ANNUAL JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND RELATED RESEARCH ACTIVITIES ON NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2016

Kenya Meteorological Department

1. Summary of highlights

The Kenya Meteorological Department (KMD) has been able to carry out verification of the WRF model over Kenya and especially at the peak of the March - May rainfall season when severe storms occur. So far the model is quite skilful over the country.
Verification of the severe weather forecasts over the Eastern Africa is done on quarterly basis and the skill scores for rainfall and wind forecasts are satisfactory.

2. Equipment in use

The operational system is composed of an 8-node workstation with the following features:

- ✓ 2 Quad Core Central Processing Units;
- ✓ Load scheduler
- ✓ 14-Terrabyte Hard Disk.

The IMIS system which is a high performance computing Linux Cluster platform that is based on the Blade solution. It has the following configuration:

- ✓ 24 -computation nodes;
- ✓ 2- Master cluster nodes;
- ✓ 3- Database nodes;
- ✓ 2-Supervision, Scheduling & Processing nodes for mastering, supervision and control;
- ✓ 1-spare- node.

4 Forecasting system

4.1 System run schedule and forecast ranges

KMD had been running two NWP models operationally; the DWD's *Consortium for Small-Scale Modeling* (COSMO) and the Weather Research and Forecasting (WRF) model. However, due to technical challenges with COSMO's configuration which is changed often, the model hasn't been run for a while.

4.1.1 COSMO

The *COSMO-Model* is a non-hydrostatic limited-area atmospheric prediction model. It has been designed for both operational Numerical Weather Prediction (NWP) and various scientific applications. The COSMO-Model is based on the primitive thermo-hydrodynamical equations describing compressible flow in a moist atmosphere.

The model equations are formulated in rotated geographical coordinates and a generalized terrain following height coordinate. A variety of physical processes are taken into account by parameterization schemes.

Besides the forecast model itself, a number of additional components such as data assimilation, interpolation of boundary conditions from a driving host model, and post-processing utilities are required to run the model in NWP-mode, climate mode or for research case studies.

The basic version of the COSMO-Model has been developed at the *Deutscher Wetterdienst* (DWD). The COSMO-Model and the triangular mesh global grid point model ICON form – together with the corresponding data assimilation schemes – the NWP-system at DWD, which is run operationally since end of 1999. Data assimilation for COSMO is carried out at the DWD, which sends the 3-hour Initial and Lateral Boundary data sets from the German Global Modell (ICON) to KMD, Nairobi, via the GTS link. This is done twice daily for the corresponding data of 00UTC and 12UTC and hence run respectively for 3 days.

The subsequent developments related to the model have been organized within COSMO. COSMO aims at the improvement, maintenance and operational application of a non-hydrostatic limited-area modelling system, which is now consequently called the COSMO-Model. COSMO is running operationally at 7km resolution at the Kenya Meteorological Department on the Integrated Meteorological Information System Linux Cluster.

4.1.2 WRF

The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs. It features two dynamical cores, a data assimilation system, and a software architecture facilitating parallel computation and system extensibility. The model serves a wide range of meteorological applications across scales from tens of meters to thousands of kilometers.

The National Weather Service's (NWS) Science and Operations Office (SOO) Science and Training Resource Center (SOO/STRC) Weather Research and Forecasting (WRF) Environmental Modeling System (EMS) is a complete, full-physics, Numerical Weather Prediction (NWP) package that incorporates dynamical cores from both the National Center for Atmospheric Research (NCAR) Advanced Research WRF (ARW) and the National Center for Environmental Predictions' (NCEP) Non-hydrostatic Mesoscale Model (NMM-WRF) releases into a single end-to-end forecasting system. Nearly all the capabilities of the individual NCEP and NCAR releases are retained within the STRC EMS. However, installation, configuration, and running of the NCEP and NCAR versions has been greatly simplified to encourage its use by NWS forecast offices and the University community. No compilers are necessary as statically-linked x32 and x64 binaries are provided for both distributed and shared memory Linux systems. The MPICH executables are also included for running on local clusters across multiple workstations.

The WRF EMS supports 1-way nesting with the WRF NMM core and 2-way nesting with the ARW core.

The WRF post currently can output fields on 47 pressure levels including 2, 3, 5, 10, 20, 30, 50, 70, 75, 100 to 1000 every 25, and 1013 mb.

WRF is running operationally on the IMIS while the same model is running on a workstation for operational research.

4.2 Medium range forecasting system (4-10 days)

KMD produces a weekly forecast every Monday and two cyclic five day forecasts updated every day. One of the five day forecasts is a special forecast for the army and it contains a forecast for parts of Somalia

4.2.2 Models

The NWP outputs from model run by KMD and from other major NWP centres such as the ECMWF, NCEP, Meteo France and UK-MetOffice are used as inputs into the forecasting process. The output from Meteo France is able to project up to 3 days while ECMWF has the longest range projection, up to 2 weeks.

4.2.2.1 The Numerics of COSMO Include the Following:

The COSMO-Model is based on the primitive hydro-thermodynamical equations describing compressible non-hydrostatic flow in a moist atmosphere without any scale approximations. A basic state is subtracted from the equations to reduce numerical errors associated with the calculation of the pressure gradient force in case of sloping coordinate surfaces. The basic state represents a time-independent dry atmosphere at rest which is prescribed to be horizontally homogeneous, vertically stratified and in hydrostatic balance.

The basic equations are written in advection form and the continuity equation is replaced by a prognostic equation for the perturbation pressure (i.e. the deviation of pressure from the reference state). The model equations are solved numerically using the traditional finite difference method. In the following we summarize the dynamical and numerical key features of the COSMO-Model.

Model Equations	• nonhydrostatic, full compressible hydro-thermodynamical equations in advection form
	• subtraction of a hydrostatic basic state (reference atmosphere) at rest. Options for
	  o a reference atmosphere defined with a constant Δt, with an increasingly negative vertical temperature gradient in the stratosphere and a limit to the vertical model extent.
	  o a reference atmosphere based on a temperature profile $T_0(z) = T_{00} + \Delta t\ EXP(-z/h\_scal)$, approaching an isothermal profile in the stratosphere and no limits of the vertical model extent.

Prognostic Variables	• horizontal and vertical cartesian wind components (u,v,w) • temperature (t) • pressure perturbation (p', deviation from the reference state) • specific humidity (q_v) and specific cloud water content (q_c) • optionally: cloud ice content (q_i), specific water content of rain (q_r), snow (q_s) and graupel (q_g) • optionally: turbulent kinetic energy (tke)
Diagnostic Variables	• Total air density • 2 meter temperature • 10 meter wind speeds • maximal wind gust in 10 meter • precipitation fluxes of rain and snow • and much more ....

Coordinate System	• rotated geographical (lat/lon) coordinate system horizontally
	• generalized terrain-following height-coordinate with user defined grid stretching in the vertical. Options for
	  o base-state pressure based height coordinate
	  o Gal-Chen height coordinate and
	  o exponential height coordinate (SLEVE) according to Schär et al. (2002)

Grid Structure	• Arakawa C-grid, Lorenz vertical grid staggering
Spatial Discretization	• Second-order finite differences. For the two time-level scheme also 1st and 3rd to 6th order horizontal advection (default: 5th order) • Option for explicit higher order vertical advection
Time Integration	Default scheme: • 2^{nd} and 3^{rd} order two time-level Runge-Kutta split-explicit scheme (Wicker and Skamarock, 2002) • TVD (Total Variation Diminishing) variant of a 3^{rd} order two time-level Runge-Kutta split-explicit scheme Additional Options: • Second-order leapfrog HE-VI (horizontally explicit, vertically implicit) time-split integration scheme, including extensions proposed by Skamarock and Klemp (1992) • Option for a three time-level 3D semi-implicit scheme (Thomas et al., 2000)
Numerical Smoothing	• 4th-order linear horizontal diffusion with option for a monotonic version including an orographic limiter • Rayleigh damping in upper layers • 2D divergence damping and off-centering in the vertical in split time steps

The Physics of COSMO are as follows:

- Two stream *radiation* scheme including long- and shortwave fluxes in the atmosphere and at the surface; full cloud - radiation feedback; diagnostic derivation of partial cloud cover (relative humidity and convection);
- Grid-scale *precipitation* scheme including parameterized cloud microphysics;
- Mass flux *convection* scheme differentiating between deep, shallow and mid -level convection;
- Level-2 scheme of *vertical diffusion* in the atmosphere, similarity theory at the surface;
- Two-layer *soil model* including snow and interception storage; three-layer version for soil moisture as an option.

The visualization software used to display the model output includes Grid Analysis and Display System (GraDS)..

The Numerical Techniques of the WRF

The WRF model is a fully compressible, non-hydrostatic model (with a hydrostatic option). Its vertical coordinate is a terrain following hydrostatic pressure coordinate. The grid staggering is the Arakawa C-grid. The model uses the Runge-Kutta 2nd and 3rd order time integration schemes and 2nd to 6th order advection schemes in both horizontal and vertical directions. It uses a time-split small step for acoustic and gravity-wave modes. The dynamics conserves scalar variables.

WRF Model Physics

WRF offers multiple physics options that can be combined in any way. The options typically range from simple and efficient to sophisticated and more computationally costly and from newly developed schemes to well tried schemes such as those in current operational models

4.2.2.2 Research performed in this field

Assimilation of NASA Sport LIS soil moisture into EMS-WRF ongoing.

4.2.1 Operationally available Numerical Weather Prediction Products

Computations are done for various model fields including:

Surface pressure (Ps) ; Temperature (T0); Water vapour (qv0) ; Cloud water(qc) ;Cloud ice (qi) -optional ; Horizontal wind (u, v); Several surface/soil parameters; Vertical velocity; Geopotential height; Cloud cover (clc) ; Diffusion coefficients(tkvm/h); Precipitation

4.3 Short Range Forecasting

KMD issues 24-hr forecasts using a Forecasting Workstation. The NWP outputs from model run by KMD and from other major NWP centres such as the ECMWF, NCEP, Meteo France and UK-MetOffice are used as inputs into the forecasting process. KMD is also a designated Regional Centre for Severe Weather Forecasting Demonstration Project (SWFDP) for the Eastern African region. KMD issues, on a daily basis, severe weather forecasts for the region using products from the above mentioned global producing centres.

4.5.1 Current Operational Status:

KMD issues daily shipping forecasts for the region of responsibility (METAREA VIII) over the west Indian Ocean. The Department receives Storm/Tropical cyclone warning/alert/advisory bulletin for the South western Indian Ocean area from the Regional Tropical Cyclone Centre based in Re-Union Island. The Storm/Tropical cyclone Warning/Advisory is then disseminated to the region of responsibility for safety at sea and navigation. KMD also issues severe weather forecast for the region using the above mentioned NWP centres.

4.5.2 Future Projections/Plans:

The Department is already implementing the NCEP Wavewatch III model products for the Western Indian Ocean. It is in the process of developing hydrodynamic products to model tidal currents and marine pollution transport along our coastline. The hydrodynamic products when operational will also be used to model storm surge and sea level/tidal variations along Kenyan Coast.

4.6 Extended range forecasts (ERF) *(10 days to 30 days)*

KMD prepares and issues monthly forecasts using Empirical/statistical models and model outputs from Global Prediction Centres (GPCs).

4.6.1 Models

Empirical/statistical models and model outputs from Global Prediction Centres (GPCs).

4.6.1.1 In operation

The main parameter being forecasted in these seasonal forecasts is rainfall although temperatures ranges may also be deduced.

4.6.2 Validation of the statistical models is regularly performed.

4.6.3 Operationally available EPS products.

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4.7 Long range forecasts (LRF) *(30 days up to two years)*

KMD prepares and issues seasonal forecasts for the March-April-May, October-November-December and June-July-August-September seasons using Empirical/statistical models and model outputs from Global Prediction Centres (GPCs).

4.7.1 In operation

The main parameter being forecasted in these seasonal forecasts is rainfall.

5 Verification of prognostic products

5.1 Annual Verification Summary

5.1.1 Verification of severe weather forecasts events

Contingency tables were used to verify occurrence of severe weather forecasts events to evaluate hits, false alarms, misses and correct negatives for the purpose of monitoring the quality of forecasts, improvement and to compare the consistency of different NWP forecast products.

The table below summarize the average quarterly verification values of severe weather events for the year 2016.

Brier scores (*BS)* at 24hrs for precipitation and wind vector at W 850hpa

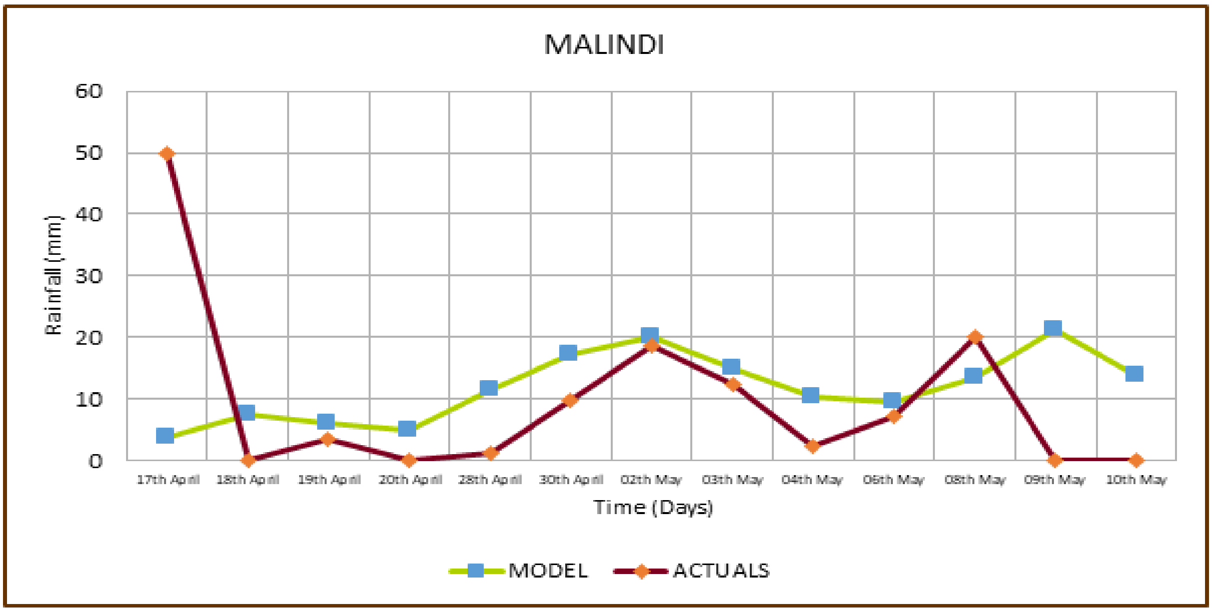
$$BS = \frac{1}{N}\sum_{t=1}^{N}(f_t - 0_t)^2$$

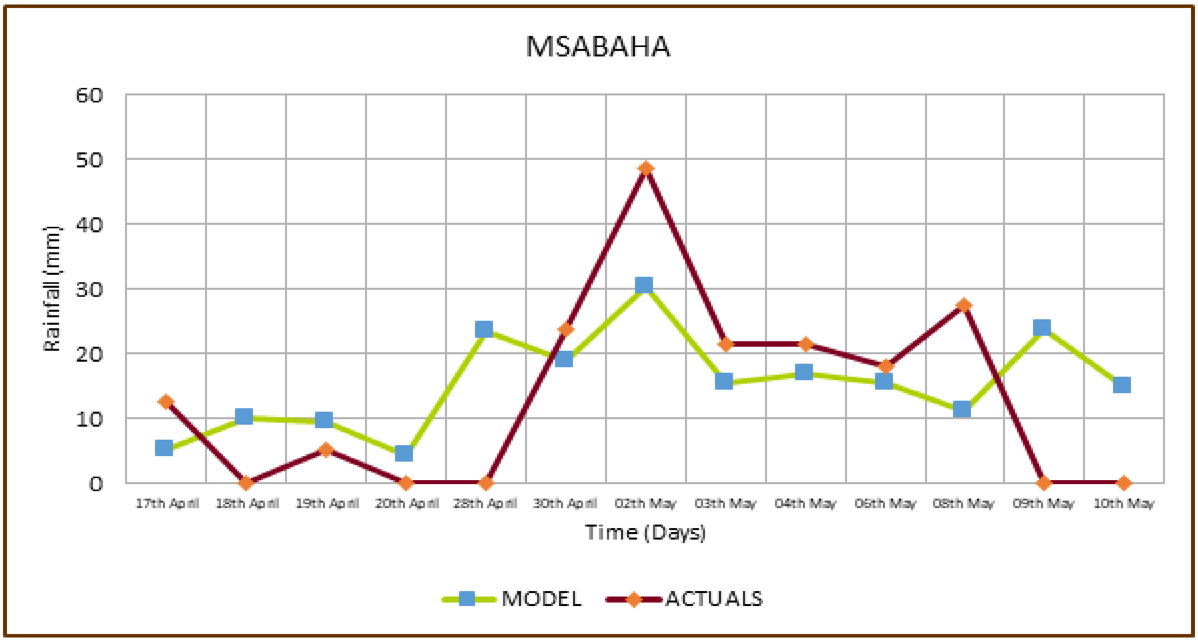
Table 1: Verification scores

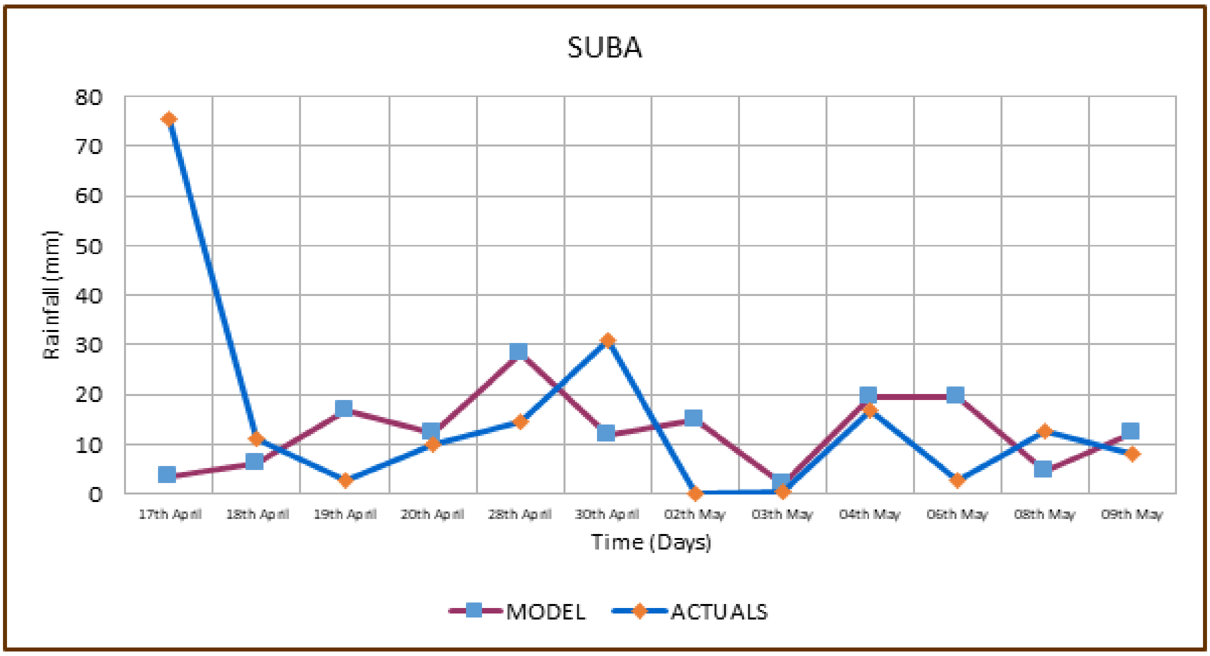
Scores	Rainfall=>50mm/24hrs	Winds at 850hpa =>25kts
Brier Score	0.047	0.043

5.2 Research performed in this field

Verification of the WRF model is ongoing. The model output products being considered in the verification exercise are the rainfall, temperature, wind fields and moisture. So far the model is doing quite well over this region. Verification was done from 17th April to May 10th 2017, when the country was experiencing severe storms. The model generally skilfully forecasts the rainy days but underestimates the magnitudes as shown in the figures below.







6 Plans for the future *(next 4 years)*

6.1 Development of the Subproject and approval

The Severe Weather Forecasting Demonstration Project (SWFDP) in Eastern Africa is focused on severe weather forecasting and warning services for the benefit of the general public and socio-economic sectors, in particular agriculture, marine and fisheries.

The SWFDP in Eastern Africa has two major components; one that is aimed at improving the severe weather forecasting and warning services for the benefit of the general public and socio-economic sectors, in particular agriculture; and another component focusing on improving severe weather forecasting and warning services over the Lake Victoria (safety and protection of fishermen).

The regional subproject focuses on the following severe weather events in order of decreasing priority (and associated hazards such as flooding):

(a) Heavy rain/flooding;
(b) Strong winds in relation to thunderstorms and any other phenomena over the Indian Ocean and major lakes;
(c) Hazardous Indian Ocean and major lake waves.

In future the project plans to include Lightening, Hail and frost forecasts.

Some of the other future plans that KMD has include:

- Expand the spatial observational network to increase the near real time data;
- Acquire a new Climate Data Base Management System (CDMS) for managing huge amounts of historical data for research purposes; and
- Implementation of data assimilation in the NWP models.

6.2 Planned research Activities in NWP, Nowcasting, Long-range Forecasting and Specialized Numerical Predictions

6.2.1: Planned Research Activities in NWP

The information provided here pertains to the operational model. Ongoing research activities in respect of this model include the following:

- Development of Model Output Statistics (MOS)
- Examination of model performance by the use of correlation analysis as well as comparison with other model outputs such as Meteo France (MFR), Climate Prediction Center (CPC)/African desk and the European Center for Medium –range Weather Forecasts (ECMWF).
- Expand the flood forecasting model to other water catchment areas vulnerable to flooding.

There is also intention of acquisition and installation of 4 radars countrywide. The data obtained from the radar systems combined with satellite data will be used in nowcasting of severe weather over this region.

6.2.2: Planned Research Activities in Nowcasting

- Installation of the EUMETSAT SAFNWC nowcasting model currently underway at KMD. The only challenge being the integration of the new PUMA system satellite products into the nowcasting model for Kenya and neighbouring member states

6.2.3: Planned Research Activities in Long-Range Forecasting

6.2.4: Planned Research Activities in Specialized Numerical Predictions

- Research into the assimilation of LIS VIIRS real time static datasets as input into the WRF model run at KMD on an experimental basis which would include:

  1) Incorporate real-time high-resolution soil moisture and temperature data from the NASA-SPoRT LIS into the KMD WRF-EMS model over East Africa
  2) Incorporate real-time NOAA/NESDIS VIIRS green vegetation fraction data into the KMS WRF-EMS model over East Africa

- High-resolution (4-km) nested WRF model runs for the counties in Western Kenya for a high resolution model forecast products in assisting and supplementing the downscaled regional forecasts under the WISER WESTERN Project

Acronym:

KMD: Kenya Meteorological Department

NASA LIS: NASA Land Information System soil moisture model products

NOAA/NESDUS VIIRS: National Oceanic and Atmospheric Administration VIIRS remotely sensed green vegetation fraction product

SAFNWC: EUMETSAT's Satellite Application Facility to NoWCasting & Very Short Range Forecasting

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