

2.4 TRANSITIONING ENHANCED LAND SURFACE INITIALIZATION AND MODEL VERIFICATION CAPABILITIES TO THE KENYA METEOROLOGICAL DEPARTMENT (KMD)

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1. INTRODUCTION

Flooding, severe weather, and drought are key forecasting challenges for the Kenya Meteorological Department (KMD), based in Nairobi, Kenya. Atmospheric processes leading to convection, excessive precipitation and/or prolonged drought can be strongly influenced by land cover, vegetation, and soil moisture content, especially during anomalous conditions and dry/wet seasonal transitions. It is thus important to represent accurately land surface state variables (green vegetation fraction, soil moisture, and soil temperature) in Numerical Weather Prediction (NWP) models.

The NASA SERVIR and the Short-term Prediction Research and Transition (SPoRT) programs in Huntsville, AL have established a working partnership with KMD to enhance its regional modeling capabilities. SPoRT and SERVIR are providing experimental land surface initialization datasets and model verification capabilities for capacity building at KMD. To support its forecasting operations, KMD is running experimental configurations of the Weather Research and Forecasting (WRF; Skamarock et al. 2008) model on a 12-km/4-km nested regional domain over eastern Africa, incorporating the land surface datasets provided by NASA SPoRT and SERVIR. SPoRT, SERVIR, and KMD participated in two training sessions in March 2014 and June 2015 to foster the collaboration and use of unique land surface datasets and model verification capabilities. Enhanced regional modeling capabilities have the potential to improve guidance in support of daily operations and high-impact weather and climate outlooks over Eastern Africa.

For enhanced land-surface initialization, the NASA Land Information System (LIS) is run over Eastern Africa at ~3-km resolution, providing real-time land surface initialization data in place of interpolated global model soil moisture and temperature data available at coarser resolutions. Additionally, real-time green vegetation fraction (GVF) composites from the Suomi-NPP VIIRS instrument is being incorporated into the KMD-WRF runs, using the product generated by NOAA/NESDIS. Model verification capabilities are also being transitioned to KMD using NCAR's Model

Evaluation Tools (MET; Brown et al. 2009) software in conjunction with a SPoRT-developed scripting package, in order to quantify and compare errors in simulated temperature, moisture and precipitation in the experimental WRF model simulations.

This extended abstract and accompanying presentation summarizes the efforts and training done to date to support this unique regional modeling initiative at KMD. To honor the memory of Dr. Peter J. Lamb and his extensive efforts in bolstering weather and climate science and capacity-building in Africa, we offer this contribution to the special Peter J. Lamb symposium. The remainder of this extended abstract is organized as follows. The collaborating international organizations involved in the project are presented in Section 2. Background information on the unique land surface input datasets is presented in Section 3. The hands-on training sessions from March 2014 and June 2015 are described in Section 4. Sample experimental WRF output and verification from the June 2015 training are given in Section 5. A summary is given in Section 6, followed by Acknowledgements and References.

2. COLLABORATING ORGANIZATIONS

The KMD, SERVIR, the Regional Centre for Mapping of Resources for Development (RCMRD), and the SPoRT Center teamed together to provide enhanced modeling and verification capabilities to KMD. The collaboration being fostered is enabled through the strengths of each organization as described below.

2.1 Kenya Meteorological Department (KMD)

The KMD has a wide range of weather and climatological responsibilities over eastern Africa and the western Indian Ocean. These include providing meteorological and climatological services to agriculture, water resources management, military/civil aviation, private sector, and public utilities for better utilizing natural resources for national development. KMD offers meteorological services and issues cyclone warnings for the western Indian Ocean to ensure safe shipping operations. They also administer surface and upper-air observations and maintain telecommunications for a timely collection and dissemination of meteorological data. In addition, KMD conducts applied research activities and develops suitable meteorological training programs that are relevant to Kenya and other participating countries.

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In recent years, KMD has run its own in-house configuration of the WRF Environmental Modeling System (EMS; Rozumalski 2014) framework. Initial and boundary conditions for the simulations are provided by the GFS model (Environmental Modeling Center 2003), which despite recent resolution enhancements (Environmental Modeling Center 2015), still provides relatively coarse-resolution initialization fields relative to the typical local/regional resolutions used in WRF-EMS for convection-allowing simulations (~4-km inner nested grid; Kain et al. 2008), based on the 0.25-deg and 0.50-deg grids disseminated to the weather and climate community.

2.2 NASA SERVIR project

A joint venture between NASA and the U.S. Agency for International Development (USAID), SERVIR provides state-of-the-art, satellite-based Earth monitoring, imaging and mapping data, geospatial information, predictive models and science applications to help improve environmental decision-making among developing nations in eastern and southern Africa, the Hindu-Kush region of the Himalayas and the lower Mekong River Basin in Southeast Asia, with an additional hub slated in 2016 over Western Africa. Developed in 2004 by researchers at NASA's Marshall Space Flight Center in Huntsville, AL, and implemented through NASA partnerships with leading regional organizations around the globe, SERVIR provides critical information and support services to help national, regional and local governments, forecasters, climatologists and other researchers track environmental changes, evaluate ecological threats and rapidly respond to and assess damage from natural disasters.

With activities in more than 30 countries, the SERVIR team already has developed more than 40 custom tools, collaborated with more than 200 institutions and trained approximately 1,800 regional support staffers, developing local solutions and linking regional offices around the globe to create a thriving, interactive network. Web-based satellite imagery, decision-support tools and interactive visualization capabilities previously inaccessible across many of these regions now enable stakeholders to work together to combat floods, wildfires, and other calamities, and also address long-term environmental shifts tied to climate change, biodiversity, drought and other factors.

In 2008, NASA partnered with RCMRD based in Nairobi, Kenya, and together they began setting up SERVIR's Africa hub. The SERVIR-Africa project builds upon the existing strengths of RCMRD and augments the data management and training capability at RCMRD. Efforts complement RCMRD's core mission and provide a springboard for the development of applications customized for the member states of RCMRD. Additional information on the SERVIR program is available at www.nasa.gov/mission_pages/servir/index.html.

2.3 Regional Centre for Mapping of Resources for Development(RCMRD)

The RCMRD was established in Nairobi, Kenya in 1975 under the auspices of the United Nations

Economic Commission for Africa and the then Organization of African Unity, known today as the African Union. RCMRD is an inter-governmental organization and currently has 20 Contracting Member States in the Eastern and Southern Africa Regions: Botswana, Burundi, Comoros, Ethiopia, Kenya, Lesotho, Malawi, Mauritius, Namibia, Rwanda, Seychelles, Somali, South Africa, South Sudan, Sudan, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe. The mission of RCMRD is to promote sustainable development through generation, application and dissemination of Geo-Information and allied Information and Communication Technology services and products in the Member States and beyond. More information can be found on their website at: <http://www.rcmrd.org/>.

2.4 NASA SPoRT Center

The NASA SPoRT Center (Jedlovec 2013) focuses on transitioning unique NASA and NOAA observations and research capabilities to the operational weather community to improve short-term weather forecasts on a regional and local scale. SPoRT demonstrates the capability of NASA and NOAA experimental products to weather applications and societal benefit, and prepares forecasters for use of data for the next generation of operational satellites. SPoRT maintains a close collaboration with numerous NOAA/NWS weather forecast offices across the United States. Beginning in 2002 with NASA funds, SPoRT delivered its first NASA satellite-based products to the NOAA/NWS Advanced Weather Interactive Processing System in 2003. Since 2009, it has been co-funded by NOAA through satellite proving ground activities such as GOES-R and JPSS.

The successful paradigm of SPoRT is one that involves the forecaster/end-user at all levels of transition activities (Figure 1). A forecast challenge is first matched to a data product and a prospective solution is developed and demonstrated in a test bed environment within the end-user's decision support system. An appropriate product training is then developed followed by an assessment of the perceived product impact on forecast operations. If the product is not yet deemed mature enough for a full transition, then the cycle is repeated to improve the components of the product needing further development. Another important aspect of this process is to have a local end-user advocate who can promote assessment of the product in the operational test bed.

3. NASA LIS AND S-NPP VIIRS GVF

3.1 LIS framework

The NASA LIS is a high performance land surface modeling and data assimilation system that integrates satellite-derived datasets, ground-based observations and model reanalyses to force a variety of LSMs (Kumar et al. 2006; Peters-Lidard et al. 2007). By using scalable, high-performance computing and data management technologies, LIS can run LSMs offline globally with a grid spacing as fine as 1 km (or better) to characterize land surface states and fluxes. LIS has also been coupled to the Advanced Research WRF

dynamical core (Kumar et al. 2007) for applications using the NASA Unified-WRF modeling framework (Peters-Lidard et al. 2015).

3.2 East Africa-LIS Configuration

In the Africa-LIS configuration, version 3.2 of the Noah LSM (Ek et al. 2003; Chen and Dudhia 2001) is run in analysis mode (i.e., uncoupled from an NWP model) over much of east-central Africa at 0.03-degree grid spacing for a continuous long simulation. The domain ranges from +/- 16° latitude and from 21° to 53° E longitude. The soil temperature and volumetric soil moisture fields were initialized at constant values of 290 K and 20 % in all four Noah soil layers (0-10, 10-40, 40-100, and 100-200 cm) on 1 January 2011, followed by a sufficiently long integration using a 30-minute timestep to near real-time, in order to remove memory of the initial soil conditions.

3.2.1 Static input fields

The Africa-LIS uses the International Geosphere-Biosphere Programme (IGBP) land-use classification (Loveland et al. 2000) as applied to the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument (Friedl et al. 2010). All static and dynamic land surface fields are masked based on the IGBP/MODIS land-use classes. The soil properties are represented by the State Soil Geographic (STATSGO; Miller and White 1998) database – the same as used in the community WRF model.

Additional parameters include a 0.05° resolution maximum snow surface albedo derived from MODIS (Barlage et al. 2005) and a deep soil temperature climatology (serving as a lower boundary condition for the soil layers) at 3 meters below ground, derived from 6 years of Global Data Assimilation System (GDAS) 3-hourly averaged 2-m air temperatures using the method described in Chen and Dudhia (2001). GVF is currently represented by the same monthly climatology dataset (Gutman and Ignatov 1998) as used in the community WRF; however, future Africa-LIS configurations will make use of the daily real-time, global NESDIS VIIRS GVF product (Vargas et al. 2015; described in Section 3.3).

3.2.2 Multi-year LIS spin-up

The Noah LSM was initialized at 0000 UTC 1 January 2011 and spun-up for several years prior to use for real-time applications in order to remove memory of the soil initial conditions. The atmospheric forcing variables required to drive the LIS-Noah integration consist of surface pressure, 2-m temperature and specific humidity, 10-m winds, downward-directed shortwave and longwave radiation, and precipitation rate. In the long-term simulation, all atmospheric forcing variables are provided by 3-hourly GDAS 0–9-h analyses and short-term forecast files (Parrish and Derber 1992; NCEP EMC 2004), except input precipitation forcing was given by half-hourly precipitation rates from the NCEP Climate Prediction Center Morphing (CMORPH) technique 8-km product (Joyce et al. 2004). The Noah LSM solution ultimately converges to a modeled state based on the GDAS and CMORPH precipitation input.

3.2.3 Real-time LIS restarts for initializing WRF

The real-time Africa-LIS cycle is initiated twice daily at 0215 and 1415 UTC from history re-start files of the simulation using GDAS-CMORPH forcing. The LIS restart times are determined primarily on the time-availability of GDAS 0–9-h files. The GDAS analyses and short-term forecasts have ~6–7-h delay following the GDAS/GFS 6-hourly cycle. For example, the previous day's 1800 UTC GDAS cycle files are available by ~0100 UTC, and are thus used to drive the 0215 UTC Africa-LIS integration through 0300 UTC. The CMORPH file production is done on a daily basis, with the previous day's files available by ~2100 UTC. The Africa-LIS cycle can thus provide real-time land surface output variables for initializing experimental WRF-EMS forecasts over Eastern Africa.

3.3 Suomi-NPP daily global VIIRS GVF

GVF is defined as the fraction of a pixel covered by healthy green vegetation if it were viewed vertically. Real-time GVF is needed in NWP, climate and hydrological models for improved representation of the surface energy budget. The current NOAA operational GVF product is derived from AVHRR top of atmosphere NDVI data at ~16-km resolution, and represented as a monthly climatology. In the Suomi National Polar-orbiting Partnership (S-NPP) era, there is a need to produce GVF as a NOAA-Unique Product using data from the Visible Infrared Imager Radiometer Suite (VIIRS) sensor for applications in NWP and seasonal climate prediction models at the National Centers for Environmental Prediction (NCEP). The retrieval algorithm uses VIIRS red (I1), near-infrared (I2) and blue (M3) bands centered at 0.640 μm, 0.865 μm and 0.490 μm, respectively, to calculate the Enhanced Vegetation Index (EVI) and derive GVF from EVI based on a linear model (Vargas et al. 2015). To meet the data needs of NCEP and other potential users, GVF is being produced as a daily rolling weekly composite at 4-km resolution (global scale) and 1-km resolution (western hemisphere regional scale). The daily global 4-km GVF became available in near real time in February 2015; however, the regional 1-km GVF is not currently available in near real time.

4. HAND-ON TRAINING SESSIONS

SERVIR, SPoRT, and KMD conducted two face-to-face training sessions; the first hosted by KMD in Nairobi, Kenya during March 2014, and the second hosted by SERVIR in Huntsville, AL during June 2015. During the first session in Nairobi, the Coauthoring KMD personnel were first acquainted with the modeling datasets and MET model verification tools to be transitioned through briefing packages. The team then delved into the components of the EMS package to configure the model to automatically ingest real-time LIS initialization fields on KMD's research workstation (Figure 2; left). They also were able to generate sample MET model verification scores by the end of the site visit, enabled by a SPoRT-developed scripting package designed to seamlessly interface with MET (Zavodsky et al. 2014).

During the site visit to Huntsville, AL in the first two weeks of June 2015, the Coauthoring KMD personnel worked closely with SPoRT and SERVIR personnel to configure a modeling domain, make near real-time simulations for multiple experiments, and generate verification statistics to compare experiment results (Figure 2; right). The experiments consisted of a 12-km/4-km nested WRF-EMS model configuration that used only GFS model initial and boundary conditions (control), LIS land surface fields in place of GFS land surface fields (experiment 1), and LIS fields with NESDIS VIIRS GVF for a third simulation (experiment 2). All simulations and verification results were generated concurrently on both a SPoRT computational cluster, and remotely on the KMD research workstation. The KMD personnel generated sample verification statistics with confidence intervals to determine statistically significant results. KMD personnel completed the training by presenting a final briefing of these efforts and experimental modeling results. This combination of training sessions provided KMD with the tools necessary to conduct future in-house modeling and verification experiments and/or generate real-time model configurations to enhance operational activities at KMD.

5. MODEL COMPARISON FROM JUNE 2015 TRAINING SESSION

During the training session in Huntsville, the team set up an experimental modeling domain over East-central Africa with a 4-km nested grid centered on western Kenya and Lake Victoria. Sensitivity simulations were made for 3 dates at the beginning of the session, so as to focus on analyzing results and producing verification statistics from these model runs. A comparison of the input deep-layer soil moisture for the 1 June 2015 simulations (Figure 3) shows how the LIS input has considerably more detail than the interpolated GFS fields, with markedly drier soil moisture initial conditions west of Lake Victoria and across portions of west-central Kenya. Similarly, the input VIIRS GVF data valid for 1 June 2015 has much more detail than the legacy AVHRR-based default monthly climatological GVF interpolated in time to 1 June (The climatology GVF consists of twelve monthly grids, valid on the 15th of each month. A more detailed MODIS-based GVF climatology recently became available to the WRF and EMS modeling communities, but this dataset was not used during training due to the very large amount of data download required upfront.) The input GVF comparison (Figure 4) shows that the real-time VIIRS GVF has lower values across portions of west/central Kenya, somewhat consistent with the drier LIS deep soil moisture initialization. However, VIIRS GVF values are higher than climatology to the west of Lake Victoria.

The propensity for lower input GVF and lower deep soil moisture generally had a warming/drying effect on the simulated 2-m temperatures and 2-m dew point temperatures, as indicated by the verification graphs produced by KMD in Figure 5. While the warming contributed to an improvement of a cool 2-m temperature bias in the control simulations

(especially during the day/evening between forecast hours 8-20 and 32-44), the drying contributed to an exacerbation of the pre-existing dry bias in 2-m dew point temperature. Obviously, a more extensive collection of simulations is necessary to determine the overall impacts and statistical significance of the alternative input land surface fields. Furthermore, an examination of the surface energy budget and alternative physical parameterization schemes in the WRF model is typically warranted to better understand the impacts of these datasets on physical processes in the model. However, with the training, methods, and alternative datasets available to KMD, they now have the ability to conduct in-house sensitivity experiments in order to enhance numerical modeling capabilities in support of operations.

6. SUMMARY AND FUTURE CONSIDERATIONS

In honor of the lifetime achievements of Dr. Peter J. Lamb, this paper presented an example of African capacity-building at work between KMD, SERVIR, and SPoRT. The collective strengths of these organizations, along with USAID and RCMRD, promoted a successful on-site training session in Nairobi, Kenya in March 2014, followed by hands-on training for two weeks during June 2015 in Huntsville, AL. The modeling exercises featured the use of KMD's own computational research workstation to conduct modeling experiments and generate verification statistics for simulations using alternative land surface initialization datasets. Emphasis was placed on understanding the process of conducting sensitivity simulation experiments and inter-comparing results, through the transition of unique land surface datasets and verification tools not previously available to KMD personnel.

Future enhancements could include the assimilation of NASA Soil Moisture Active Passive (SMAP; Entekhabi et al. 2010) soil moisture retrievals into the Africa-LIS to further improve modeled soil moisture estimates. The SMAP satellite offers global coverage of accurate, near-surface soil moisture estimates. In addition, the CMORPH precipitation estimated could be replaced with quantitative precipitation estimates from the NASA Global Precipitation Measurement (GPM) mission to drive the LIS simulations and verify WRF-EMS model precipitation forecasts. GPM's IMERG product features the best, new method in satellite precipitation estimation, merging the GPM core instrument with the constellation of passive microwave satellites. Finally, for enhanced situational awareness for drought and/or flooding concerns, a soil moisture climatology would be beneficial to place the LIS fields into historical context.

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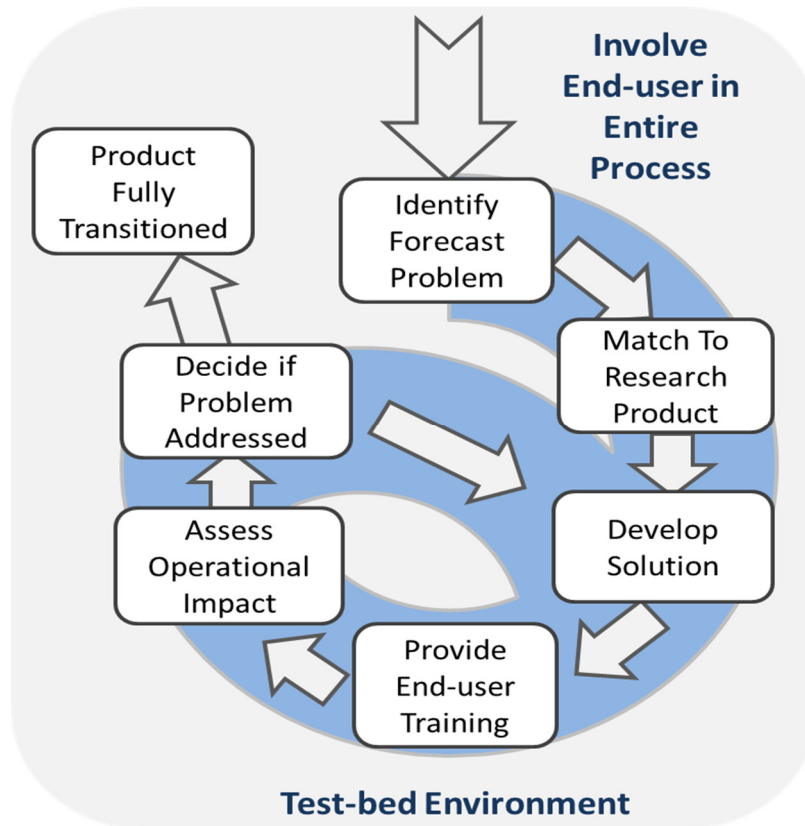


Figure 1. Illustration of the SPoRT paradigm of transitioning research to operations in a test bed environment.



Figure 2. KMD, SERVIR, and SPoRT personnel during hands-on training at (left) Kenya Meteorological Department during March 2014, and (right) SERVIR collaboration laboratory during June 2015.

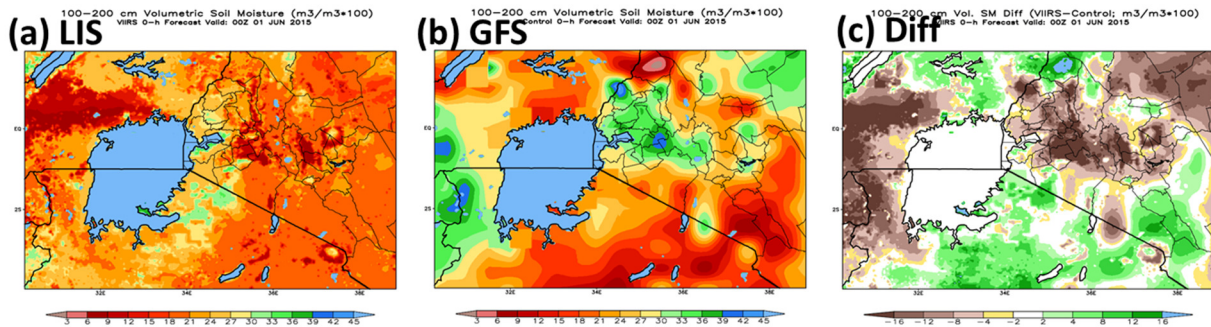


Figure 3. Deep soil moisture initialization (100-200 cm layer), depicting (a) LIS soil moisture, (b) GFS model soil moisture, and (c) Difference (LIS minus GFS) for the 4-km experimental WRF-EMS simulation domain initialized at 0000 UTC 1 June 2015.

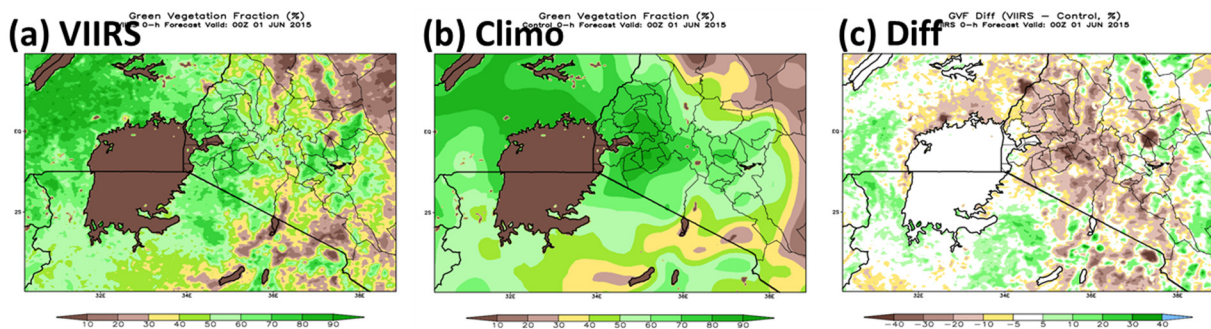


Figure 4. Green vegetation fraction (GVF) initialization, depicting (a) NESDIS VIIRS GVF, (b) time-interpolated monthly climatology GVF, and (c) Difference (VIIRS minus Climatology) for the 4-km experimental WRF-EMS simulation domain initialized at 0000 UTC 1 June 2015.

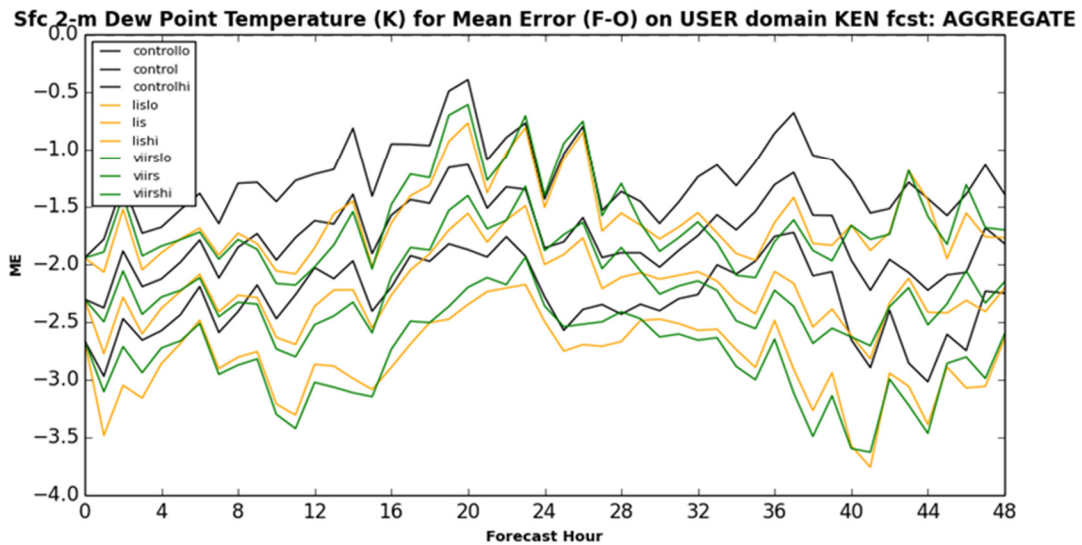
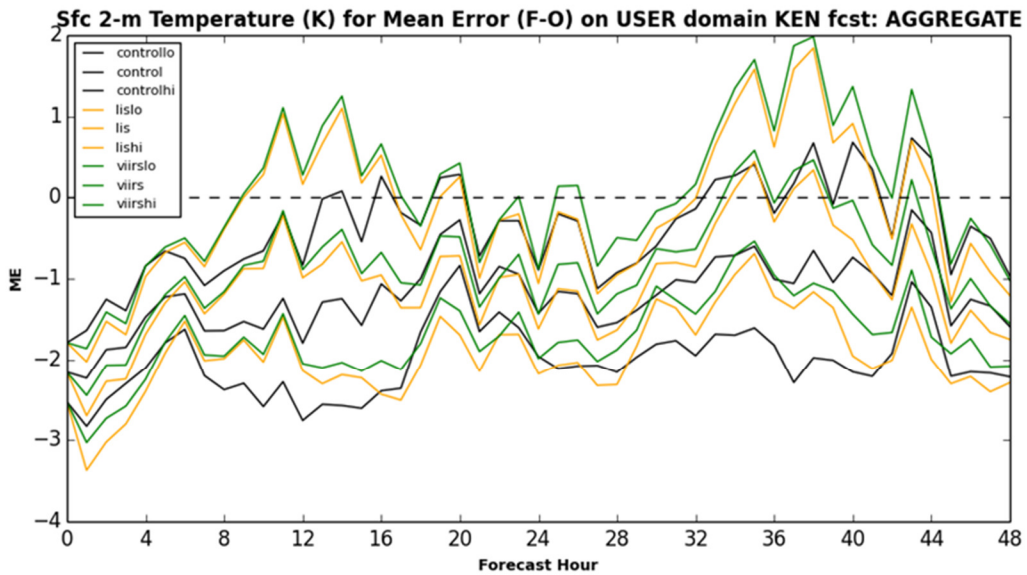


Figure 5. Sample aggregated model verification statistics with confidence intervals generated on KMD's research workstation, and produced from three experimental near-real-time model simulations during the June 2015 training sessions in Huntsville, AL. (top) mean error [forecast minus observed] for simulated 2-m temperature; (bottom) mean error for simulated 2-m dew point temperature as a function of forecast hour on the experimental 4-km WRF-EMS domain.