Description of UM based Analysis-Forecast System

1. Introduction

A MoU was signed between MoES and Met Office, UK in August 2008, to collaborate for developing a seamless numerical modelling system for prediction over different time ranges and spatial scales. The initial focus of this collaboration is on implementation of Met Office Unified Model (UM) global forecast suite at NCMRWF which includes atmospheric modelling and data assimilation.

With the arrival of IBM-P6 HPC in April 2010 at NCMRWF, UM (version 7.4) was successfully compiled and tested at N320L50 (~40 km at mid-latitudes) using Met Office Initial conditions. Daily runs of UM7.4 at N320L50 started in June 2010 with Met Office initial conditions. At the end of the monsoon season of 2010, model's vertical levels were increased to 70. Later on in the same year, model's horizontal resolution was upgraded to N512 (~25 km at mid-latitudes). Subsequently, the model's versions were upgraded to versions 7.5, 7.6, 7.7, 7.8 and 7.9 at repository level. Daily runs with UM version 7.6 started in June 2011 at N512L70 resolution. A detailed description of the implementation of the system can be found in Rajagopal et al., 2012.

2. Components of the UM global forecast suite

Observation Processing System (OPS), four dimensional variational data assimilation system (4D-VAR) and Unified Model (UM) are the main components of the UK Met Office (UKMO) global forecast suite. The OPS prepares quality controlled observations for 4D-VAR in the desired format. 4D-VAR system produces the analysis, which is the best estimate of the atmospheric state, used as the initial condition for the UM forecast. The OPS system processes and packs six hourly data, centered at 00, 06, 12 and 18 UTC for the four data assimilation cycles (00, 06, 12 & 18 UTC cycles). The 4D-VAR data assimilation is carried out for all cycles to produce the analysis valid for these cycles. The UM short forecast run are also carried out based on this analysis for all the four cycles, which in turn are used as the background (first guess) for the next cycle in OPS and 4D-VAR. A deterministic 168 hr forecast is prepared everyday based on 00 UTC analysis. A detailed description of these components can be found in Rajagopal et al., 2012. In the following pages a brief description of the UM based Analysis-Forecast System running at NCMRWF is given.

3. Computing Time

The computing time (Wall Clock Time) required to complete a 24 hr forecast with UM at N512L70 on 16 nodes (16x32) of IBM-p6 HPC in dedicated mode is about 700 sec (~12 minutes). OPS and VAR together takes about 1 hour 15 minutes per cycle of analysis on 16 nodes of IBM-p6 HPC.

Table.1: Observations used in the UM data assimilation system at NCMRWF

Observation file (obstore)	*Observation Details*
Surface.obstore	Land surface (SYNOPS), Mobile SYNOP, Ships, BUOY
Sonde.obstore	TEMP (land and marine), PILOT (land and marine), DROPSONDE, Wind profilers
Aircraft.obstore	AIREP, AMDAR, TAMDAR (N. American AMDAR), Tropical cyclone BOGUS winds
Satwind.obstore	AMV from Meteosat-7, Meteosat-9, GOES-11, GOES-13, MTSAT-1R, MODIS (TERRA and AQUA), AVHRR from NOAA-15/6/7/8/9
Scatwind.obstore	Scattrometer winds: ASCAT winds from MetOp satellite WINDSAT winds from Coriolis satellite
ATOVS.obstore	ATOVS Radiance from MetOp-2, NOAA-15, NOAA-17, NOAA-18, NOAA-19
IASI.obstore	IASI Radiance from MetOp-2 satellite
SSMIS.obstore	SSMI/S Radiance from DMSP
SEVIRIClear.obstore	Clear sky IR radiances from METEOSAT Second Generation satellites
AIRS.obstore	AIRS radiance from AQUA satellite
GPSRO.obstore	Bending angle (radio occultation data) from GPS satellites

Table 2: Details of the various components used in the Data Assimilation system

Components	Version	Resolution
UM Global Model	UM 7.7	N512L70 (1024x769) (70 vertical levels)
Variational Analysis (4D-VAR)	VAR 27.1.0	N216L70 (432x325) (70 vertical levels)
Observation Processing System (OPS)	OPS 27.1.0	

Data Assimilation Features

- 4D-VAR (Rawlins et al., 2007)
- Perturbation forecast (PF) and adjoint models to provide explicit representation of the time dimension within a 6-hour data window.
- PF model has simplified linearised physics, including a very simple boundary layer, cloud latent heat release, convection and large-scale precipitation
- Weak constraint digital filter to the perturbation forecast (Gauthier and Thépaut, 2001), penalising high frequencies using a pressure-based energy norm.
- **Horizontal Grid** 1/3 of Model Grid

Surface Analysis Features

- SOIL MOISTURE (Best and Maisey 2002)
  - The global soil moisture is updated using a nudging scheme based on errors in NWP forecasts of screen level temperature and humidity.
- SNOW
  - Imported from NCEP
- SST
  - Sea-surface temperatures are taken from the Met Office's Operational SST and Sea Ice Analysis (OSTIA) system.
- Sea-Ice
  - Sea-ice is taken from the Met Office's Operational SST and Sea Ice Analysis (OSTIA) system

Model Dynamics

- Non-hydrostatic dynamics with a deep atmosphere
  - –appropriate for all scales from >300km to <1km
- Grid point model
  - – Global Latitude/Longitude
  - – Quasi Uniform Regional Grid using rotated pole
  - –Staggered Horizontal C-Grid
- Semi-implicit time integration with 3D semi-Lagrangian advection.
- Height vertical coordinate with levels transition from terrain following to height (Charney Phillips Staggered)
- High order advection
- Diffusion kept to minimum

Model Physics

- Interactive **Cloud/Radiation** : Spectral band "Edwards-Slingo" radiation
- Mixed phase **precipitation** with prognostic ice/water
  - –New Prognostic Cloud/Condensate
- **Boundary Layer** revised with non-local mixing in unstable conditions and entrainment
- **Surface Exchange** : Tiled surface types (JULES)
- **Convection** Mass Flux scheme including a shallow convection scheme and convective momentum transports (but not required for km-scale modelling)
- Sub-Grid **Orography**: data based on high resolution elevation data smoothed to remove grid-scale forcing

Details of the Physical Processes

Radiation: *Based on Edwards, Slingo (1996)*

- Rigorous solution of the two-stream scattering equations including partial cloud cover. Full treatment of scattering and aerosols. Consistent treatment of cloud radiative properties in solar and thermal regions of spectrum. Ice crystals are treated as non-spherical.
- Treatment of aerosols using a background aerosol climatology (Cusack et. al. 1998)
- Inclusion of biogenic aerosols

Clouds: *Based on Smith(1990)*

- Prognostic cloud scheme based on conserved variables T_L and q_T and a sub-grid scale probability distribution of these variables, to derive cloud amounts and water contents assuming critical relative humidity. The scheme is modified such that only water clouds are defined from T_L and q_T and a sub-grid probability distribution. Ice water content is determined by the mixed phase microphysics scheme with ice cloud fraction calculated diagnostically from ice water content.
- Plus additional parameterisation to derive cloud area as well as volume

Precipitation: *Based on Wilson and Ballard, 1999*

- Bulk microphysics scheme with one ice variable and explicit calculation of transfers between vapour, liquid and ice phases. Cloud microphysics with an additional ice variable and explicit calculation of transfers between vapour, liquid and ice phases.
- Improved microphysics – including changes to auto-conversion, consistent sub-grid model to represent grid-box heterogeneity, two particle distribution of ice, calculation of ice fall speeds, changes to deposition and sublimation of ice, and revised ice nucleation, (3C microphysics)

Gravity Wave Drag: *Based on Webster et al., 2003*

- Flow blocking scheme that simplifies diagnosis of hydrostatic gravity waves and low level drag based on Froude Number. Updated to use GLOBE orography.
- Including a parameterisation of orographic roughness (Milton & Wilson, 1996)

Boundary Layer : *Based on Lock et al., 2000 & Martin et al., 2000*

- Stability dependent surface exchanges based on Monin-Obukhov length. Boundary layer mixing scheme diagnoses 7 boundary layer types with non-local mixing and explicit entrainment parameterisation for unstable boundary layers, local Richardson number-based scheme used for stable layers.
- Additional shear driven turbulent BL (type 7)
- Revisions to BL & surface transfer
  - Non-local mixing for momentum (Brown et. al. 2007)
  - Surface scalar transfer over sea – adjustment to roughness length to reduce exchange coefficient for heat and moisture at high wind speeds in line with observations. Effect of salinity in reducing saturation vapour pressure included (Edwards (2007)
- Changes to depths of non-local mixing in decoupled stratocumulus boundary layers
- Stability functions:
  - Sharpest over the sea
  - Long tails
  - Louis function. near surface & sharp above

Convection: *Based on Gregory & Rowntree, 1990; Gregory & Allen, 1991; Grant 2001; Grant & Brown,1999*

1. Modified mass flux scheme including changes to diagnosis and triggering of deep and shallow convection
2. Plus convective momentum transport.
3. Plus representation radiative effects of anvils
4. Adaptive detrainment for deep & mid-level convection (Maidens & Derbyshire, 2007)

- CAPE closure based on humidity threshold. Default timescale for removal of CAPE in the column and hence mass flux triggering convection at base is set to 30 minutes.
- W-based CAPE closure in Regional UM– CAPE depends on vertical velocity above a given threshold (decreases with increasing w)

Diffusion, Advection and Time Steps in UM

	Global NWP N512 ~25km	Regional (12km)
Horizontal/Vertical advection	cubic	cubic
Vertical advection (q)	quintic	cubic
q horizontal diffusion	target	target
u, v, theta horizontal diffusion	4th order	None
u, v vertical diffusion	Selected levels/latitudes	None
Model time step	10 min	5 min
Radiation time step	180 min	60 min
Convection time step	5 min	2.5 min

Reference

Rajagopal, E.N., G.R. Iyengar, John P. George, Munmun Das Gupta, Saji Mohandas, Renu Siddharth, Anjari Gupta, Manjusha Chourasia, V.S. Prasad, Aditi, Kuldeep Sharma and Amit Ashish, 2012: Implementation of Unified Model based Analysis-Forecast System at NCMRWF, NMRF/TR/2/2012, 45 p.