Joint WMO Technical Progress Report on the Global Data Processing and Forecasting System and Numerical Weather Prediction Research Activities For 2016

PAKISTAN METEOROLOGICAL DEPARTMENT

1. Summary of highlights

Pakistan Meteorological Department (PMD) is currently issuing 3-days numerical weather forecast for general public and 7-days forecast for National Weather Forecasting Centre (NWFC) using ICON model at 13km horizontal grid resolution for the domain spread over 30 – 100ºE and 0 – 55ºN. PMD also established an automated phone based weather forecast system for 139 districts of Pakistan. The system provides model based forecast using a speech interface where users can call and get updates about the weather by speaking the name of the desired district. The forecast information is updated twice daily i.e. 00 and 12 UTC.

PMD started indigenous numerical weather forecast using High-resolution Regional Model (HRM) in 2006. HRM was hydrostatic regional weather forecast model with horizontal grid resolution flexible between 0.25° – 0.05° (~ 28 to 6 km) and hybrid vertical coordinate, 30 – 60 layers. Initially, the model was configured at 22km horizontal grid resolution and forecast was generated two times a day at 00:00 and 06:00 GMT using initial and boundary conditions from Global Model, GME by DWD (Deutscher Wetterdienst, German Weather Service). Later in September 2010 after successful deployment of powerful 256 cores High Performance Computing Cluster (Blade Servers) having peak performance of about 1.7 TFlops, HRM was configured at finer horizontal grid resolution of 11km and the forecast was generated three times a day 00:00, 06:00 and 12:00 GMT. PMD started simulating HRM with fine resolution initial and boundary conditions after the GME data resolution was improved from 30km to 20km in March 2012.

PMD switched from hydrostatic model HRM to non-hydrostatic Model COSMO (Consortium for Small-scale Modelling) in February 2014. The model was configured at horizontal grid resolution of 14km. On 20th January, 2015, DWD replaced the old global model GME with the new development, ICON. ICON (ISOsahedral Nonhydrostatic) modelling framework is a joint project between the Deutscher Wetterdienst (DWD) and the Max-Planck-Institute for Meteorology (MPIM) for developing a unified next-generation global NWP and climate modelling system. The operational regional weather forecast model of PMD, COSMO is temporarily suspended, till the acquisition of more powerful HPCC, because the current HPCC is not capable to further downscale the Global Model ICON i.e., up to 5–7km horizontal grid resolution. PMD anticipated to acquire new HPC having peak performance of 20 TF and to establish Specialized Medium Range Forecasting Center by the year 2018.

2. Equipment in use

Pakistan Meteorological Department established High Performance Computing centre comprising of HP rack mount servers in 2006 to cope with the computational needs of numerical models. Later in September 2010 PMD successfully deployed 256 cores High Performance Computing Cluster (Blade Servers) having peak performance of about 1.7TFlops that is operational to simulate regional weather forecast and climate models at fine grid resolutions. The technical specifications of Rackmount and Blade servers are as under.

High Performance Computing Cluster (Rack mount Servers)

HP Proliant DL380 G4

Compute Nodes: 09 Nos.
Processor: 3.4 GHz Intel Xeon dual process each
RAM: 4 GB each

HP Proliant DL380 G5

Compute Nodes: 04 Nos.
Processor: 3.0 GHz Intel Xeon dual core dual processor each
RAM: 4 GB each

PowerEdge R720 Rack Server

Compute Nodes: 02 Nos.
Processor: Intel® Xeon® processor E5-2600
RAM: 8 GB each
Storage Capacity: SAS 12TB (5 SAS Drives of 2.4TB each)

PowerEdge R930 Rack Server

Compute Nodes: 04 Nos.
Processor: Intel® Xeon® processor E7-8800
RAM: 16 GB each
Storage Capacity: SAS 24TB (20 SAS Drives of 1.2TB each)

Storage:

DELL Power Vault MD1000 Direct Attached Storage
Capacity: 12 TB (12 SATA Drives of 1TB each)

Connectivity:

Gigabit Ethernet

High Performance Computing Cluster (Blade Servers)

Peak Computational Performance 1.7 TFlops

Dell Power Edge M600 Blade Servers

Compute Nodes: 32 Nos.
Processor: 3.33GHz 2 x Quad Core Intel Xeon Processors
RAM: 8 GB Each

Connectivity:

Infiniband Interconnect 20Gbps

Fiber Channel 8Gbps

Storage:

SAN Dell/EMC CX4-120 with Fiber Channel 8 Gbps Interconnect
12 TB SATAII (12 drives of 1 TB each)
FC 5.2 TB (13 Drives of 400 GB each)

3. Data and Products from GTS in use

A GTS link via ftp has been established in 2011 between China Meteorological Agency (CMA), and PMD Islamabad. NWP products of CMA's Global Spectral Model (GSM) in Grib-1 format are being uploaded to PMD's ftp server daily at 00:00, 06:00, 12:00, and 18:00 GMT. GSM has a horizontal resolution of TL639 (0.28125 deg) and is used for Short- and Medium-range forecast. Outputs of GSM in graphical form are updated daily on website of PMD after post processing.

4. Forecasting system

4.1. System run schedule and forecast ranges

The ICON model forecast is generated two times a day i.e. 00 and 12 GMT to issue 72 hours forecast for general public and 7-days forecast for NWFC. The forecast is generated at 13km horizontal grid resolution on 03 hourly intervals i.e. 00, 03, 06, 09, 12, 15, 18 and 21 GMT.

The operational regional weather forecast model of PMD, COSMO is temporarily suspended, till the acquisition of more powerful HPCC, because the current HPCC is not capable to further downscale the Global Model ICON i.e., up to 5–7km horizontal grid resolution.

Global Forecast System (GFS) Model at 0.25^{o} horizontal grid resolution is used to generate one week forecast at 06 hourly intervals i.e. 00, 06, 12 and 18 GMT.

GSM Model at 30km horizontal grid resolution is used to generate one week forecast at 00 and 12 GMT at 12 hourly intervals.

Theses forecasts are available and regularly updated on Pakistan Meteorological Department website (http://www.pmd.gov.pk/rnd/rndweb/rnd_new/numerical.php).

4.2 Short-range forecasting system (0-72 hrs)

4.2.1 Data assimilation, objective analysis and initialization

Initial and Boundary Conditions

The regional weather forecast model COSMO like other regional systems needs boundary data from a driving model. For the NWP-mode it is possible to use the ICON (or old GME) and the IFS as driving models. Also, the COSMO-Model data can be used as boundary data for a higher resolution COSMO run. In an operational NWP-mode, initial conditions for the COSMO-Model are produced by Data Assimilation. Nudging procedure is included in the COSMO-Model that nudges the model state towards available observations.

Data Assimilation

Basic Method:

Continuous four-dimensional data assimilation based on observation nudging is used, with lateral spreading of upper-air observation increments along horizontal surfaces. Explicit balancing is done

by a hydrostatic temperature correction for surface pressure updates, a geostrophic wind correction, and a hydrostatic upper-air pressure correction.

Assimilated Atmospheric Observations:

The model uses observations from radiosonde (wind, temperature, humidity), aircraft (wind, temperature), wind profiler (wind), and surface-level data (SYNOP, SHIP, BUOY: pressure, wind, humidity) for assimilation. Optionally Radio Acoustic Sounding System (RASS) temperature, radar VAD (Velocity Azimuth Display) wind, and ground-based GPS (integrated water vapour) data is used. Surface-level temperature is used for the soil moisture analysis only.

Radar derived rain rates:

Assimilation of near surface rain rates based on latent heat nudging. It locally adjusts the three-dimensional thermodynamical field of the model in such a way that the modelled precipitation rates should resemble the observations.

Surface and Soil Fields – Additional two-dimensional intermittent analysis:

Soil Moisture Analysis – Daily adjustment of soil moisture by a variational method in order to improve 2-m temperature forecasts; use of a Kalman-Filter-like background weighting.

Sea Surface Temperature Analysis – Daily Cressman-type correction, and blending with global analysis. Use of external sea ice cover analysis.

Snow Depth Analysis – 6-hourly analysis by weighted averaging of snow depth observations, and use of snowfall data and predicted snow depth.

Analyses and Forecast from Global Model

DWD provides the analyses and forecasts of ICON on 90 model layers and horizontal grid resolution of 13 km. Different forecast ranges of ICON are as follows:

Forecast range:

180h / 00, 12 UTC

120h / 06, 18 UTC

30h / 03, 09, 15, 21 UTC

4.3 Model

4.3.1 In-operation - ICON – COSMO

The ICOsahedral Nonhydrostatic model ICON is the new global numerical weather prediction model developed jointly by DWD and MPIM. It is operational since 2015-01-20, replacing the old global model GME. The horizontal ICON grid consists of a set of spherical triangles that seamlessly span the entire sphere. The grid is constructed from an icosahedron which is projected onto a sphere. DWD simulates the ICON model at 13km grid resolution for the whole globe and provide its raw output at regional scale for regional weather forecast under license agreement. The output can be used to generate weather forecast products at same resolution or can be further dynamically downscaled, subject to the availability of enough computational resources, to generate more fine resolution forecast. PMD is currently simulating the forecast at 13km grid resolution and is in process to acquire more computational resources to run the model at finer grid resolution of up to 5km.

The COSMO (Consortium for Small-scale Modelling) - 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 on the meso-β and meso-γ scale. 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 used to run the model in NWP-mode, climate mode or for case studies.
The COSMO-Model is available free of charge for scientific and educational purposes, especially for co-operational projects with COSMO members.

Numerics of COSMO:

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 – Two time-level 2nd and 3rd order Runge-Kutta split-explicit scheme after Wicker and Skamarock (2002) and a TVD-variant (Total Variation Diminishing) of a 3rd order Runge-Kutta split-explicit scheme. Option for a 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 3-d semi-implicit scheme (Thomas, Girard et al. 2000) based on the leapfrog scheme.

Numerical Smoothing – 4th-order linear horizontal diffusion with option for a monotonic version including an orographic limiter. Rayleigh damping in upper layers. 2-d divergence damping and off-centering in the vertical in split time steps.

4.3.2. Research performed in this field

Several studies have been conducted to evaluate the performance and fine tune the models for improved weather forecast. Some of these are listed as follows:

- Persistent Heavy Downpour in Desert Areas of Pakistan in South Asian Monsoon (Cheema, Zaman et al. 2012).
- Third Successive Active Monsoon over Pakistan – An analysis and Diagnostic Study of Monsoon (Faisal, Jameel et al. 2013).
- Diagnosis and Numerical Simulation of Heavy Rainfall Event in winter over upper parts of Pakistan (Zafar and Rasul 2009).
- Predictability of Summer Monsoon Rainfall using High-resolution Regional Model HRM (Mahmood and Rasul 2012).
- Heavy Rainfall forecast by High Resolution Regional Model (HRM) and its validation for Pakistan (Ali, Mahmood et al. 2014).

4.3.3 Operationally available NWP products

The NWP products are generated twice daily i.e. 00 and 12 UTC. The products include weather forecast information for the following variables generated using ICON, GFS and GSM.

ICON:

24-Hourly Forecast

- Daily Total Precipitation
- Daily Maximum Temperature
- Daily Minimum Temperature
- Daily Snow and Rainfall
- Snow Depth
- Snow Density

3-Hourly Forecast

- Precipitation
- Total Cloud Cover
- Mean Temperature
- 200 (mb) Height & Wind
- 500 (mb) Height & Wind
- 700 (mb) Height & Winds
- 850 (mb) Height & Winds
- Convective Available Potential Energy (CAPE)

Global Forecast System (GFS):

6-Hourly Forecast

- Precipitation
- Daily Maximum Temperature
- Daily Minimum Temperature
- Mean Temperature
- 200 mb Height and Wind
- 300 mb Height and Wind
- 500 mb Height and Wind
- 500 mb Vorticity
- 700 mb Height and Wind
- 850 mb Height and Wind
- 850 mb Vorticity
- Sea Level Pressure

Global Spectral Model (GSM):

12-Hourly Forecast

- Precipitation
- Mean Temperature
- 200 mb Height & Wind
- 500 mb Height & Wind
- 700 mb Height & Winds
- 700 (mb) Vorticity
- 850 mb Height & Winds
- 850 (mb) Vorticity
- Surface Pressure
- K Index

5. Plans for the future *(next 4 years)*

- Establishment of Specialized Medium Range Weather Forecasting Centre (SMRFC) with acquisition of powerful High Performance Computing Cluster having computing power of about 20 TFLOPS and 200 TB storage.
- Development of Weather Guidance System based on multiple models i.e.
    - DWD ICON 0.125 deg
    - US GFS 0.25 deg
    - JMA GSM 0.18 deg
    - CMA ensemble 1.0 deg
    - US NCEP ensemble 1.0 deg
- Deployment of regional weather forecast model COSMO at finer grid resolution of up to 5km.
- Installation of S-Band Doppler Pulse Compression Solid State Radar System to have improved now casting system.
- Incorporation of radar and in-situ data in COSMO using Data Assimilation techniques for improved weather forecast.
- Improved model verification methodology to validate model quantitative forecast on regular basis.
- Development of weather forecast and alert applications for various sectors i.e. Tourism, Disaster Management, Agriculture Sector, Water Sectors and General Public.
- Enhancement of automated phone based weather forecast system from district to sub-district level.

6. References

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PMD – Numerical Weather Products (http://www.pmd.gov.pk/rnd/rndweb/rnd_new/numerical.php)