NCMRWF Unified Model and Data Assimilation System

NCMRWF Unified model (NCUM) is being used for generating10-day numerical weather forecasts routinely since 2012. The NCUM system is based on the Unified Model (UM) developed under the UM Partnership by Met Office, UK, BoM/CSIRO, Australia, KMA, South Korea, NIWA, New Zealand and MoES/NCMRWF, India. The NCUM system is upgraded periodically to adapt new Scientific and Technological developments for improving the global and regional numerical weather predictions (NWP).

Uniqueness of the Unified Model is its seamless modelling approach. The same dynamical core and, where possible, the same parameterization schemes are used across a broad range of spatial and temporal scales. The UM's dynamical core solves compressible non-hydrostatic equations of motion with semi-Lagrangian advection and semi-implicit time stepping. Sub-grid scale processes such as convection, boundary layer turbulence, radiation, cloud, microphysics and orographic drag are represented by parameterization schemes, which are being improved over the years. The model uses "ENDGame" dynamics. Important aspect of ENDGame is that it is designed around an iterative approach to solving the semi-implicit aspects of the scheme. This permits more accurate coupling of the scheme to the physics parameterizations. This was major step forward in atmospheric modelling which helps the seamless modelling approach.

Prediction of future state of the atmosphere by the NWP model is largely depends upon the initial condition (analysis) used by the model. The process of preparation of the "analysis" is known as Data Assimilation (DA). Quality controlled (and thinned, if required) observations are used in the DA system for the preparation of analysis. Data assimilation techniques provide the best estimate of the state of a physical system by combining the information from model and observations. Advanced data assimilation methods have the ability to extract more useful information on the state of the atmosphere from the observations assimilated. Four-dimensional variational data assimilation (4D-Var) is one of the advanced data assimilation method used by many global NWP centres.

NCMRWF adapted the 4D-Var data assimilation system of UK Met Office and is being used for preparation of analysis for NCUM operationally since April 2012. In October, 2016 the 4D-Var systemswas upgraded to Hybrid 4D-Var data assimilation system. One of the major weakness of traditional 4D-Var approach is the difficulty of representing 'Errors of the Day' – the variations in

error due to the locations of recent instabilities and observations. To address this issue, hybrid 4D-Var method was developed, where the term “hybrid” refers to the combination of climatological covariance model with covariances calculated from an ensemble of forecasts, designed to sample the current forecast uncertainty.The Hybrid 4D-Var system combines the advantages of traditional 4D-Var and the ensemble data assimilation. NCUM hybrid 4D-Var system uses the forecasts from the NCMRWF Ensemble Prediction System (NEPS).

In the new 2.8 PF HPC (Mihir) at NCMRWF, the NCUM has been upgraded to the latest operational high resolution analysis-forecast system of UM. Major improvement of this system in comparison with the earlier version of NCUM system is the use of higher resolution global model and improvements in data assimilation system. A detailed description of the new NCUM system is presented in following sections.

New NCUM System

In the new upgradation of NCUM, horizontalresolution of the model is increased from ~17 km (N768L70) to ~12 km (N1024L70). Hybrid 4D-Var method is used for data assimilation. Major improvements of the new NCUM data assimilation system in comparisons with previous system used at NCMRWF is the use of improved version of the radiative transfer model and theimproved ability of the new system to assimilate more satellite observations. The global ensemble prediction system is also upgraded with high resolution model (12 km). A brief description of various components of the data assimilation system (Observation pre-processing system, Observation Processing System, Variational Assimilation), model and ensemble prediction system are given below:

Observation Pre-processing system

NCMRWF receives global meteorological observations through Global Telecommunication System (GTS) via Regional Telecommunication Hub (RTH) at IMD, New Delhi and large volume of satellite observations through internet data services directly from various satellite data producers (NOAA/NESDIS, EUMETSAT, ISRO etc.). Continuous efforts are on to acquire and utilize maximum number of observations from various platforms, with special emphasis on Indian satellite observations.

The NCUM observation pre-processor system packs observations in the "obstore" format which can be read by the Observation Processing System.The new observation pre-processingsystem developed at NCMRWF now has the ability to processes and pack more types of observations (Newly added observations includeFY3C, Himawari-8, Meteosat-11, AMSR-2 radiances, WindSat ocean surface winds, Meteosat-11 Atmospheric Motion Vectors). List of observations assimilated in the new NCUM DA system is given in Table-1

Table 1: Observations Assimilated in NCUM Global Data Assimilation System

Observation Type	Observation Description	Assimilated Variables
AHIClear	Advanced Himawari Imager radiances from Himawari-8	*Brightness Temperature (*T_b)
Aircraft	Upper-air wind and temperature from aircraft	u, v, T
AIRS	Atmospheric Infrared Sounder of MODIS	T_b
AMSR	Radiances from AMSR-2 onboard GCOM satellite	T_b
ATOVS	AMSU-A, AMSU-B/MHS, HIRS from NOAA-18 &19, MetOp-A&B	T_b
ATMS	Advanced Technology Microwave Sounder in NPP satellite	T_b
CrIS	Cross-track Infrared Sensor observations in NPP satellite	T_b
FY3C	MWHS radiances from FY3C	T_b
GOESClear	Cloud clear Imager radiances from GOES	T_b
GPSRO	Global Positioning System Radio Occultation observations from various satellites (including MT-ROSA)	Bending Angle
GroundGPS	Ground based GPS observations from various locations	Zenith Total Delay
IASI	Infrared Atmospheric Sounding Interferometer from MetOp-A&B	T_b
IN3DSndr	INSAT-3D Sounder Radiances	T_b
MTSAPHIR	SAPHIR microwave radiances from Megha-Tropiques	T_b
Satwind	Atmospheric Motion Vectors from various geostationary and polar orbiting satellites (including INSAT-3D)	u, v
Scatwind	Advanced Scatterometer in MetOp-A & B, ScatSat-1, WindSat	u, v
SEVIRIClear	Cloud clear observations from SEVIRI of METEOSAT 8 &11	T_b
Sonde	Radiosonde observations, upper-air wind profile from pilot balloons,wind profiles, VAD wind observation from Indian DWR	u, v, T, q
Surface	Surface observations over Land and Ocean	u, v, T, q, P_s
SSMIS	SSMIS Radiances	T_b

Observation Processing System (OPS)

The OPS (OPS component of extract and process) prepares quality controlled observations for Hybrid 4D-Var in the desired format. OPS reads the decoded observations packed by the OPPS in the "obstore" format. OPS perform quality control on the observations and reformat the observations for its use in the Hybrid 4D-Var. OPS extract and process has two components, the extract component retrieves the observations and calculates background values at the observation locations and the process component performs the quality control and reformats them ready for its use in the Hybrid 4D-Var. The OPS system processes and packs observations within the six hourly assimilation window (plus or minus 3 hour in the DA cycle of 00, 06, 12 and 18 UTC).

Hybrid 4D-Var Data Assimilation (VAR)

The Hybrid 4D-Var system blends the "climatological" background error with day-to-day varying flow dependent background errors from the new high resolution NCMRWF ensemble prediction system (NEPS). The hybrid approach is scientifically attractive because it elegantly combines the benefits of ensemble data assimilation with the known benefits of 4D-Var within a single data assimilation system. Global atmospheric analysis is produced at 00, 06, 12 and 18 UTC. Various components of the data assimilation system and their dependences are depicted in Figure-1. Salient features of the data assimilation system are given in Table-2

Surface Analysis Preparation System (SURF)

The surface analysis system ("SURF") implemented at NCMRWF prepares the surface initial fields of Snow (amount and depth), Sea Surface Temperature (SST), Sea Ice extent & depth and Soil Moisture for NCUM model forecast. SST and Sea Ice conditions are obtained from the OSTIA analysis. The SURF system interpolates these analyses to the model resolution for its use in the model (surface boundary conditions). The Snow analysis (snow depth and amount) is produced by the SURF system using the using snow cover data from NESDIS ("IMS Snow") and the model forecast. In the new SURF implementation also, Extended Kalman Filter (EKF) based system prepares soil moisture analysis. EKF system implemented at NCMRWF uses JULES (the Joint UK Land Environment

Simulator) land surface model. Soil moisture observations from ASCAT as well as the surface analysis increments of moisture and temperatures (prepared by 3D-Var screen analysis system) are used in the EKF system. Some of the important aspects of new SURF system are given in Table-2.

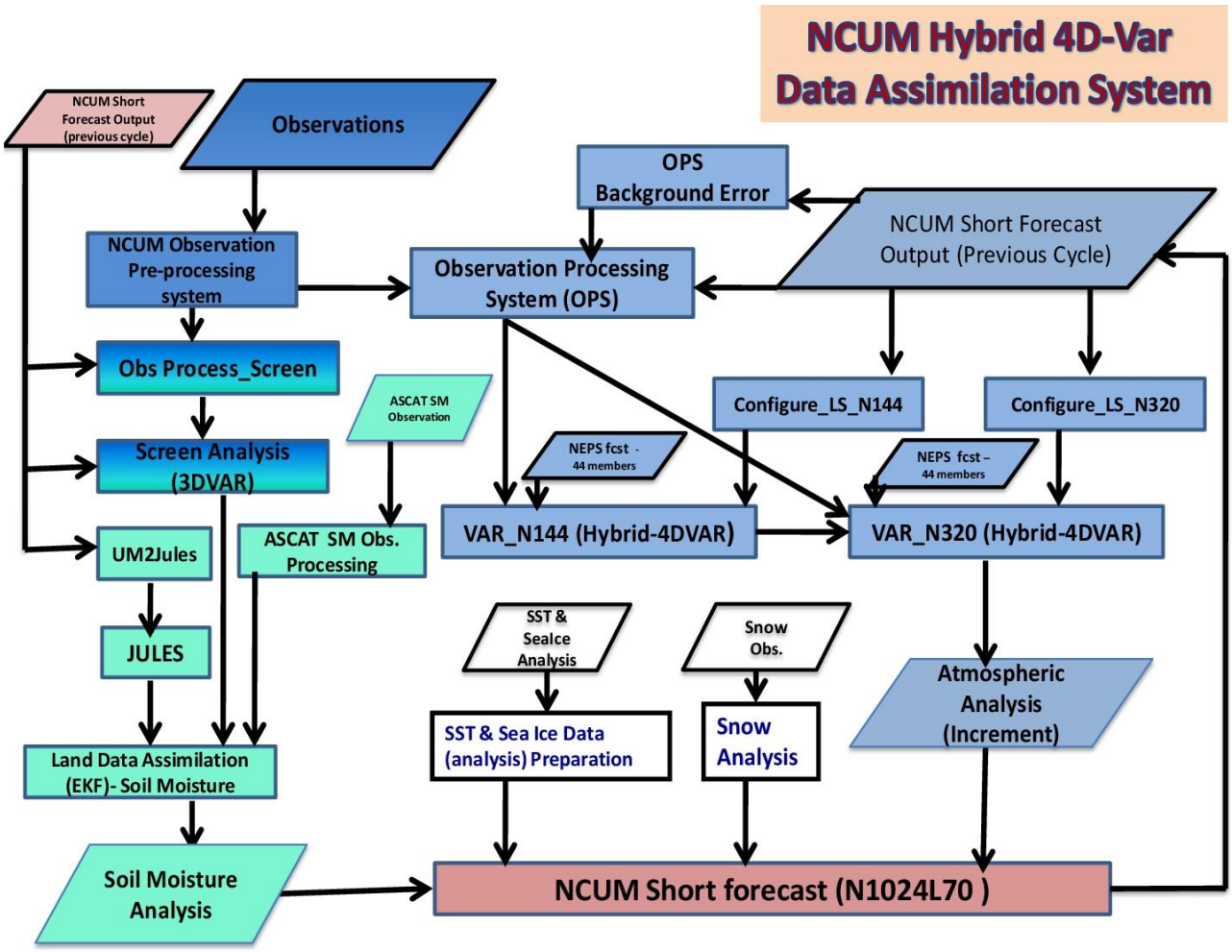

Figure1: Flow chart of NCUM Data Assimilation System

NCMRWF Unified Model (NCUM)

Unified Model version 10.8 (UM10.8), which is the part of latest "Operational Global Suite" (PS40) of UK Met Office, is adapted as the new NCUM. There is not much difference in dynamics or representation of physical processes in the new model version in comparison with previous version (UM10.2) used at NCMRWF. However, the horizontal resolution of the model is increased to ~12 km in this up-gradation. Details are given in Table-2.

Table 2: Details of the new NCUM system

Model	Atmospheric Data Assimilation	Surface analysis
Model: Unified Model; Version 10.8 **Domain:** Global and regional **Resolution:** 12 km, Levels 70 **Grid:** 2048x1536 **Time Step:** 5 minutes **Physical Parametrizations:** based on GA6.1 (Walters et al, Geosci. Model Dev., 10: 1487-1520, 2017) **Dynamical Core:**ENDGame **Forecast length:** 10 days (based on 00 UTC and 12 UTC initial conditions)	**Resolution:** N320L70 (~40 km) with N144L70 Hessian based pre-conditioning **Method:** Hybrid incremental 4D-Var. Information on "errors of the day" is provided by NEPS forecast at every data assimilation cycle **Data Assimilation Cycles:** 4 analyses per day at 00, 06, 12 and 18 UTC. Observations within +/- 3 hrs from the cycle time is assimilated in the respective DA cycle **Observations:** Observation Processing System does the quality control of observations. Variational bias correction is applied to satellite radiance observations. List of observations assimilated aregiven in Table-1	**Soil Moisture analysis:** *Method:* Extended Kalman Filter *Analysis time:* 00, 06, 12 and 18 UTC *Observations assimilated:* ASCAT soil wetness observations, Screen Temperature and Humidity (pseudo observations from 3D-Var screen analysis) **SST**: Updated at 12 UTC DA cycle with OSTIA based SST and sea-ice analysis **Snow Analysis:** Satellite-derived snow analysis. Updated at 12 UTC DA cycle

NCMRWF Ensemble Prediction System(NEPS)

The new global ensemble prediction system (NEPS) prepares 10 day forecasts at 12 km horizontal resolution. Details of the new NEPS system is given in Table-3

Table 3: Details of the new NEPS system

Model Details	Initial Condition and Perturbations	Forecast length and Ensemble size
Model: Unified Model; Version 10.8 **Resolution:** 12 km, Levels 70 **Domain:** Global **Grid:** 2048x1536 **Time Step:** 5 minutes **Physical Parametrizations**: based on GA6.1 **Dynamical Core:** ENDGame	**Initial condition:** Analysis from global deterministic Hybrid 4D-Var data assimilation system. **Initial Condition Perturbations:**Perturbations are generated by Ensemble Transform Kalman Filter (ETKF). **Surface Perturbations:** SST perturbations, Deep soil temperature and soil moisture perturbations **Model Perturbations:** Stochastic Kinetic Energy Backscatter (SKEB) scheme and Random Parameters	**Forecast length:** 10 days **Number of Ensemble members:** 22

Rose/Cylc Software Environment for development & managing suites

NCUM system uses the Python based Rose/cylc environment for managing and running operational jobs. Rose is a framework for managing and running suites (suite is a collection of scientific application software for a common purpose).Rose contains all the features required for configuration management of suites and their components. Cylc is the suite engine or work flow engine (tools formanaging the workflows required by the Rose) that drives task submission and monitoring. Cylc has all the key features required for both operational and research job scheduling including run, rerun, kill, poll, hold individual task or a family of tasks. NCMRWF uses Rosie

database for suite management. Both Rose and Cylc are Open Source software managed under GitHub.