Global NCMRWF Unified Model (NCUM-G) System

NCMRWF Unified model (NCUM) is being used for numerical weather prediction (NWP) since 2012. The NCUM is based on Unified Model (UM) system 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 has been upgraded periodically to adapt new scientific and technological developments for improving the global and regional NWP.

Uniqueness of the UM 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 physical parameterization schemes, which are being improved over the years. Dynamical core, so-called heart of the atmospheric models, is the component of the model that deals with the numerical solution of the primitive equations. Advanced "ENDGame" (Even Newer Dynamics for General atmospheric modelling of the environment) dynamical core is used in the model.

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". Good DA system provides the "best estimate" of the "state of a physical system" by combining the information from model and observations. Advanced data assimilation methods, such as the one used in the NCUM system, have the ability to extract more useful information on the state of the atmosphere from the observations assimilated and provide accurate "analysis".

NCMRWF adapted advanced 4D-Var data assimilation system of UK Met Office for operational use in April 2012. One of the major weakness of traditional 4D-Var approach is the difficulty of representing 'errors of the day' –flow dependent errors. To address this issue, "Hybrid 4D-Var" method was developed, where the term "Hybrid" refers to the combination of climatological covariance with covariances calculated from an ensemble of forecasts. The "Hybrid 4D-Var" system

combines the advantages of traditional 4D-Var and the ensemble data assimilation. In October, 2016 the NCUM data assimilation system was upgraded to “Hybrid 4D-Var” (adapted from “UM Partnership”). NCUM “Hybrid 4D-Var” system uses the ensemble forecasts of “NCMRWF Ensemble Prediction System (NEPS)”.

There have been six major upgrades of NCUM global assimilation-forecast system since 2012 and the latest upgrade (10-June-2020), which is described below, is the sixth one (NCUM-G:V6).

NCUM-G:V6

Highlighting features of this up-gradation are the improvements in the data assimilation system and the forecast model. The new data assimilation system has the capability to assimilate cloud-affected microwave observations from ATOVS (AMSU-A). This data assimilation system uses an advanced version of fast radiative transfer model RTTOV (version 12) for satellite radiance processing. The new data assimilation system has the capability to assimilate satellite observations from latest sensors. Major improvement in the atmospheric model is the use of advanced Global Atmosphere (GA) version 7 science configurations. A brief description of various components of the data assimilation system (Observation pre-processing system, Observation Processing System, Variational Assimilation) and the model are given below:

(i) Observation Pre-processing system (NOPpS)

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 being made to acquire and utilize maximum number of observations from various platforms, with special emphasis on Indian satellite observations.

The NCUM observation pre-processor system (NOPpS) packs observations in the “obstore” format which can be read by the Observation Processing System. The new observation pre-processing

system has the capability to processes and packs more types of observations. List of observations assimilated in the NCUM-G:V6 data assimilation 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-W1 satellite	T_b
ATOVS	AMSU-A (including cloud affected radiances), AMSU-B/MHS from NOAA-18 &19, MetOp-A&B	T_b
ATMS	Advanced Technology Microwave Sounder in NPP& NOAA20 satellites	T_b
CrIS	Cross-track Infrared Sensor observations in NPP&NOAA20 satellite	T_b
FY3C	MWHS radiances from FY3C	T_b
GMI	Global Precipitation Measurement (GPM) Microwave Imager (GMI) instrument	T_b
GPSRO	Global Positioning System Radio Occultation observations from various satellites	Bending Angle
GroundGPS	Ground based GPS observations from various locations	Zenith Total Delay
IASI	Infrared Atmospheric Sounding Interferometer from MetOp-A&B	T_b
IN3DImgr	INSAT-3D Imager Radiances	T_b
SAPHIR	SAPHIR microwave radiances from Megha-Tropiques	T_b
Satwind	Atmospheric Motion Vectors from various geostationary and polar orbiting satellites (including INSAT-3D& INSAT-3DR)	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 (TAC & BUFR),Pilot balloons, Wind profiles &Radar VAD winds	u, v, T, q
Surface	Surface observations over Land and Ocean (TAC & BUFR), TC bogus *(*Surface Pressure)	u, v, T, q, P_s
SSMIS	SSMIS Radiances	T_b

(ii) Observation Processing System (OPS)

The Observation Processing System prepares quality controlled observations for Hybrid 4D-Var in the desired format. OPS read the decoded observations packed by the OPpS in the "obstore" format. The system has two components, the extract component retrieves the observations and calculates background values at the observation locations and the process component performs the quality controland 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 of 00, 06, 12 and 18 UTC).

(iii) Hybrid 4D-Var Data Assimilation (Hybrid 4D-Var)

The "Hybrid 4D-Var" system used for data assimilation blends the "climatological" background error with day-to-day varying flow dependent background errors from the high resolution (~12 km) NCMRWF ensemble prediction system (NEPS). 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.

(iv) Surface Analysis Preparation System (SURF)

The surface analysis system ("SURF") 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 "OSTIA analysis". The SURF system interpolates these analyses to the required resolution for its use in the NCUM (surface boundary conditions). The Snow analysis (snow depth and amount) is produced by the SURF system using the snow cover data from NESDIS ("IMS Snow") and the NCUM forecast. Extended Kalman Filter (EKF) based Land data Assimilation System (LDAS) prepares soil moisture analysis. Capability to assimilate INSAT-3D Land Surface Temperature (LST) is developed in LDAS. 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.

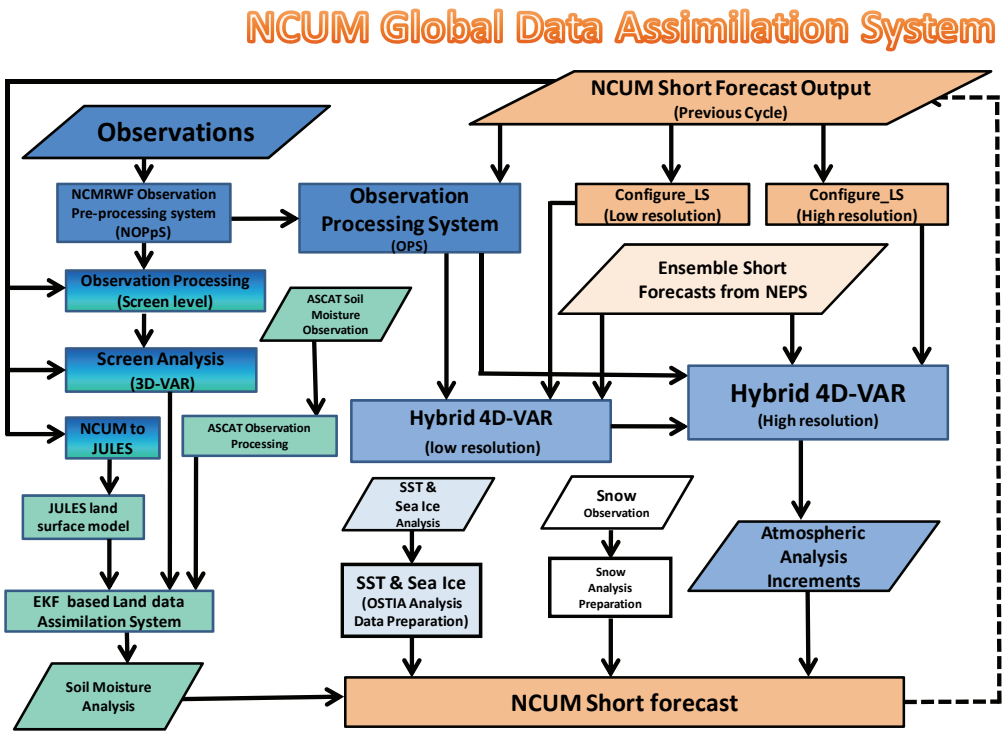

Figure 1: Flow chart of NCUM Data Assimilation System

(v) NCMRWF Unified Model (NCUM)

Unified Model version 11.2 (UM11.2), part of the latest "Operational Global Suite" (PS43) of UK Met Office, is adapted as the new NCUM. There are improvements in the science configuration of the model with the use of "Global Atmosphere (GA) 7.2" (https://doi.org/10.5194/gmd-12-1909-2019). Land surface model, Joint UK Land Environment Simulator(JULES) land surface model, is improved with "Global Land (GL) 8.1" configuration (https://doi.org/10.5194/gmd-12-1909-2019). The details of the NCUM Global model configuration are given in Table 2.

Table 2: Details of the NCUM system (NCUM-G:V6)

Model	Atmospheric Data Assimilation	Surface analysis
Model: Unified Model; Version 11.2 **Domain:** Global **Resolution:** 12 km, Levels 70 (Top: 80 km) **Grid:** 2048x1536 **Time Step:** 5 minutes **Physical Parametrizations:** Based on GA7.2 **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 are given 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