PROGRESS REPORT ON NUMERICAL WEATHER PREDICTION FOR 2005 FOR KENYA

Part I: A brief summary of Research and Development and main operational changes

The Numerical Weather Prediction (NWP) section of the Kenya Meteorological Department is one of the sections within the Forecasting Division of the Department. It was established five years ago with the sole purpose of:

- Improving the skill of the short and medium range weather forecasts;
- Adopting and customizing a suitable Limited Area Model (LAM) that could be implemented for the country.

The computer models used for numerical weather prediction calculate the formation, growth, movement and decay of the systems within which weather events, including severe weather, are embedded. The models are complex and integrate fluid motion, thermodynamics and radiation on a rotating globe that includes topography, land and seas differences and the diurnal cycle. In addition, mathematical schemes for representing very small-scale processes, such as cloud and turbulence, are included. By the end of year 2005, installation and use of various LAMs had been attempted. These include the following:

- HRM/DWD developed from the EM/DM at Deutcher Weterdienst (DWD) Germany. The HRM is optimized to run on multiple-processor shared memory platforms;
- NCEP/ETA model (USA);
- NCEP/RSM (USA);
- NCAR/PENNSTATE UNIVERSTY MM5 (USA);
- RAMS of the Colorado State University (USA)
- Weather Research and Forecasting Model WRF (USA)

The Regional Atmospheric Modeling System (RAMS**)** of the Colorado State University (CSU), the NCEP/ETA as well as the Weather Research and Forecasting (WRF) models have now been successfully installed and tested. The only handicap to these models is the enormous initialization data (which we are unable to access) and advanced computing facilities required. For instance in the case of the latter model, downloading of the entire global data is required. Despite these handicaps, however, the HRM model is now running operationally in the Department. The model is optimized to run on Multiple-Processor shared-memory platforms and uses FORTRAN90/95 compilers.

Part II: Research and Development in Data Assimilation and in Numerical Forecasting

II.1. Research and Development in Data Assimilation

The information provided here pertains to the operational HRM model as well as the other promising model namely; the Weather Research and Forecasting (WRF) model.

II.1.1: The HRM Model

Data assimilation is carried out at the DWD, which sends the 3-hour Initial and Lateral Boundary data sets from the German Global Modell (GME) to KMD, Nairobi, via the GTS link. This is done twice daily for the corresponding data of 00UTC and 12UTC.

II.1.1. Numerical Techniques for the High Resolution Model (HRM)

The HRM model has been implemented on a 2 processor PC under Redhat Linux version 7.3 operating system. The model is initialized using the GME output datasets from DWD operational runs of the global model. The visualization software used to display the model output includes Grid Analysis and Display System (GraDS) and Vis5D. Computations are done for various model fields including:

Surface pressure (P_s) ; Temperature (T0); Water vapour (q_{v0}) ; Cloud water(q_c) ; Cloud ice (q_i) - optional ; Horizontal wind (u, v); Several surface/soil parameters; Vertical velocity (ω) ; Geopotential height (ϕ); Cloud cover (clc) ; Diffusion coefficients(tkvm/h); Precipitation

II.1.2: The Numerics of HRM Include the Following:

- Regular or rotated latitude/longitude grid;
- Mesh sizes between 0.25° and 0.05° (~ 28 to 6 km);
- Arakawa C –grid stagger, second order centered differencing;
- Hybrid vertical coordinate, 20 to 40 layers ;
- Split semi-implicit time stepping; $\Delta t = 150s$ at $\Delta = 0.25°$;
- Helmholtz equation solved by direct method Fast Fourier Transformation (FFT) and Gauss solver;
- Lateral boundary formulation ;
- Radiative upper boundary condition as an option ;

- Linear fourth-order horizontal diffusion, slope correction for temperature;
- Adiabatic implicit nonlinear normal mode initialization.

II.1.3: The Physical Parameterizations of HRM are as follows:

- δ-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.

II.2: The Weather Research and Forecasting (WRF) model

II.2.1. Numerical Techniques

The WRF model is a fully compressible, nonhydrostatic 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.

The model requires FORTRAN 90 or 95, C compiler and a perl 5.04 or better. It also supports net CDF,PHD5 AND GriB 1 formats

At the Kenya Meteorological Department, this model has been installed on a Linux Workstation (Single processor)

II.2.2 Model Physics and Diffusion Options

II.2.2.1 Physics Options

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.

The choices vary with each major WRF release, but here we will outline those available in WRF Version 2.0.

II.2.2.1.1 Microphysics

- Kessler scheme: A warm-rain (i.e. no ice) scheme used commonly in idealized cloud modeling studies.
- Lin et al. scheme: A sophisticated scheme that has ice, snow and graupel processes, suitable for real-data high-resolution simulations.
- WRF Single-Moment 3-class scheme: A simple efficient scheme with ice and snow processes suitable for mesoscale grid sizes.
- WRF Single-Moment 5-class scheme: A slightly more sophisticated version of (c) that allows for mixed-phase processes and super-cooled water.
- Eta microphysics: The operational microphysics in NCEP models. A simple efficient scheme with diagnostic mixed-phase processes.
- WRF Single-Moment 6-class scheme: A scheme with ice, snow and graupel processes suitable for high-resolution simulations.
- Thompson et al. scheme: A new scheme related to Reisner2 with ice, snow and graupel processes suitable for high-resolution simulations.
- NCEP 3-class: An older version of (c)
- NCEP 5-class: An older version of (d)

II.2.2.1.2 Longwave Radiation

- RRTM scheme: Rapid Radiative Transfer Model. An accurate scheme using look-up tables for efficiency. Accounts for multiple bands, trace gases, and microphysics species.
- GFDL scheme: Eta operational radiation scheme. An older multi-band scheme with carbon dioxide, ozone and microphysics effects.

II.2.2.1.3 Shortwave Radiation

- Dudhia scheme: Simple downward integration allowing efficiently for clouds and clear-sky absorption and scattering.
- Goddard shortwave: Two-stream multi-band scheme with ozone from climatology and cloud effects.
- GFDL shortwave: Eta operational scheme. Two-stream multi-band scheme with ozone from climatology and cloud effects.

II.2.2.1.4 Surface Layer

- MM5 similarity: Based on Monin-Obukhov with Carslon-Boland viscous sub-layer and standard similarity functions from look-up tables.

- Eta similarity: Used in Eta model. Based on Monin-Obukhov with Zilitinkevich thermal roughness length and standard similarity functions from look-up tables.

II.2.2.1.5 Land Surface

- 5-layer thermal diffusion: Soil temperature only scheme, using five layers.
- Noah Land Surface Model: Unified NCEP/NCAR/AFWA scheme with soil temperature and moisture in four layers, fractional snow cover and frozen soil physics.
- RUC Land Surface Model: RUC operational scheme with soil temperature and moisture in six layers, multi-layer snow and frozen soil physics.

II.2.1.6. Planetary Boundary layer

- Yonsei University scheme: Non-local-K scheme with explicit entrainment layer and parabolic K profile in unstable mixed layer.
- Mellor-Yamada-Janjic scheme: Eta operational scheme. One-dimensional prognostic turbulent kinetic energy scheme with local vertical mixing.
- MRF scheme: Older version of (a) with implicit treatment of entrainment layer as part of non-local-K mixed layer

II.2.1.7. Cumulus Parameterization

- Kain-Fritsch scheme: Deep and shallow sub-grid scheme using a mass flux approach with downdrafts and CAPE removal time scale.
- Betts-Miller-Janjic scheme. Operational Eta scheme. Column moist adjustment scheme relaxing towards a well-mixed profile.
- Grell-Devenyi ensemble scheme: Multi-closure, multi-parameter, ensemble method with typically 144 sub-grid members.

II.2.2 Diffusion and Damping Options

Diffusion in WRF is categorized under two parameters, the diffusion option and the K option. The diffusion option selects how the derivatives used in diffusion are calculated, and the K option selects how the K coefficients are calculated. Note that when a PBL option is selected, vertical diffusion is done by the PBL scheme, and not by the diffusion scheme.

II.2.2.1 Damping Options

These are independently activated choices.

- Upper Damping: Either a layer of increased diffusion or a Rayleigh relaxation layer can be added near the model top to control reflection from the upper boundary.
- w-Damping: For operational robustness, vertical motion can be damped to prevent the model from becoming unstable with locally large vertical velocities. This only affects strong updraft cores, so has very little impact on results otherwise.
- Divergence Damping: Controls horizontally propagating sound waves.
- External Mode Damping: Controls upper-surface (external) waves.

  Time Off-centering: Controls vertically propagating sound waves.

Part III: Research and Development Results for the Application of NWP Products

The HRM model gives predictions up to 72 hours (3 days). Due to computational cost, it is run once daily at the Kenya meteorological Department (KMD). Ongoing research in respect of this model include the following:

- Development of Model Output Statistics (MOS)
- Validation of the model products against the actual observations on a location-to-location.
- Examination of model performance is being done 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).

Part IV: Outstanding Research and Development Activities Related to the Analysis Forecast System in Operational Use in the Previous Year

- There were regular provisions of experimental NWP forecasts information on fine spatial and temporal scales to the Central Forecasting Office (CFO) for inclusion in the routine four-day and weekly outlooks. Thus, the NWP products continued to form vital inputs to operational forecasting activities at the Central Forecasting Office in KMD. Efforts are still being made to generate downscaled and user tailored forecasts from the appropriate NWP model.

- Towards the end of the review period, the HRM outputs had also started being used in a hydrological application model (a GIS based model) for flood flow forecasting for the Tana River basin. This application is currently on a research mode.
- Human resources are pivotal in NWP modeling. However, there is a notable lack of expertise for numerical weather prediction in the country. Currently three meteorologists are undergoing trainings at Masters of Science level in Numerical modeling related courses at the University of Nairobi

Part V: Plans for Future Research and Development Activities Related to the Improvement of the Operational System

A number of fundamental elements are necessary to fully realize the success of Numerical Weather Prediction system. These include data availability, computing facilities and human resources among others.

Data:

- Data acquisition for initialization from remote sites is via FTP over the Internet. The volume is large and the process slow. Faster transfer of information is envisaged via efficient communication links with the Global Data Centers
- Validation of the NWP products is critical if the products are to be of any meaningful use to users. Automation of databases and data rescue strategies is, therefore, envisaged for purposes of verifying NWP model outputs**.**

Computing resources

Numerical Data analysis and processing require high-performance computing resources and high-speed processing is necessary for high-resolution runs. Further, most models require optimized multiple-processor shared-memory platforms. Currently the Department has only one single processor (Pentium III) Workstation running on Linux version 7.3. This workstation is over-utilized and has run out of disk space. KMD is therefore exploring means and ways of acquiring an eight node Linux Cluster and two IBM RISC System 6000, in order to meet the NWP needs.

Human Resources

Training in software technology especially programming (particularly in relevant software like UNIX and FORTRAN) is envisaged. This has been prompted by the continually changing nature of software in the market.

Others

Besides the three fundamental elements alluded to above, a number of activities geared towards research and development are envisaged. These include:

- Assessment of the potential of Ensemble Prediction Systems (EPSs) in medium-range and seasonal weather forecasting
- Data assimilation of Radio-Sonde atmospheric sounding data for East African stations with such data;
- Continuously evaluate the performance of the regional model by validating the outputs against observed data
- Seek means and ways of obtaining real time data to effect the running of the other already installed models i.e. The Regional Atmospheric Modeling System (RAMS)), the NCEP/ETA as well as the Weather Research and Forecasting (WRF) models.
- Make the flood forecasting model operational in the Department

Part VI: Development in Objective Interpretation and Verification Procedures Including Performance Statistics

- There is need for the establishment of a comprehensive verification system, consisting of calculations of forecasted Root Mean Square Errors (RMSE) and bias between the forecasts and analyzed fields for the standard pressure levels;

- There is need to Integrate remotely sensed data from weather radar and Meteosat Second Generation (MSG) satellites

Performance of the installed models will be evaluated through comparisions of their output with observed information as well as products from reknown NWP centers such UK Met office, Meteo France (MFR), Climate Prediction Center (CPC)/African desk, IRI, the European Center for Medium–range Weather Forecasts (ECMWF) and the Beaureu of Meteorology (Australia).

Part VII: Publications

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