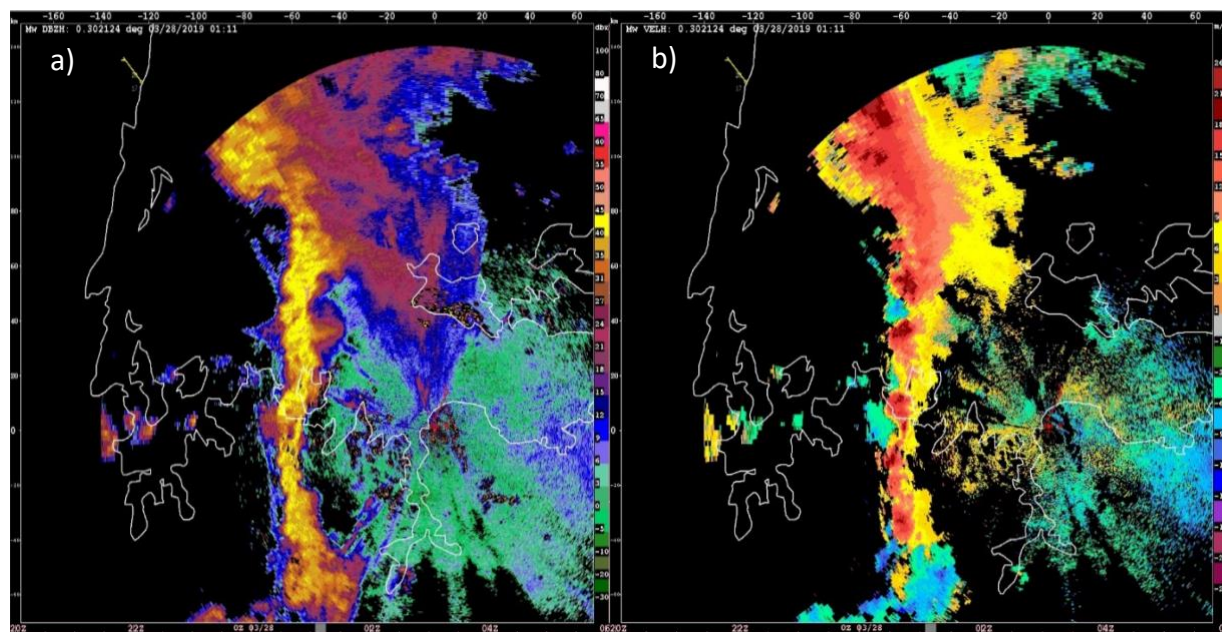


Figure 13. Radar reflectivity (a) and Doppler velocity (b) from the TMA Mwanza radar on 28 March 2019 at 01:11 UTC. The color-scales on the right side of each image indicate the reflectivity (dBZ) and Doppler velocity (ms^{-1}) values. The images show a squall line with heavy rain, strong near-surface winds and the possibility of waterspouts over the lake that likely posed a dangerous threat to small water craft.

From 15-18 July 2019, TMA hosted a radar interpretation workshop at their Dar es Salaam forecast offices (Fig. 14). Training was provided by NCAR radar meteorologists (Rita Roberts and Jim Wilson) on interpretation of the Mwanza radar data and how to make use of the radar data for nowcasting thunderstorms and accompanying severe winds over the lake. This training was very successful. By the end of the training workshop, forecasters and engineers were able to make one and two hour nowcasts of severe weather over the lake. Coincident with the training workshop, TMA hosted an Awareness Event on the HIGHWAY Project for various media outlets. Later, during the week of 5-14 August, TMA used CAPEX funds to arrange a visit to the Mwanza radar site by an EEC radar engineer to conduct radar preventative maintenance and calibration training for technicians, engineers and forecasters. This training exercise went very well.



Figure 14. Participants in the TMA radar interpretation training workshop.

During the remainder of the FC, the following additional derived fields have been requested to be archived to disk: the hydrometeor classification, corrected rain rate, rainfall, and vertically integrated liquid (VIL) fields. These products should provide additional useful information for the forecasters.

Météo Rwanda Radar

The Météo-Rwanda C-Band dual-polarimetric radar is located near Kigali and is used to detect and monitor heavy rainfall in that area and the potential for wind shear over the Kigali International Airport and the new Bugesera International Airport under construction. This radar is not controlled by Météo Rwanda but forecasters have access to the data and can view the data on a CIDD display. At the time of this report, no data from this radar has been shared with HIGHWAY partners during the FC and archival of this data for the HIGHWAY FC has not occurred. It is not known if any of the radar data is being archived to disk at Météo Rwanda.

UNMA Radar

The Entebbe weather radar (manufactured by VAISALA) has been installed and successfully configured in late June. The polarimetric radar has a wavelength of 5 cm (C-band) and a beamwidth of 1°. An official opening ceremony of the Entebbe radar by Uganda's authorities was planned for the beginning of July. At the time of this report, data collection and archival procedures are not known.

2.5 Lightning Networks

Earth Networks Total Lightning Network

Multiple near real-time commercial lightning networks cover the HIGHWAY experiment domain having varying detection performance owing to the design, location and density of sensors in Africa. Comparison studies show that the Earth Networks Total Lightning Network (ENTLN) is best for detecting total lightning activity over the Lake Victoria basin due to the high density of stations surround Lake Victoria. Special arrangements were made with Earth Networks to make this data available, free of charge, to the Highway Field campaign. Weekly 5-min daily animation loops of the ELTLN are posted to the Highway Field Catalog. An example of all lightning strokes for September 2019 is shown in Fig 15.

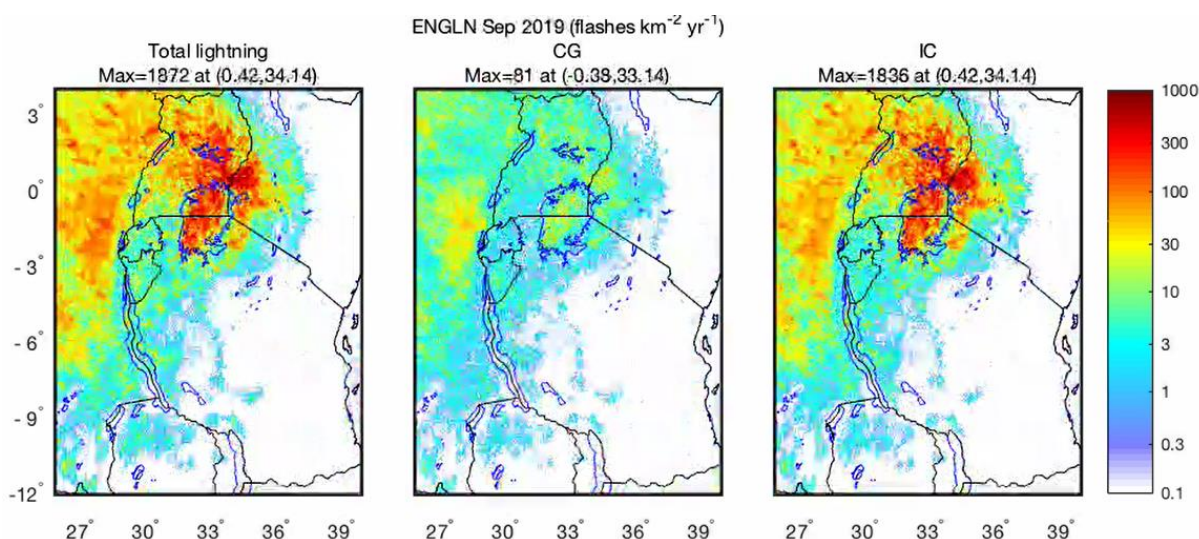


Figure 15. Earth Networks Global Lightning (ENGLN) for September 2019. Left panel (Total lightning), Middle panel (CG lightning), Right panel (IC lightning). Color scale at right in strokes $\text{km}^{-2} \text{yr}^{-1}$.

Comparison studies of the lightning with radar data showed a close relationship between radar reflectivity values greater than 35-40 dBZ with lightning flashes. This is evident from the lightning flashes from the ELTLN for a 15 min period centered on the time of the Mwanza radar reflectivity image (see Figs. 17b,d).

Virts and Goodman have developed lightning climatological statistics from the period September 2014 to August 2018. These statistics nicely show the frequency of lightning by hour and month and clearly illuminate the diurnal evolution of the thunderstorms over the lake and surrounding land. They have recently submitted a paper to Monthly Weather Review entitled "Prolific Lightning and Thunderstorm

Initiation Over Lake Victoria Basin in East Africa” that provides additional detail on the lightning statistical results.

UK ATDnet

In Africa, lightning-strike data are available at 5 min intervals through EUMETCAST, a 1 min resolution or ‘bundled” into data packages delivered at 15 min intervals and can be displayed on local workstations or overlaid onto other datasets such as satellite IR imagery. The ATDnet system can detect about one-third of the cloud-to-cloud and cloud-to-ground lightning strikes; much less than is observable with the EarthNetworks system. The UKMO collects and archives this data routinely. All data requests should be directed to the UKMO.

2.6 Vertical Profiling Systems

Additional instrumentation was highly desired for the Field Campaign to provide continuous, automatic, hourly reports of total precipitable water throughout the atmosphere. This data can be used in forecast offices to monitor day-to-day variations in the flow of moisture being supplied to thunderstorms forming over the lake, and to validate NWP analyses and forecasts, and NWP-satellite nowcast products, such as NearCast.

MODE-S

The MODE-S equipment is used to collect data from aircraft as they take-off, land, or pass over airports. These data can be interpreted to provide meteorological information. During the FC these data were not available in real-time but were collected and archived periodically by the UKMO. Equipment for the MODE-S receivers were installed in February through August at five airports: Entebbe, Mwanza, Kisumu, Nairobi, and Dar es Salaam with training given on the use of the equipment and troubleshooting procedures. Installation of a MODE-S receiver at Rwanda’s Kigali Airport is planned during Oct-November.

GPS-TPW

Originally at least one Global Position System (GPS)-Total Precipitable Water (TPW) instrument was planned for installation in the LVB region. However, the GPS-TPW requires access to US precision data which has very high licensing costs. The cost of procuring equipment suitable for accessing this data was outside of the budget allocated in the CAPEX experiment.

IGS

IGS data is available on hourly basis and is free while Continuously Operating Reference Systems (CORS) stations are privately operated networks that provide data at a cost. The UKMO has been involved in the collection and archival of this data. Request for this data should be made to the UKMO.

AMDAR

Kenya is still in the initial stages of testing Aircraft Meteorological Data Relay (AMDAR) equipment that has been installed on Kenya Airways aircraft. This data was not available for EOP-1 and EOP-2 of the Field Campaign.

2.7 Water measurements

No NMHSs buoys were deployed during the FC. The HyVic ferry boat measurements were collected up to November 2018, 3 months prior to the FC. No measurements were made during the period from

December 2018 – March 2019. The computer for collecting the ferry boat measurements would not boot in April 2019 and a computer virus was suspected as the cause. No other information is available on whether any water measurements were made for HyVic or during the remainder of the HIGHWAY FC.

2.8 UKMO NWP forecast fields

During EOP-1 of the Field Campaign, the UKMO ran two NWP models that include the East African region: the Operational Global Model (with parameterized convection) and the 4 km Tropical African Model (explicit convection). Model forecast fields are available to the forecasters for viewing primarily through the Met Office WMO VCP African Web Viewer, <https://www.metoffice.gov.uk/premium/vcpafrica>

Satellite and ATD lightning data observations are also available for viewing at this web site. Table 6 shows the run times, regional coverage, grid size and forecast hours of these models. During the FC the domain of the Tropical African Model was expanded to include a broader region of East Africa. The change in the domain size is shown in Fig. 16.

Table 6. Attributes of the UKMO Global and African NWP models.

| | Global Original | Global Current | African Original | African Current |
|------------------------------|------------------------------|---------------------------|------------------------------|----------------------------|
| Run Times | 00 and 12 | 06 and 18 | 00 and 12 | 06 and 18 |
| Regional Coverage | 5.5N - 12S 28.8-42.2E | 15N - 12S 22-52E | 5.5N - 12S 28.8-42.2E | 15N - 12S 22-52E |
| Grid Points | 187x96 | 288x214 | 438x337 | 676x751 |
| Forecast hours | 3 hourly from 15-33 hours | Vary by product | 3 hourly from 15-33 hours | Vary by product |
| Disk Space/day | ~10Mb | ~44Mb | ~65Mb | ~386Mb |

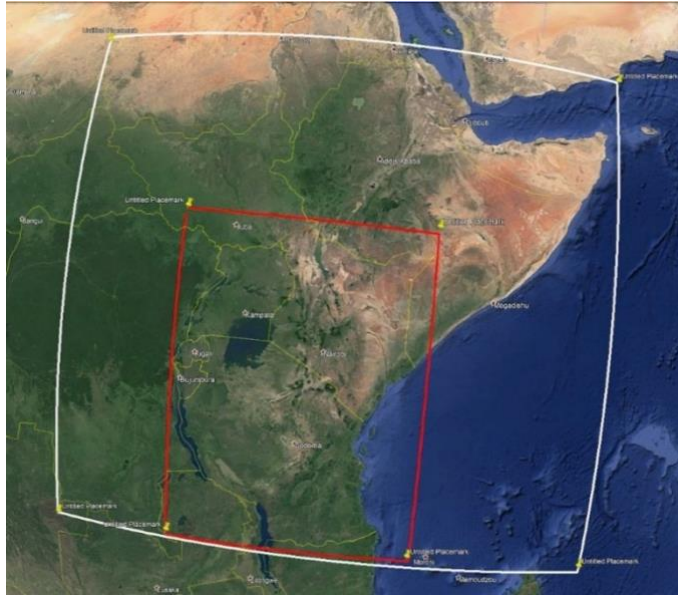


Figure 16. Domain in original model set-up (red outline) and in current set-up (white).

UKMO NWP fields are archived at the UKMO and at NCAR. Requests for UKMO NWP fields should go through Andy Hartley and Caroline Bain at the UKMO. Tropical African model fields are ingested into the CIDD display for comparison with the observational datasets. Figure 17 shows the 21 h precipitation forecast field from this model and the radar, satellite and lightning observations at forecast valid time. NCAR has data archived from 12 April through 25 September, with 13 days of missing data. Data stored at NCAR is available upon permission by the UKMO. The list of product fields archived at NCAR are shown in Table 7.

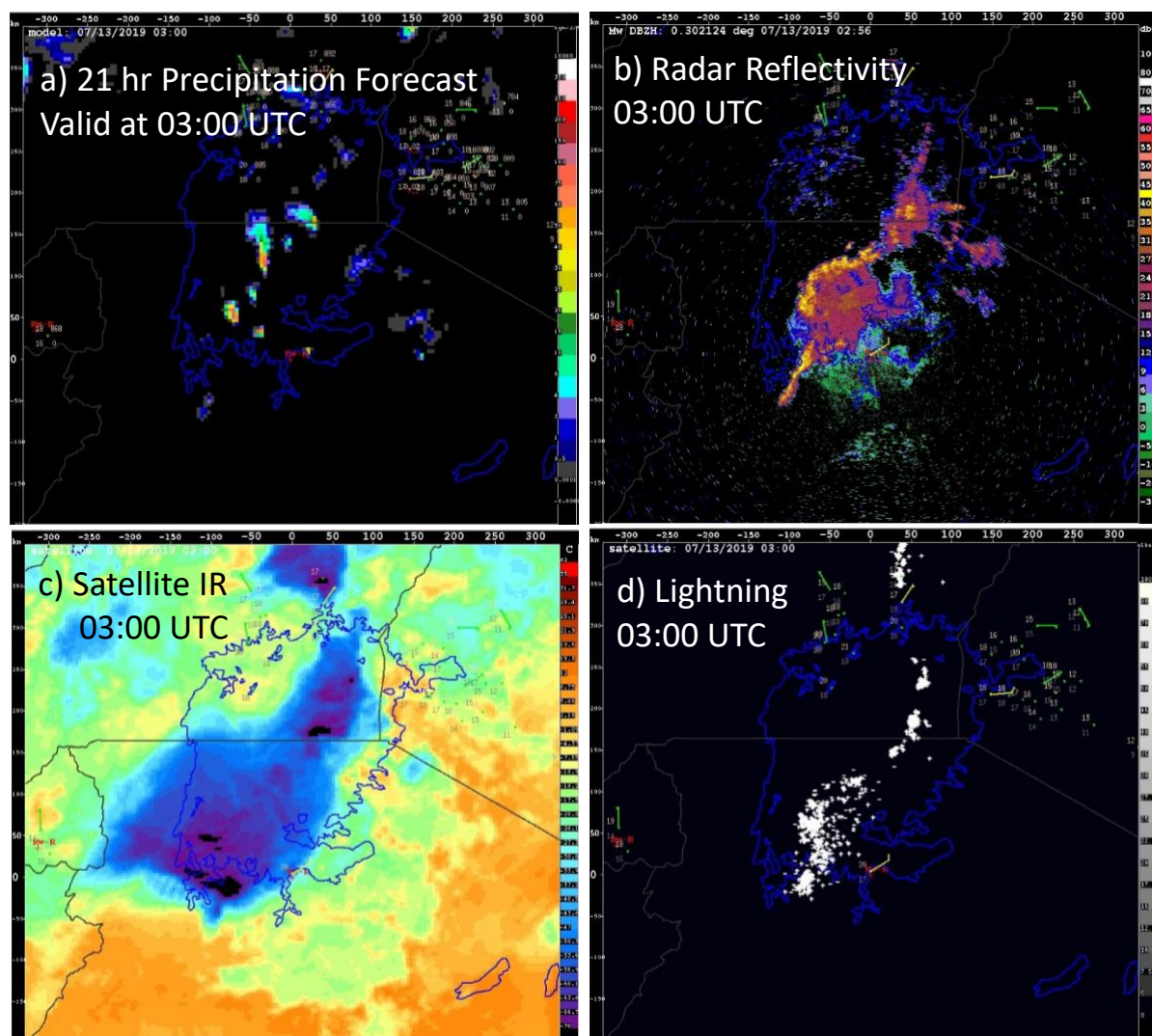


Figure 17. a) Twenty-one hour model precipitation forecast for 11 July 2019 at 0300 UTC; b) radar reflectivity from Mwanza low PRF scan at 0300 UTC; c) IR satellite image at 0300 UTC; d) location of 10 min strike accumulations at 0300 UTC.

Table 7. List of product fields available in the African Tropical model archived at NCAR.

| Product Field | Levels | Forecast Hours |
|------------------------------------|---------------------------------|---|
| Instantaneous Temperature | 1.5 m and 850, 700, 500, 200 mb | -1 Hourly, from 13-24 hr forecast periods and -3 Hourly, from 14-33 hr |
| Instantaneous Dewpoint Temperature | 1.5 m and 850, 700, 500, 200 mb | -1 Hourly, from 13-24 hr forecast periods and -3 Hourly, from 14-33 hr |
| Instantaneous Uwind, Vwind | 10 m and 850, 700, 500, 200 mb | -1 Hourly, from 13-24 hr forecast periods and -3 Hourly, from 14-33 hr |

| | | |
|--|-----------------------|---|
| Relative Humidity | 850, 700, 500, 200 mb | -1 Hourly, from 13-24 hr forecast periods and -3 Hourly, from 14-33 hr |
| 3 hr Stratiform rainfall amount | | 3 Hourly, from 13 – 35 hr forecast periods |
| 6 hr Stratiform rainfall amount | | 6 Hourly, from 13 – 35 hr forecast periods |
| Instantaneous Stratiform rainfall flux | | Hourly, from 13 – 35 hr forecast periods |

2.9 HyVic Pilot Flight Campaign

As part of the HyVic, MOYA², and HyCRISTAL programs, research aircraft flights were conducted during the period from 24-28 January 2019 to collect atmospheric observations over the lake during the pre-convective environment and examine the diurnal cycle of lake and land breezes. Flight path tracks were oriented from the Entebbe to the SE side shore of Lake Victoria. One of the evening transects cut right through a lake breeze front. Dropsondes were released across the lake to obtain vertical profiles of circulations. The flights were deemed very successful, meeting the data collection and research objectives. To complement the instrumented aircraft observations, data from surface stations located in the LVB region were provided by TAHMO to the UKMO for inclusion in the data analysis. Table 8 shows the TAHMO stations included in this study.

Table 8. Locations of the TAHMO stations being included in HyVic aircraft flight research analyses.

| ID | Name | Country | Latitude | Longitude |
|---------|------------------------------|----------|----------|-----------|
| TA00146 | Greenergia | Kenya | -0.148 | 34.623 |
| TA00374 | JOUST | Kenya | -0.093 | 34.26 |
| TA00401 | Homa Bay High School | Kenya | -0.538 | 34.46 |
| TA00499 | Urudi Mixed Secondary School | Kenya | -0.284 | 34.955 |
| TA00500 | Osodo Secondary School | Kenya | -0.524 | 34.256 |
| TA00589 | Juma Island | Tanzania | -2.438 | 32.747 |
| TA00590 | LVBWB | Tanzania | -2.538 | 32.906 |
| TA00214 | Bukasa Secondary Sch | Uganda | -0.454 | 32.495 |
| TA00216 | Makerere Synoptic | Uganda | 0.334 | 32.569 |
| TA00424 | Wanyange Girls School | Uganda | 0.483 | 33.244 |
| TA00445 | Koome Island HQ | Uganda | -0.081 | 32.733 |

² For information on the MOYA campaign, see <http://homepages.see.leeds.ac.uk/~earjrmc/MOYA/MOYA/index.html>

2.10 NMHS forecast reports

TMA, KMD and UNMA are routinely uploading their 24 h Forecasts for fishermen on Lake Victoria to the HIGHWAY Field Catalog (<http://catalog.eol.ucar.edu/highway/reports>). An example of the reporting section of the Field Catalog is shown in Fig. 18 below.

The screenshot shows the 'HIGHWAY Field Catalog' interface with a green header. Below the header is a navigation bar with links: Home, Reports (selected), Products, Case Studies, Tools & Links, and Help. The main content area shows the 'Reports' section for '2019-10-14 (UTC)'. It includes a 'View files' section with a table of reports. The table has columns for 'View files', 'Latest report', and 'Action'. The reports are categorized into 'Agency Reports', 'Discussions', and 'Summaries'. Each report entry includes the agency name, the latest report date and time (UTC), and buttons for 'Write new report' and 'Upload file'.

| View files | Latest report | Action |
|--|------------------------|--|
| Agency Reports | | |
| Kenya Meteorological Department | 2019-10-14 18:00 (UTC) | Write new report Upload file |
| Lake Victoria Basin Commission | 2019-10-11 03:30 (UTC) | Write new report Upload file |
| Meteo Rwanda | 2019-10-11 03:30 (UTC) | Write new report Upload file |
| Tanzania Meteorological Agency | 2019-10-14 06:00 (UTC) | Write new report Upload file |
| Uganda National Meteorological Authority | 2019-10-14 12:43 (UTC) | Write new report Upload file |
| UK Met Office | 2019-10-11 03:30 (UTC) | Write new report Upload file |
| Discussions | | |
| Field Catalog Image Outages | 2019-10-07 22:00 (UTC) | Write new report Upload file |
| Scientific Report | 2019-09-27 00:00 (UTC) | Write new report Upload file |
| Summaries | | |
| Weekly Lightning Loops | 2019-10-04 00:00 (UTC) | Write new report Upload file |
| Weekly Weather Summary | 2019-09-06 00:00 (UTC) | Write new report Upload file |

Figure 18. HIGHWAY Field Catalog web page for uploading 24 h forecast reports posted by TMA, KMD, and UNMA. Weekly animations of EarthNetworks lightning data and weekly weather summary reports produced by NCAR are also posted to this page.

TMA Weather Summary

TMA began uploading their 24 h weather summaries starting on 24 March. Their weather summaries include 3 hr reports temperature, 24 h rainfall accumulations, wind speed and direction from the weather stations located around the Lake and radar images at selected time periods that show weather activity over the lake (Fig. 19). Advisories for weather, winds, and wave heights are also included in the report.

TANZANIA METEOROLOGICAL AGENCY
HIGHWAY FIELD CAMPAIGN
WEATHER SUMMARY FOR THE PAST 24HOURS FROM 20/08/2019-0000 UTC
TO 21/08/2019-0000 UTC

1. Introduction

During the period, mainly dry conditions dominate the Lake

Impact

We have not received an impact associated with the storms

Meteorological Data from Automatic Weather Stations around the Lake Victoria

1. Muleba AWS (Lat 01°51'07.7"S Long ...31°39'03.9" Altitude 1188M)

| Parameter | 0000Z | 0300Z | 0600Z | 0900Z | 1200Z | 1500Z | 1800Z | 2100Z | 0000Z |
|------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| Temperature(°C) | / | / | / | 24.2 | 29.5 | 24.6 | 20.0 | 17.2 | 18.4 |
| Rainfall(24hrs) | 0.0 mm | | | | | | | | |
| W/Direction(Deg) | / | / | / | 124 | 143 | 25 | 358 | 212 | 130 |
| W/Speed(m/s) | / | / | / | 3.5 | 1.2 | 1.7 | 0.5 | 0.5 | 0.6 |

2. Chato AWS (Lat 2°38'10"S Long 31°44'16" Altitude 1181M)

| Parameter | 0000Z | 0300Z | 0600Z | 0900Z | 1200Z | 1500Z | 1800Z | 2100Z | 0000Z |
|------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| Temperature(°C) | 20.9 | 18.5 | 21.7 | 26.6 | 29.6 | 27.8 | 23.2 | 21.6 | 21.4 |
| Rainfall(24hrs) | 0.0 mm | | | | | | | | |
| W/Direction(Deg) | 239 | 218 | 147 | 93 | 44 | 39 | 322 | 241 | 144 |
| W/Speed(m/s) | 2.4 | 1.2 | 3.5 | 3.2 | 2.7 | 2.6 | 1.1 | 2.2 | 0.3 |

3. Ukerewe AWS (Lat 2°5'23.9" , Long 33°5'28.0", Altitude 1175M.)

| Parameter | 0000Z | 0300Z | 0600Z | 0900Z | 1200Z | 1500Z | 1800Z | 2100Z | 0000Z |
|------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| Temperature(°C) | 20.9 | 21.0 | 22.4 | 26.5 | 29.5 | 28.4 | 23.3 | 22.5 | 22.6 |
| Rainfall(24hrs) | 0.0 mm | | | | | | | | |
| W/Direction(Deg) | 72 | 87 | 99 | 99 | 143 | 224 | 317 | 10 | 94 |
| W/Speed(m/s) | 0.8 | 2.9 | 3.3 | 3.4 | 1.2 | 1.3 | 1.2 | 1.2 | 1.6 |

4. Tarime AWS (Lat 01°51'07.7"S Long 31°03'03.9" Altitude 1353M)

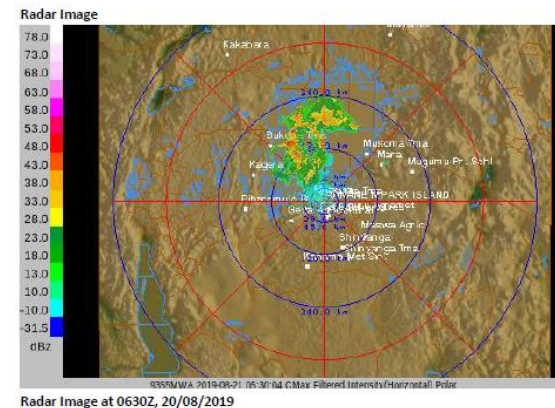
| Parameter | 0000Z | 0300Z | 0600Z | 0900Z | 1200Z | 1500Z | 1800Z | 2100Z | 0000Z |
|------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| Temperature(°C) | 18.0 | 19.5 | 21.9 | 27.1 | 28.9 | 24.1 | 18.9 | 19.3 | 20.1 |
| Rainfall(24hrs) | 0.6 mm | | | | | | | | |
| W/Direction(Deg) | 118 | 355 | 76 | 177 | 287 | 298 | 68 | 81 | 231 |
| W/Speed(m/s) | 1.5 | 0.7 | 2.2 | 1.3 | 2.5 | 1.9 | 1.2 | 1.0 | 0.7 |

MARINE WEATHER FORECAST FOR LAKE VICTORIA FOR NEXT 24 HOURS VALID FROM 21st
AUGUST 2019 AT 0000Z UNTIL 22nd AUGUST 2019 AT 0000Z.

| ADVISORY | STRONG WINDS REACHING 40 KM/HR AND LARGE WAVES REACHING 2M AT TIMES ARE EXPECTED. | | |
|--------------------------------------|---|---|-------------|
| PORT SECTOR | WEATHER | WIND | WAVE HEIGHT |
| NW: BUCORA, KIMONOKI, HUMBURI, | Partly Cloudy condition, Thunderstorms over few areas and sunny periods. Visibility: MODERATE. | SE at 5-10KT for the next 12hours, becoming N at 5- 10KT for the next 6hours., becoming NW at 5-10KT for the remaining forecast time. | 1.0-2.0m |

| | | | |
|---|---|---|----------|
| NE: MUSOGA, SIKUTU, MUDANNO, MURI, MAITA | Partly Cloudy condition, Thunderstorms over few areas and sunny periods. Visibility: MODERATE. | SE at 5-10KT for the next 6hours, becoming SW at 5-15KT for the next 6hours, becoming NW at 5-10KT for the next 6hours., becoming NE at 5-10KT for the remaining forecast time. | 1.0-2.0m |
| SW: CHATUNYAMBEMBE, BUKONDO, KIZUA | Partly Cloudy condition and sunny periods. Visibility: GOOD. | SE at 5-20KT for the next 6hours, becoming NE at 5-10KT for the next 6hours, becoming N at 5-10KT for the next 6hours, becoming SW at 5-10KT for the remaining forecast time. | 1.0-2.0m |
| SE: MWARUA, NANSIO, UGARA, BUBU, KAMANDA, KUMI, MAKOME | Partly Cloudy condition and sunny periods. Visibility: GOOD. | SE at 5-20KT for the next 6hours, becoming NW at 5-10KT for the next 6hours, becoming N at 5-10KT for the next 6hours, becoming SE at 5-10KT for the remaining forecast time. | 1.0-2.0m |

Figure 19. Example of TMA 24 hr weather summary report.



KMD 24 h Forecasts

Starting on 30 March, KMD has been uploading their 24 h forecast for the fishermen on Lake Victoria. They also provide graphical forecasts for Zones 1 and 2 that include information on wind strength, wave height, cloud cover, rainfall and rainfall distribution, visibility and color-coded hazard level over the lake (Fig. 20a-c).

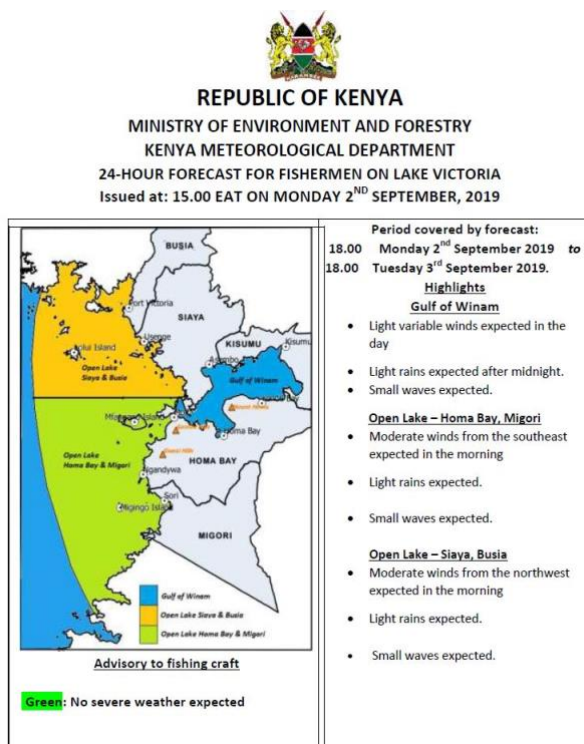


Figure 20. a) KMD's 24 h forecast for fishermen; b) KMD's Zone 1 graphical forecast; c) KMD's Zone 2 graphical forecast.

| Zone 1: Gulf of Winam | | | | | | |
|------------------------------------|-----------------------------|-------------|--------------------------|--------------------------|------------|---------|
| Monday 02/09/2019 | Wind strength /direction | Wave height | Rainfall/ Cloud cover | Rainfall distribution | Visibility | Hazards |
| Night before midnight | | | | | | |
| Night after midnight | | | | | | |
| Tuesday 03/09/2019 Morning | | | | | | |
| Tuesday 03/09/2019 Afternoon | | | | | | |

| Zone 2. Open Lake - Homa Bay, Migori | | | | | | |
|--------------------------------------|-----------------------------|-------------|--------------------------|--------------------------|------------|---------|
| Monday 02/09/2019 | Wind strength /direction | Wave height | Rainfall/ Cloud cover | Rainfall distribution | Visibility | Hazards |
| Night before midnight | | | | | | |
| Night after midnight | | | | | | |
| Tuesday 03/09/2019 Morning | | | | | | |
| Tuesday 03/09/2019 Afternoon | | | | | | |

UNMA 24 h Forecasts

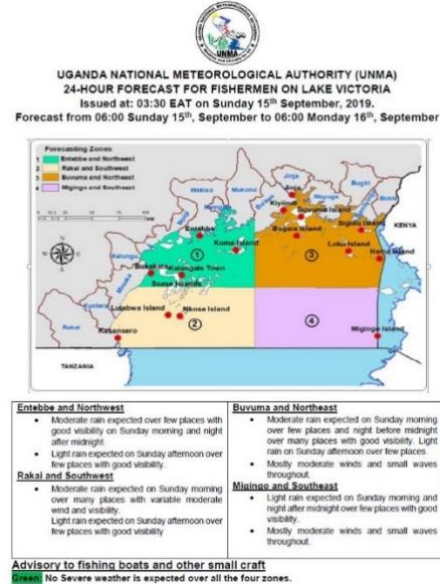
From 9-12 September, UNMA hosted a 4-day workshop in Kalangala, Ssese Islands to intermediaries to improve their understanding of UNMA marine forecasts (Figure 21a) communicated to local people through WhastApp. Each day of the workshop a different group of intermediaries attended. Starting on 14 September, UNMA began routinely uploading their 24 h forecasts for fisherman on Lake Victoria to the HIGHWAY catalog (Fig. 21b-d).



Zone 1: Entebbe and Northwest

| Sunday 15/September | Wind strength | Wind direction | Wave height | Weather | Rainfall distribution | Visibility | Hazards |
|-----------------------|---------------|----------------|-------------|---------------|-----------------------|------------|---------|
| Sunday Morning | Moderate | Northeast | Small waves | Moderate rain | Few places | Good | |
| Sunday Afternoon | Moderate | Southeast | Small waves | Light rain | Few places | Good | |
| Night before midnight | Light | Northwest | Small waves | Partly cloudy | | | |
| Night after midnight | Light | Variable | Small waves | Moderate rain | Few places | | |

Figure 21. a) Intermediaries being trained on UNMA marine forecasts; c) Zone 1 forecasts.



Zone 2: Rakai and Southwest

| Sunday 15/September | Wind strength | Wind direction | Wave height | Weather | Rainfall distribution | Visibility | Hazards |
|-----------------------|---------------|----------------|-------------|---------------|-----------------------|------------|---------|
| Sunday Morning | Moderate | Variable | Small waves | Moderate rain | Many places | Moderate | |
| Sunday Afternoon | Moderate | Southeast | Small waves | Light rain | Few places | Good | |
| Night before midnight | Light | West | Small waves | Partly cloudy | | | |
| Night after midnight | Moderate | South | Small waves | Partly cloudy | | | |

b) UNMA 24 h marine forecast from 15 September; d) Zone 2 forecasts.

3 Data Archival and Displays

A subset of the NMHS synoptic AWS stations are archived continuously on the GTS. As the UAS are resurrected in the region, these data are or will be transmitted and archived on the GTS. Under the WMO strategic goals, acquisition of all in-situ and space-based observing systems within the WMO will be consolidated into a single integrated system: the WMO Integrated Global Observing System (WIGOS) which will become operational in 2020, unfortunately after the HIGHWAY FC has concluded. For the HIGHWAY FC, KMD is tasked with setting up a regional data archival system. Procurement of this archival system is ongoing.

NCAR Field Catalog

At start of the FC on 1 March, HIGHWAY participants were notified that a HIGHWAY Field Catalog web site (<http://catalog.eol.ucar.edu/highway>) was created by NCAR for viewing observations collected during the FC EOP periods. Initially the Meteosat-11 satellite imagery and EarthNetworks lighting data were posted to this web site under the "Products" tab (see Fig. 22). As additional observations, videos, photos, and

weather forecast reports (see Figs. 18-21 above) became available, these data were also posted to the field catalog and HIGHWAY partners were notified of the new products. Figure 20 shows all of the satellite-based products that can be viewed currently on the web site. Images can be animated over 6, 12 or 24 hour periods. The available imagery from any day during the FC can be viewed at this web site by clicking on the “Choose Other Date” button and selected the date of interest.

Figure 22. HIGHWAY Field Catalog Products page. Satellite, radar, lightning, surface station and upper air plots are posted to these web pages. Shown here are the list of satellite fields from 13-14 October that are available for viewing. Movie loops (animations) of these images are also possible by selecting on the right-hand side of this page to loop the last 6, 12 or 24 images. Other days of data can be viewed by selecting to Choose Other Date (UTC) at the top or bottom of this page.

UK and EUMETSAT NWC SAF forecast/nowcast displays

During the FC, The UKMO provides both the Global and the Tropical Africa 4km model products to the East Africa partners, along with satellite and lightning observations. There are a variety of platforms available for viewing these fields. The primary tool for viewing the operational products is the UKMO WMO VCP Africa web viewer located at <https://www.metoffice.gov.uk/premium/vcpafrica>. Another platform for viewing the NWP products is located at http://gws-access.ceda.ac.uk/public/mo_forecasts/restricted/TropAfrica/mo_f_tufr_dtime.html. This website is intended for use by scientists and NMHSs who are collaborating on projects with the UKMO. The

EUMETSAT NWC SAF products for East African, which include the Rapidly Developing Thunderstorms (RDT) satellite-based product, are available for viewing on the NCAS African SWIFT catalog (<https://sci.ncas.ac.uk/swift/categories/view/176>) page.

NCAR CIDD display

Working closely with Pascal Waniha and the IT team at TMA, Mike Dixon (NCAR) installed the NCAR CIDD display system on TMA's three Edge machines at the Dar es Salaam forecast office from 27-29 May 2019. An overview document was added to the GitHub web page, showing how to start up CIDD for the various radar cases stored on the Edge workstations. See: <https://github.com/NCAR/lrose-projects-lakevic>. Two USB drives of Mwanza radar data were left at TMA so that they can be used when running CIDD. Forecasters were trained by Roberts and Wilson on the use of CIDD during the radar interpretation training workshop at TMA in July.

On 29 May, Dixon travelled to Mwanza and worked with the radar engineer to install CIDD on the Edge workstations at the TMA Meteorological office at the Mwanza Airport. Dixon worked with Benedict Katole and Augustino Nduganda (Fig. 23). Staff at the Mwanza office were shown the basics of the CIDD capabilities - zooming, vertical sections, time control, movie loops, changing fields, and other field manipulation steps. Mwanza staff caught on really quickly; good progress was made. An example of the CIDD display system installed on one of the Edge workstations at Mwanza is shown on the right-hand side in Fig. 23.

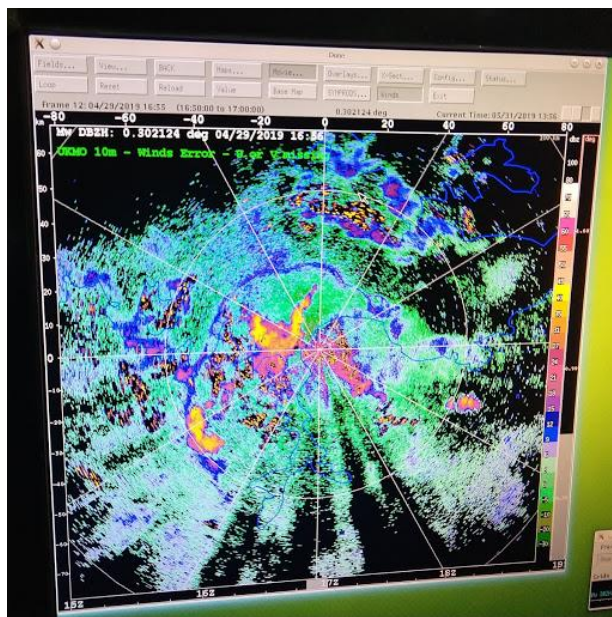


Figure 23. CIDD installation on Edge workstations at Mwanza radar site.

4 Recommendations

4.1 Sustainability of an Early Warning System

Experience during the Highway Field Campaign has highlighted the problem of insufficient local funding to maintain an inventory of spare parts, to support or hire sufficient engineering and technician staff to maintain instruments, purchase maintenance contracts as needed, and train meteorological staff on how to produce severe storm nowcasts. This is not unexpected and has been part of the motivation for the HIGHWAY project and provision of CAPEX funds. While CAPEX funds have contributed toward improving the situation, long term, dedicated funding is required if progress is to be made in developing a long-term detection, nowcasting and early warning system for high impact weather over LVB. A sustainable EWS requires observations, nowcast products and NWP forecasts be transmitted in real-time to a centralized location in the forecast office so that a forecaster has the latest information available for guidance in producing warnings for LVB. Lack of observations due to instrument failure, poor quality of data due to insufficient maintenance, or delays in communications greatly hamper the forecaster's ability to provide accurate and timely warnings that could save lives. Therefore, the sustainability of an EWS will be dependent on long term funding for instrumentation maintenance, support of engineer and meteorologist involvement, and funding training.

4.2 Radar Coverage over LVB

The Mwanza radar has demonstrated that it can consistently observe thunderstorms over the entire lake even though the northern part of the lake is >350 km away from the radar. This is based on comparison of radar echoes and lightning strokes from the Earth Networks lightning array. Although the radar beam at this range is about 8.5 km above the lake, the tall heights of these storms has allowed the storm tops to be detected by radar at far ranges. At closer radar ranges, within about 120 km, the Mwanza radar routinely observed convergence lines associated with land breezes, sea breezes and gust fronts. There were also numerous convergence lines of unknown origin that may possibly have been associated with horizontal temperature gradients in the lake. Storm initiation was often traced to these various types of convergence lines and inferred updrafts. Detecting these convergence lines prior to storm initiation provides additional lead time in nowcasting thunderstorm initiation. In addition, Doppler radial velocities provide measurements of wind speeds associated within thunderstorms and winds at low-levels over the lake. These velocity observations can be used to provide warnings of high winds associated with intense thunderstorm outflows. Small rotations have been observed in the Doppler velocity field along convergence lines (see Fig. 13b, for example). These rotations have the potential to evolve into waterspouts (Fig. 24) when stretched vertically by the updrafts of developing storms overhead. Lastly, the dual-polarimetric fields collected by the Mwanza radar provide the ability to monitor the microphysical changes within the storms and storm intensification. As the storm composition quickly changes from water drops to mixtures of water, graupel, ice and hail, forecasters can use this information to issue warnings for severe storms. The hydrometeor classification field that is based on a combination of dual-polarimetric fields and is available through the EEC Edge software is an important field for the forecaster, providing automated classification of hydrometeor types within storms, especially hail and heavy rain.

These capabilities observed with the Mwanza radar significantly elevate the possibility that major advances in an early warning system can be realized and that lives can be saved. It is reasonable to expect

that these same capabilities will be evident in the recently installed Entebbe radar on the northwest coast of the lake. We recommend that a new dual-polarimetric radar be purchased and installed on the north east side of the lake in Kenya. This will enable complete, high resolution coverage of storms and low-level flow over the lake, particularly within KMD's maritime zones. Specific recommendations for the EAC radars follow.

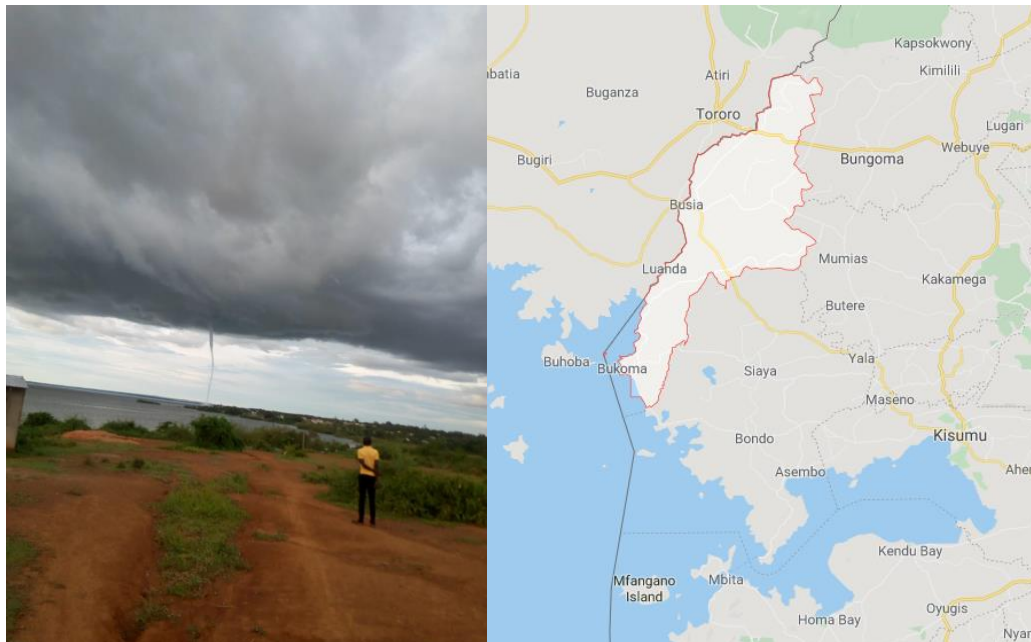


Figure 24. Waterspout observed and reported by a volunteer observer for the fishery forecast on 18 October 2019 in Kenya's Busia County over the open lake. Busia County is outlined in red on the Google map (see right-hand panel). The waterspout occurred in a region where no low-level radar observations are available. Note the flat cloud-based indicative of the storm updraft region. (Photo courtesy of Paul Oloo).

KMD

- Install a dual-polarimetric, S-band, 1° beamwidth radar on the northeast shore of Lake Victoria
- Implement scanning strategies to: a) optimize storm detection, structure and evolution over Lake Victoria and its basin; b) optimize the ability to observe convergence lines in regions outside of precipitation areas over the lake and land.
- Employ dedicated engineer and radar meteorologist with suitable radar training.
- Archive all data.

UNMA

- Implement scanning strategies for the Entebbe radar to: a) optimize storm detection, structure and evolution over Lake Victoria and its basin; b) optimize the ability to observe convergence lines in regions outside of precipitation areas over the lake and land.
- Obtain long term maintenance contract

- Develop efficient procedures to archive radar data and to maintain the radar
- Employ dedicated engineer and radar meteorologist with suitable training.

TMA

- Establish a long-term archive of collected radar data and develop climatologies of storm occurrence and evolution for the Lake Victoria Basin.
- Produce regional radar mosaics for LVB using data from Mwanza, Entebbe, and Rwanda radars

Météo Rwanda

- Establish a long-term archive of collected radar data and develop climatologies of storm occurrence and evolution for the Lake Victoria Basin.
- Collaborate with TMA and UNMA on producing regional radar mosaics

4.3 Regional High Resolution Lightning Network

During the field campaign lightning data was routinely available from EarthNetworks and also the UK's ATDnet. It has been long recognized that the ATDnet system can only detect about one-third of the cloud-to-cloud and cloud-to-ground lightning strikes and this is much less than is possible with the EarthNetworks system. Ongoing research studies with the EarthNetworks system (Virts and Goodman 2019) show that because of the density of lightning receivers around the lake, this high resolution dataset is very useful for diagnosing the onset and development of high impact convective weather over LVB. High resolution lightning data should be included within an EWS of hazards over the lake. It is important that the NMHSs obtain access to a regional, high resolution lightning network or work to establish their own lightning network that is similar in quality to that obtained by EarthNetworks.

With the launch of the EUMETSAT's Meteosat Third Generation (MTG) satellite in late 2021, the new MTG-Flexible Combined Imager (FCI), Infrared Sounder (IRS) and Lightning Imager (LI) will serve as additional data sources to diagnose and characterize the pre-convective environment and monitor storm evolution over the region. This data should become available through the suite of EUMETSAT products and available to NMHS through their EUMETSAT receivers and workstations. However, in the short-term it is recommended that funds be made available to obtain lightning data from a regional lightning network and make this data routinely available to forecasters to help them prepare for the MTG era when improved spatial and temporal satellite and lightning observations become available. Coupled with the new and forthcoming observations is a need for forecaster training on image interpretation, numerical weather prediction, and nowcasting tools. Webinars and virtual or on-site training are also recommended.

4.4 Maintenance and Enhancement of Upper Air Station Sites

The temperature and moisture profiles from Upper Air Stations (UASs) radiosonde launches characterize the diurnal changes in the environment and atmospheric stability in the region and are necessary observations for assimilation into NWP models. No upper air stations were operational during EOP-1 of the FC. On 7 August and 16 October, the UAS sites at Nairobi and Lodwar respectively, became

operational, launching twice daily soundings. The UAS sites at Entebbe and Dar es Salaam are expected to come online during EOP-3. A constant supply of consumables is needed following the end of the Field Campaign to support the twice daily sounding launches from all of the resurrected Upper Air Station (UAS) in the region. Once the UAS site is resurrected in Entebbe, atmospheric changes occurring along the northern region of the LVB will be available. With the complex topography surrounding Lake Victoria and the local and mesoscale forcing of the weather over LVB, installation of a UAS along the south shore of the lake is recommended to obtain representative atmospheric profiles along the southern side of LVB. The long-term, continued operation of these sounding sites falls under recommendation 1 and the need to be able to sustain an Early Warning System.

4.5 Lake Victoria Water Measurements

Early on during the FC, it was realized that no buoys would be deployed on Lake Victoria severely restricting the opportunity to collect temperature and wind measurements of the water and near-surface atmosphere, and measurements of wave heights. Emphasis was placed on obtaining water measurements from instruments installed on Jubilee Hope hospital ship and Blue Bird Ferry for the HyCristal and HyVic field campaigns. Numerous computer system problems occurred during the period of the HIGHWAY FC, and to-date, no data has been obtained from these instruments. While it is not known definitely, it is unlikely that there will be any buoys installed during EOP-3. We highly recommend that existing buoys be repaired, and new fixed buoy stations be purchased and installed on the lake. There should be a buoy located in each marine zone of the lake to obtain temperature, moisture, wind and wave height information.

As discussed in 4.2 above, convergence lines of unknown origin have been observed in the Mwanza radar data which we hypothesize are associated with temperature gradients in the water. Buoy measurements would assist in understanding these features and the range of temperature gradient values that are associated with storm initiation in those regions. Installation of buoys on the lake will initially help to facilitate improved understanding of the role the lake plays on storm development and evolution, particularly changes occurring within and/or at the surface of the lake. For example, we know from the few surface stations on the islands that the water can be a few degrees warmer at night than the temperatures over land and thus more favorable for convection over the lake at night. But how strong and how frequently does this happen, and does it only happen in regions of the lake where there are also strong temperature or wind gradients? This is the research that should be done with the buoys initially and a climatology compiled. Thus, the buoy measurements are needed for scientific research, real-time monitoring of conditions on the lake, and later for inclusion in location-specific nowcasts of new thunderstorm development and thunderstorm severity, and for verification of NWP forecasts of wind strength and wave height on the lake.

Sea surface temperatures derived from passive satellite remote sensing would also be of great value for monitoring the horizontal water temperature gradients and short-term changes in water temperature and how these changes are related to locations of new storm development or storm intensification. We recommend NMHSs establish a collaboration with researchers in the UK or at Météo France for obtaining this type of product and using it to improve scientific understanding of the lake processes.

In addition, observations supplemental to the conventional UAS profiles are needed directly over the lake to provide continuous automatic reports of total precipitable water (TPW) of the atmosphere and to monitor variations in moisture depth critical to storm initiation over the lake. A GPS-TPW vertical profiling

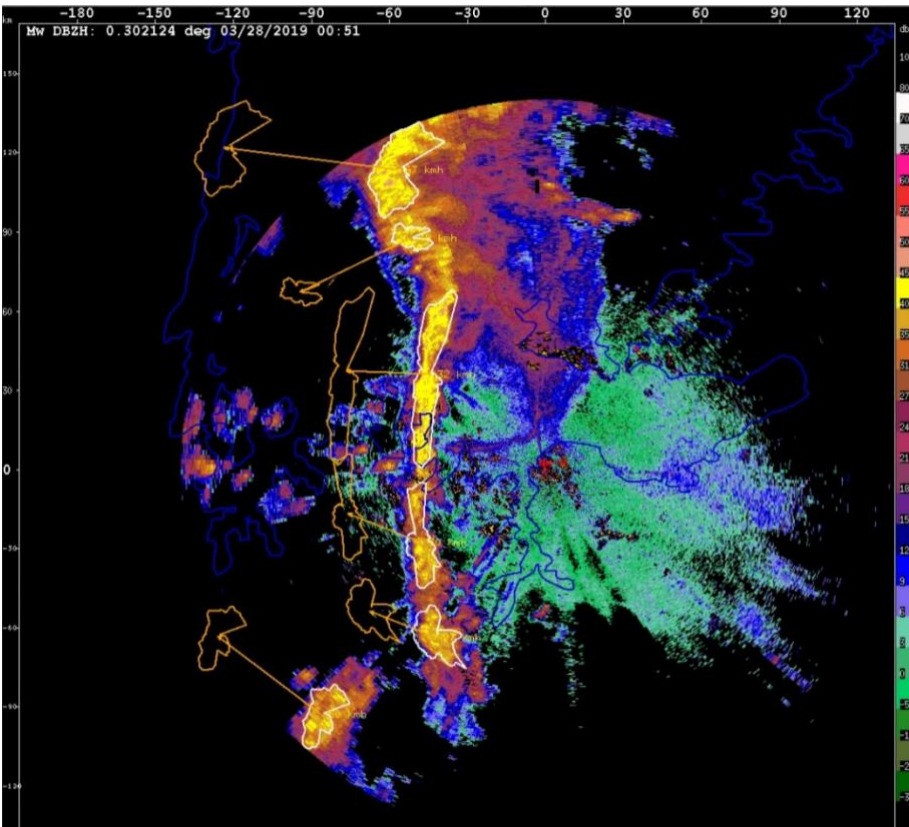
system should be considered for installation on one or more islands in the lake. Establishing temperature and wind profiling systems should also be considered on one or more islands. In the broader domain, efforts to pull in data from the IGS system should be considered.

4.6 Integrated Displays and Nowcasting Algorithms for EWS

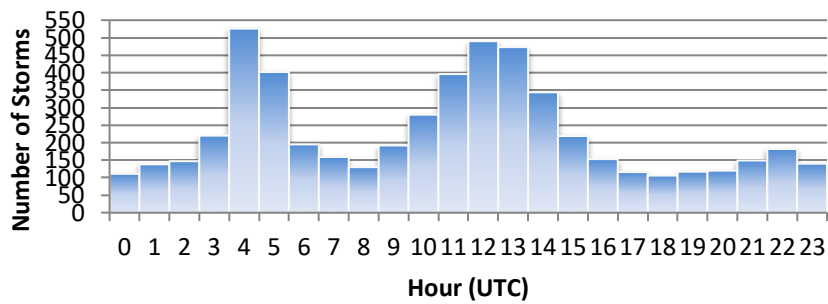
Nowcasting and warning of severe weather requires a forecaster to continually monitor radar, lighting, buoy, and satellite observations of rapidly evolving thunderstorms and winds. A forecaster cannot provide timely detection and short-term prediction (0-2hr) of severe weather unless these observations are transmitted in real-time to a centralized location for ingest into an integrated display system. A dedicated data communications system and software protocol for transmission of real-time observations is required. In the integrated display system, all data sources need to be rendered onto the same domain with the same horizontal grid resolution so that the forecaster can toggle between fields or overlay the fields on-top of each other. The ability to animate the fields is extremely useful for detection of high impact weather and monitoring changes that may be occurring. This requires a display that can efficiently and quickly be operated. An integrated display system like NCAR's CIDD enables forecasters to view all concurrent observations and have a clear picture of high impact weather occurring over LVB. Archived, historical data can also be viewed in CIDD. CIDD has been used by the authors to view all of the HIGHWAY datasets. CIDD was also installed at TMA for forecaster to view the Mwanza radar data. Additional observational datasets could be added to this display if desired.

Integrated display systems have been developed by several institutions and are likely available at some cost. Developing such capabilities are time consuming and expensive. Fortunately, the CIDD display and associated data ingest algorithms are available to all at no expense except for the computer and communication lines to receive the data. The CIDD software is available for free through the Lidar Radar Open Software Environment (LROSE) which is funded by the U.S. National Science Foundation (<https://www.eol.ucar.edu/content/lidar-radar-open-software-environment>). The overall goal of LROSE is to provide high-quality, open-source software to the community of scientists, researchers and operational organizations that are using lidars, radars and profilers.

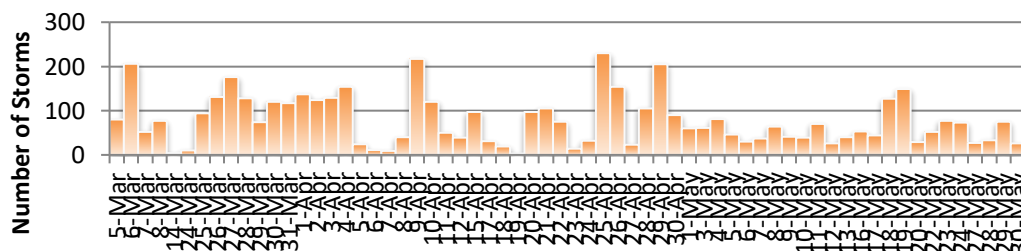
Algorithms that ingest high resolution observations and produce nowcast products can save forecasters much time in monitoring and processing critical changes in the weather over LVB. The most common nowcast products are those that extrapolate storms into the future based on their past motion. Existing storm tracking algorithms such as NCAR's Thunderstorm Identification, Tracking, Analysis and Nowcasting (TITAN) algorithm that runs on radar data are available for free to download at the LROSE site (<https://github.com/NCAR/lrose-titan>). Examples of the type of products and climatological statistics available from this software are shown in Fig. 25. The NWCSAF Rapidly Developing Thunderstorm (RDT) nowcast tool which has similar functionality but is satellite and lightning-based is available as part of the SAF suite of products, along with the satellite-based Convective Rainfall Rate (RCC). These types of nowcast tools provide the forecaster with guidance on nowcasting and issuing severe weather warning for an EWS.



Number of Storms



Number of Storm Tracks Per Day



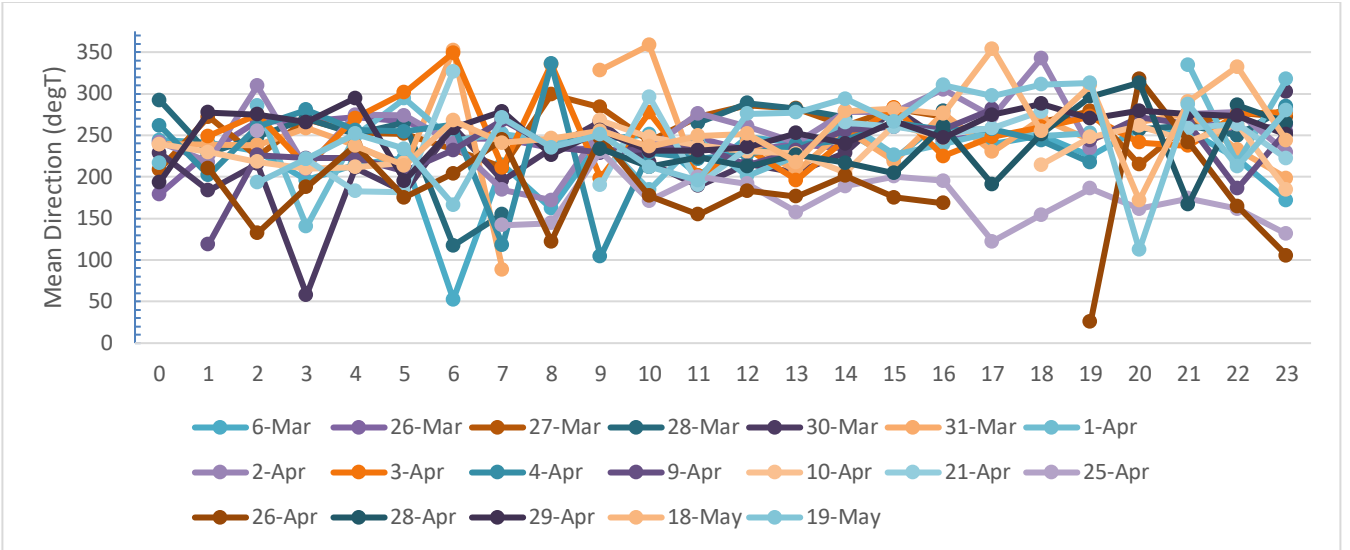


Figure 25. TITAN nowcast and climatology products. Top panel: TITAN storm detections (white polygons) and 60 min extrapolated storm positions (orange polygons) are overlaid onto the Mwanza radar reflectivity field. Lower three panels are storm climatology statistics from all the days of data during EOP-1 showing: the number of storms per hour during; number of storm tracks per day; and prevailing storm track direction (from Roberts et al 2019).

4.7 Surface Weather Stations

It was apparent from the Field Campaign that refurbishment and maintenance of surface stations is a significant ongoing problem and that considerably more effort is required to have a suitable and sustainable network. Because of the lack of surface observations over the lake, a high priority is to locate additional surface stations on islands in the lake.

A dense network of surface stations is also desirable. Since surface weather stations only observe the atmosphere at a single point their measurement values are very dependent on their geographical location and location relative to a weather phenomenon. For example, temperature, dewpoint temperature, winds and precipitation vary considerably dependent on proximity to the lake and elevation. For detecting and nowcasting changing conditions in the boundary layer, it is highly desirable to obtain gridded, Cartesian fields of a specific variable derived from one or more networks of surface stations to quickly see changes occurring. For example, to obtain a Cartesian field of temperature or dewpoint temperature, it is desirable to have a dense network of stations so that a Barnes analysis or Cressman weighting technique can be applied to produce a horizontal grid of temperature and dewpoint values across the LVB domain.

4.8 Regional Data Archival System

NCAR archived data that was available from the Field Campaign and placed much of the data on the HIGHWAY Field Catalog that NCAR set up and has maintained. However, after the Field Campaign ends, NCAR will no longer be archiving data from LVB. One or more of the NMHSs must take on this activity. For the HIGHWAY program, KMD was tasked to set up a regional data archival system but that has not happened yet. Procurement of hardware is still ongoing. Data archiving is one of the required activities for a sustainable Early Warning System. It will always be necessary to examine past data when investigating boating accidents and for developing improved nowcasting capabilities.

References

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- Virts, K., and S. Goodman, 2019: Prolific lightning and thunderstorm initiation over the Lake Victoria Basin in East Africa. *Mon. Wea. Rev.*, in review.
- Waniha, P. F., R. D. Roberts, J. W. Wilson, B. Katole, and A. Kijazi, 2019: Dual-polarization radar observations of deep convection over Lake Victoria Basin in East Africa. *Atmosphere*, accepted for publication.

Appendices

Appendix 1 - List of FC instrumentation

Table A1. List of potential Field Campaign observations and readiness for data collection and archival.

| | | LEGEND | Completed | In Progress | PLAN-NED | End date | | | | | | | | | | |
|--|---------|--------|-----------|-------------|----------|----------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Activity | Sep -18 | Oct-18 | Nov-18 | Dec-18 | Jan-19 | Feb -19 | Mar -19 | Apr -19 | May -19 | Jun -19 | Jul -19 | Aug -19 | Sep -19 | Oct -19 | Nov -19 | Dec -19 |
| Assessment of observation systems | | | | | | | | | | | | | | | | |
| Upper air systems (KMD, UNMA, TMA) | | | | | | | | | | | | | | | | |
| GPS-TPW | | | | | | | | | | | | | | | | |
| MODE-S | | | | | | | | | | | | | | | | |
| KMD Surface stations | | | | | | | | | | | | | | | | |
| UNMA Surface stations | | | | | | | | | | | | | | | | |
| TMA Surface stations | | | | | | | | | | | | | | | | |
| Meteo Rwand Surface stations | | | | | | | | | | | | | | | | |
| 3D-PAWS sites (UNMA and KMD) | | | | | | | | | | | | | | | | |
| TAHMO stations | | | | | | | | | | | | | | | | |
| Procurements and/or purchase of systems, instruments, materials, and expendables | | | | | | | | | | | | | | | | |
| KMD Upper Air stations, civil work, radiosonde s | | | | | | | | | | | | | | | | |
| TMA Upper Air stations, civil work, radiosonde s | | | | | | | | | | | | | | | | |

| | | LEGEND | Completed | In Progress | PLAN-NED | End date | | | | | | | | | | |
|---|--|--------|-----------|-------------|----------|----------|--|--|--|--|--|--|--|--|--|--|
| UNMA Upper Air Stations, civil work, radiosonde s | | | | | | | | | | | | | | | | |
| NMHS surface stations | | | | | | | | | | | | | | | | |
| Upgrade Mwanza radar | | | | | | | | | | | | | | | | |
| Upgrade Mwanza radar data transmission to Dar es Salaam | | | | | | | | | | | | | | | | |
| Purchase spare parts for Mwanza radar | | | | | | | | | | | | | | | | |
| Purchase spare parts for Entebbe radar | | | | | | | | | | | | | | | | |
| Purchase of MODE-S receivers | | | | | | | | | | | | | | | | |
| Purchase dropsondes MOYA field campaign | | | | | | | | | | | | | | | | |
| TAHMO data sharing agreement | | | | | | | | | | | | | | | | |
| Purchase / Assembly of MODE-S | | | | | | | | | | | | | | | | |
| Production of 3D-PAWS station components | | | | | | | | | | | | | | | | |
| Installations | | | | | | | | | | | | | | | | |
| Resurrection of upper air system (Kenya) | | | | | | | | | | | | | | | | |
| Resurrection of upper air system (Tanzania) | | | | | | | | | | | | | | | | |
| Resurrection of upper air system (Uganda) | | | | | | | | | | | | | | | | |
| Installation of NMHS AWS stations | | | | | | | | | | | | | | | | |

| | | LEGEND | Completed | In Progress | PLAN-NED | End date | | | | | | | | | | |
|---|--|--------|-----------|-------------|----------|----------|--|--|--|--|--|--|--|--|--|--|
| Installation of buoys | | | | | | | | | | | | | | | | |
| GPS-TPW data sharing start | | | | | | | | | | | | | | | | |
| Install radar display software at TMA | | | | | | | | | | | | | | | | |
| Installation of FOREST display system and upgrade | | | | | | | | | | | | | | | | |
| Install nowcast products | | | | | | | | | | | | | | | | |
| TAHMO data sharing start | | | | | | | | | | | | | | | | |
| Installation of MODE-S | | | | | | | | | | | | | | | | |
| Installation of UNMA radar | | | | | | | | | | | | | | | | |
| Installation of 3D-PAWS | | | | | | | | | | | | | | | | |

Appendix 2 - Reports

a) Journal articles and Weather Articles

Virts, K., and S. Goodman, 2019: Prolific lightning and thunderstorm initiation over the Lake Victoria Basin in East Africa. *Mon. Wea. Rev.*, *in review*.

Kiwanuka-Tondo, J., F. Semazzi, and K. Pettiway, 2019: Climate risk communication of navigation safety and climate conditions over Lake Victoria basin: Exploring perceptions and knowledge of indigenous communities. *Cogent Social Sciences*, 5:1588485, <https://doi.org/10.1080/23311886.2019.1588485>.

Waniha, P. F., R. D. Roberts, J. W. Wilson, B. Katole, and A. Kijazi, 2019: Dual-polarization radar observations of deep convection over Lake Victoria Basin in East Africa. *Atmosphere*, *Accepted for publication*.

Woodhams, B. J., C. E. Birch, J. H. Marsham, C. L. Bain, N. M. Roberts, D.F.A Boyd, 2018: What is the added value of a convection-permitting model for forecasting extreme rainfall over Tropical East Africa? *Quart. J. Roy. Meteor. Soc.*, **146**, 2757-2780.

Woodhams, B. J., C. E. Birch, J. H. Marsham, T. P. Lane, C. L. Bain, and S. Webster, 2019: Identifying key controls on storm formation over the Lake Victoria Basin. *Mon. Wea. Rev.*, **147**, 3365-3390.

b) Technical Reports

Aura, S., R. Muita, P. Oloo, D. Muchemi, P. Kucera, S. Mwangi, N. Maingi, E. Muigai, and M. Steinson, 2019: Intercomparison of TAHMO, 3DPAWS Automatic weather stations and KMD synoptic weather stations data at Dagoretti Corner, Nairobi. Technical report, 25 pp.

Bain, C., 2019: HIGHWAY Visualization Fact Sheet, 4 pp.

Hanley, K., 2018: Convective-scale NWP model configurations for the Lake Victoria Basin Region. UK Met Office and WISER Technical Report, 35 pp.

Hanley, K., 2019: Assessment of the Tropical Africa model over the Lake Victoria basin region. UK Met Office and WISER Technical Report, 23 pp.

Kucera, P., and M. Steinson, 2019: KMD-UCAR Data analysis workshop summary report. Technical report, 5pp.

c) Conference abstracts and presentations

Goodman, S. J., K. Virts, R. Roberts, J. Wilson, R. Petersen, L. Cronic, A. Hartley, L. Chang'a, 2019: Severe storms in the Lake Victoria Basin. *European Conference on Severe Storms*, Krakow, Poland, 4-8 November.

Roberts, R. D., J. Wilson, D. Megenhardt, P. Waniha, and B. Katole, 2019: Patterns of thunderstorm evolution over Lake Victoria Basin based on meso- and local-scale environmental factors. *AMS 39th International Conference on Radar Meteorology*, Nara, Japan, 16-20 September.

Roberts, R. D., J. W. Wilson, A. Hartley, and C. Bain, 2020, Analysis and prediction of high impact weather over Lake Victoria in East African. *AMS Conference on Weather and Forecasting, Boston, Massachusetts*, 13-16 January.

Waniha, P., A. Kijazi, R. Roberts, and J. Wilson, 2018: Dual-polarization radar observations of deep convection over the Lake Victoria Basin in East Africa. 10th European Conference on Radar Meteorology and Hydrology, Ede, The Netherlands.

Waniha, P., R. Roberts, J. Wilson, B. Katole, and A. Kijazi, 2019: Introduction for radar now casting of severe weather events over Lake Victoria Basin in East Africa. *AMS 39th International Conference on Radar Meteorology*, Nara, Japan, 16-20 September.

Appendix 3 - KMD Nairobi Upper Air Sounding Data

Table A3. List of available KMD Nairobi (63741) upper air station data through 1 October 2019.

| Date | Time (UTC) | |
|-----------|------------|-----------|
| | 11-12 UTC | 23-00 UTC |
| 9-Aug | ✓ | - |
| 10-16 Aug | ✓ | ✓ |
| 17-Aug | ✓ | - |
| 18-Aug | Bad | - |
| 19-28 Aug | ✓ | ✓ |
| 29-Aug | - | ✓ |
| 30-31 Aug | ✓ | ✓ |
| 1-3 Sep | ✓ | ✓ |
| 4-Sep | - | ✓ |
| 5-Sep | ✓ | - |
| 6-11 Sep | ✓ | ✓ |
| 12 Sep | - | - |
| 13-Sep | - | ✓ |
| 14-Sep | - | - |
| 15-Sep | - | - |
| 16-Sep | - | - |
| 17-30 Sep | ✓ | ✓ |
| 1-Oct | ✓ | - |

Appendix 4 - TMA Mwanza Radar Data Archival

Table A4. List of archived TMA radar data from the Mwanza, Tanzania radar site through 31 August 2019. Green blocks represent archived data; white blocks represent no radar data available.

| Date | 00-06 UTC | 06-12 UTC | 12-18 UTC | 18-00 UTC | Comments |
|-----------|-----------|-----------|-----------|-----------|---|
| 1-4 Mar | | | | | Backup generator was down from 1-23 March. Radar transmitted only occasionally on commercial power. |
| 5-8 Mar | | | | | |
| 9-13 Mar | | | | | |
| 14 Mar | | | | | |
| 15-23 Mar | | | | | |
| 24-31 Mar | | | | | |
| 1-11 Apr | | | | | |
| 12 Apr | | | | | Persistent data archival problems during the period from 00-06UTC, from 12 Apr to 5 Jul |
| 13 Apr | | | | | |
| 14 Apr | | | | | |
| 15 Apr | | | | | |
| 16 Apr | | | | | |
| 17 Apr | | | | | |
| 18 Apr | | | | | |
| 19 Apr | | | | | |
| 20 Apr | | | | | |
| 21 Apr | | | | | |
| 22 Apr | | | | | |
| 23 Apr | | | | | |
| 24 Apr | | | | | |
| 25 Apr | | | | | |
| 26 Apr | | | | | |
| 27 Apr | | | | | |
| 28 Apr | | | | | |
| 29 Apr | | | | | |
| 30 Apr | | | | | |
| 1 May | | | | | |
| 2 May | | | | | |
| 3 May | | | | | |
| 4 May | | | | | |
| 5 May | | | | | |
| 6 May | | | | | |
| 7 May | | | | | |
| 8 May | | | | | |

| Date | 00-06 UTC | 06-12 UTC | 12-18 UTC | 18-00 UTC | Comments |
|-----------|-----------|-----------|-----------|-----------|--|
| 9 May | | | | | |
| 10 May | | | | | |
| 11 May | | | | | |
| 12 May | | | | | |
| 13 May | | | | | |
| 14 May | | | | | |
| 15 May | | | | | |
| 16 May | | | | | |
| 17 May | | | | | |
| 18 May | | | | | |
| 19 May | | | | | |
| 20 May | | | | | |
| 21 May | | | | | |
| 22-24 May | | | | | |
| 25-27 May | | | | | From 25 May-4 Jul, persistent transmitter and data archival problems, limiting data collection |
| 28-30 May | | | | | |
| 31-May | | | | | |
| 1-3 Jun | | | | | |
| 4 Jun | | | | | |
| 5-30 Jun | | | | | |
| 1-4 Jul | | | | | EEC maintenance on 4 Jul fixed transmitter and data archival problems. |
| 5 Jul | | | | | |
| 6-20 Jul | | | | | |
| 21 Jul | | | | | Additional EEC maintenance on 21-22 Jul |
| 22 Jul | | | | | |
| 23-31 Jul | | | | | |
| 1 Aug | | | | | |
| 2-6 Aug | | | | | |
| 7 Aug | | | | | EEC training conducted from 7-11 Aug |
| 8 Aug | | | | | |
| 9 Aug | | | | | |
| 10 Aug | | | | | |
| 11 Aug | | | | | |
| 12 Aug | | | | | |
| 13-31 Aug | | | | | |