NMRF/TR/06/2020

TECHNICAL REPORT

NCUM Global NWP System: Version 6 (NCUM-G:V6)

Sumit Kumar, M. T. Bushair, Buddhi Prakash J., Abhishek Lodh, Priti Sharma, Gibies George, S. Indira Rani, John P. George, A. Jayakumar, Saji Mohandas, Sushant Kumar, Kuldeep Sharma, S. Karunasagar, and E. N. Rajagopal

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National Centre for Medium Range Weather Forecasting
Ministry of Earth Sciences, Government of India
A-50, Sector 62, Noida-201 309, INDIA

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9	Originating Unit	NCMRWF
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Abstract

NCMRWF Unified Model (NCUM) assimilation-forecast system is being used for global Numerical Weather Prediction (NWP) since 2012. The NCUM system is upgraded periodically at NCMRWF to incorporate new scientific and technological advancements. In June 2020, the NCUM global NWP system has been upgraded with a latest UM components (Parallel Suite 43 of Met Office, PS43). The new global NCUM system (NCUM-G:V6) uses improved version of atmospheric model as well as land surface model. Major improvements in the data assimilation system include capability to assimilate cloud-affected microwave radiances of ATOVS. NCUM's observation pre-processing system is enhanced with the capability to process latest satellite observations. NCUM atmospheric data assimilation system produces analyses at 00, 06, 12 and 18 UTC. Based on 00 UTC and 12 UTC analyses, 10 days forecasts are generated routinely and the products are made available at NCMRWF web site. A comparison of the analyses and forecasts from the new global NCUM system (NCUM-G:V6) with the previous operational system (NCUM-G:V5) for May 2020 is also described briefly in this report.

1. Introduction

NCMRWF Unified model (NCUM) analysis-forecast system is being used for Numerical Weather Prediction (NWP) for nearly a decade (Rajagopal et al., 2012, George et al., 2016, Sumit Kumar et al., 2018). Major components of the NCUM system are adapted from the Unified Model (UM) seamless prediction system developed under “UM Partnership”. NCUM system is upgraded periodically to adapt new science and technology advancements. There have been six major upgrades of NCUM global assimilation-forecast system since 2012 and the recent upgrade, is described in this report (NCUM-G:V6). NCUM system consists of components for observation pre-processing, observation processing and quality control, data assimilation, forecast model and tools for post processing. The UM components used in the various upgrades of NCUM global assimilation-forecast system are given in Table-1.

The major features of this up-gradation are the improvements in the data assimilation system and the forecast model. In the data assimilation system, capability to assimilate cloud-affected microwave radiances from ATOVS (AMSU-A) is the major improvement. This data assimilation system uses an advanced version of fast radiative transfer model RTTOV (version 12) for satellite radiance processing. This new data assimilation system has the capability to assimilate satellite observations from the latest sensors.

Major changes in the atmospheric model are the use of advanced Global Atmosphere (GA) version 7.2 science configurations. GA7.2 science configuration (Walters et al., 2019) has more than 30 model science improvements compared to the older version of Global Atmosphere configuration (GA6) being used in NCUM until recently. The major changes in GA7.2 include:

- Improved treatment of gaseous absorption in the radiation scheme (and sub-grid cloud structure based on McICA, improvements in ice optical & microphysical properties, etc.)
- Improvements in the treatment of warm rain and ice cloud (New warm-rain microphysics, forced shallow Cu, turbulent production of liquid cloud, etc.)
- Improvements in model’s convection scheme (w-based CAPE timescale, etc.)

The land surface of the model, Joint UK Land Environment Simulator (JULES) land surface model (Best et al., 2011; Clark et al., 2011), is improved with Global Land (GL) 8.1 configuration. Multi-layer snow scheme is the major change in the land surface model.

Table 1: Description of major components of NCUM Global NWP system and the corresponding UM versions

Implementation Month/Year	NCUM (Version)	OPS (Version)	VAR (Version, Resolution and DA Method)	SURF (Version)	UM (UM Version, Dynamical Core and Resolution)
April-2012	NCUM-G:V1	OPS 27.1	VAR27.1 (N216L70) (4D-Var)	UKMO Surface files	UM7.7 (ND) (N512 L70)
Dec-2012	NCUM-G:V2	OPS 27.2	VAR27.2 (N216L70) (4D-Var)	SURF30.0	UM7.9 (ND) (N512 L70)
Nov-2015	NCUM-G:V3	OPS 30.1	VAR30.0 (N320L70) (4D-Var)	SURF30.0.1 (Soil Moisture-EKF)	UM8.5 (EG) (N768 L70)
Oct-2016	NCUM-G:V4	OPS 32.1	VAR32.0 (N320L70) (Hybrid 4D-Var)	SURF32.0 (Soil Moisture-EKF)	UM10.2 (EG) (N768 L70)
May-2018	NCUM-G:V5	OPS 2017.07	VAR 2017.07 (N320L70) (Hybrid 4D-Var)	SURF 2017.07 (Soil Moisture-EKF)	UM10.8 (EG) (N1024L70)
June-2020	NCUM-G:V6	OPS 2019.02.0	VAR 2019.02.01 (N320L70) (Hybrid 4D-Var)	SURF 2019.02.0 (Soil Moisture-EKF)	UM11.2 (EG) (N1024L70)

ND= New Dynamics; EG= ENDGame; EKF= Extended Kalman Filter

In house developed **N**CUM **O**bservation **Pre-p**rocessing **S**ystem (NOPpS), is improved with an advanced version of "**A**TOVS and **A**VHRR **P**re-processing **P**ackage" (AAPP; Version 8.3), which has the capability to process satellite radiances from latest instruments. Observation processing and quality control is also improved with the use of more frequent of background fields in Observation Processing System (OPS).

2. Components of NCUM-G: V6

Major components of the new NCUM global assimilation-forecast system are described in the following sections.

2.1 NCUM Observation Pre-processing System (NOPpS)

The real-time meteorological observations, both from conventional instruments and satellites, received at NCMRWF from different sources/agencies (from Global Telecommunication System of WMO, IMD, ISRO, NOAA/NESDIS and EUMETCast etc.) are processed using NOPpS to produce the "obstore" format observation files for the Observation Processing System, which does the quality control and further processing (Figure-1). In house developed pre-processing system (Figure 1) is capable to handle observations received in various formats; NCEP BUFR, ECMWF BUFR, HDF and ASCII. UK-Met office Encode/Decode, AAPP and ECMWF ecCodes software are also used in addition to in-house developed software to process the multi-spectral and hyper-spectral radiances from various satellites to create "obstore" format files for the respective assimilation windows (21-03 UTC, 03-09 UTC, 09-15 UTC and 15-21 UTC for the preparation of 00, 06, 12 and 18 UTC analysis). In this up-gradation, AAPP8.3 is included in the NOPpS pre-processing system for processing of observations from latest satellites (https://www.nwpsaf.eu/site/software /aapp/).

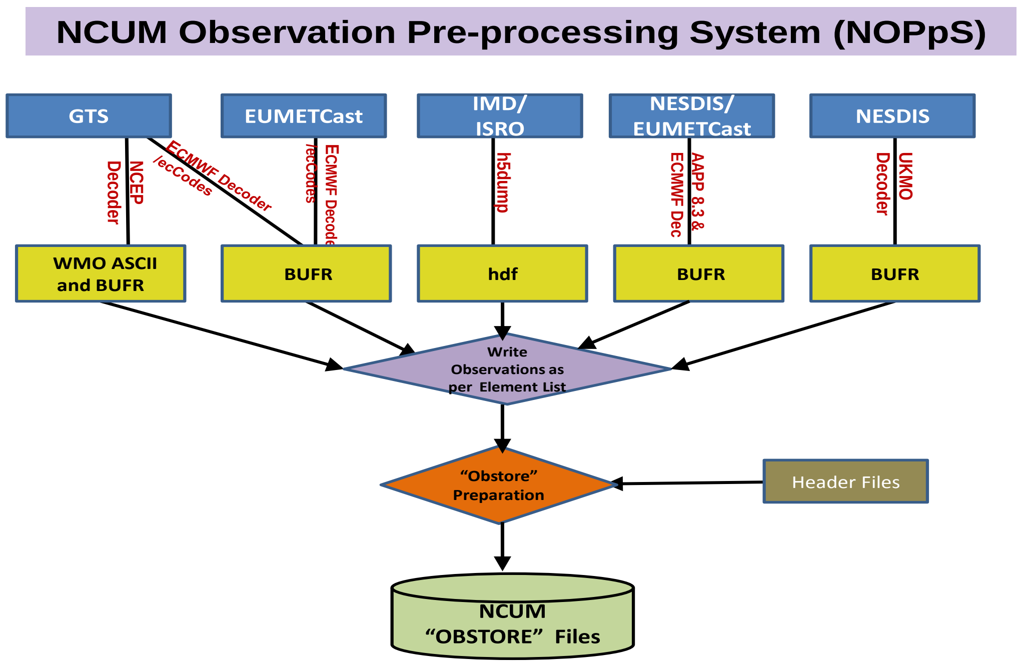

Figure 1: Flowchart of NCUM Observation Pre-processing System

2.2 Observation Processing System

Observation Processing System (OPS) adapted from the UM system reads observations in the "obstore" format and the model background fields produced by the short forecast run of the forecast model (from previous data assimilation cycle). The major change in the new OPS compared to earlier version is the *capability to use hourly background fields instead of 3 hourly background fields*. OPS assign "data use flags" containing the information such as whether a particular observation/station should be used (based on the information available in the stations list file), error of each observation (PGE: Probability Gross Error) assigned by the quality control procedures done within OPS etc. The quality control procedures include extreme value checks, buddy checks, background checks, track checks, sonde consistency checks, etc. The main OPS outputs are the files containing quality controlled and processed observations (VarObs), the model forecasts interpolated in time and position to match observation in the VarObs file (VarCx) and the optional output like "modelobs" which are exactly equivalent of "VarObs" but from model forecast (for some observations "modelobs' will match with "VarCx", in some cases VarCx contents will slightly differ from "modelobs"). "VarObs" and "VarCx" files are used in the assimilation step.

2.3 Atmospheric Data Assimilation

Atmospheric data assimilation produces the best possible estimate of the state of the atmosphere using observations and short lead time forecast (background) of the model. NCMRWF implemented the 4D-Var data assimilation system adapted from UK Met Office in 2012. This system was upgraded to "hybrid 4D-Var" system in which flow dependent background errors are used from ETKF (Ensemble Transform Kalman Filter) based NCMRWF Ensemble Prediction System (NEPS) in 2016. The hybrid approach is scientifically attractive as it elegantly combines the benefits of ensemble data assimilation with the benefits of 4D-Var within a single data assimilation system (Barker, 2011). The "hybrid 4D-Var" data assimilation system in new the NCUM system (NCUM-G:V6) is improved with capabilities to assimilate cloud affected microwave radiances from AMSU-A of ATOVS instrument onboard several satellites. List of observations assimilated in the new NCUM system is given in Table-2.

The NCUM "Hybrid 4D-Var" global data assimilation system produces analyses valid at 00, 06, 12 and 18 UTC routinely. In each 6 hourly data assimilation cycle, the available observations distributed over the 6 hour assimilation window (centre of the analysis cycle ± 3 hr) are combined with the model background to produce the NCUM global analysis. The linear perturbation forecast (PF) model in this "hybrid 4D-Var" system uses a simplified model formulation with a lower resolution (N320L70)) than the full forecast model which produced the background fields at high resolution (N1024 L70).

Salient features of the new NCUM global data assimilation system are listed below:

- Hybrid 4D-Var data assimilation method is used. Flow dependent error information is provided by 6 hr forecast from the high resolution global NEPS (N1024, ~12 km resolution) for all the four data assimilation cycles
- Data assimilation is done at N320L70 resolution (~40 km horizontal resolution with 70 vertical levels reaching the height of 80 km) with N144L70 Hessian based pre-conditioning
- Six hourly data assimilation cycle (time window of the assimilation) centered at 00, 06, 12 and 18 UTC
- Variational bias correction for satellite radiance observations.

Table 2: Observations assimilated in Hybrid 4D-Var Data Assimilation system of NCUM-G:V6

Conventional Observations	**Satellite Observations**						
	Satellite Winds (AMV)		***Scattero-meter winds***	***Satellite radiances***			***GPSRO***
	GEO	***LEO***		***GEO***	***LEO***		***LEO***
				IR	***IR (HyS)***	***MW***	***Bending Angle***
Surface: Land SYNOP (TAC & BUFR), SHIP (TAC & BUFR), BUOY, TC BOGUS *Profiles:* PILOT, TEMP (RS/RW- Both TAC & BUFR), Wind Profiler, Drop Sonde, DWR VAD Winds *Aircraft:* AMDAR, AIREP	INSAT-3D	NOAA-15	ASCAT (MetOp-A)	INSAT-3D Imager	IASI (MetOp-A)	AMSU-A (MetOp-A)	COSMIC-1
	Meteosat-8	NOAA-18	ASCAT (MetOp-B)	SEVIRI (Meteosat-8)	IASI (MetOp-B)	AMSU-A (MetOp-B)	GRAS-A
	Meteosat-11	NOAA-19	Scatsat	SEVIRI (Meteosat-11)	AIRS (AQUA)	AMSU-A (NOAA-18)	GRAS-B
	HIMAWARI	MetOp-A	Windsat (Coriolis)	GOES Imager (GOES-15)	CrIS (SNPP)	AMSU-A (NOAA-19)	TanDEM-X
	GOES-16	MetOp-B		AHI (HIMAWARI-8)	CrIS (NOAA 20)	AMSU-A (NOAA-15)	TerraSAR-X
	GOES-17	AQUA		INSAT-3D Sounder		MHS (MetOp-A)	FY-3C
		TERRA				MHS (MetOp-B)	COSMIC-2
		SNPP				MHS (NOAA-19)	
		NOAA-20				MT-SAPHIR	
						ATMS (SNPP)	
						SSMIS (DMSP-F17)	
						AMSR 2 (GCOM-W1)	
						FY3C	
						GMI (GPM)	
						ATMS (NOAA-20)	

2.4 Surface Analysis Creation

Surface analysis system (SURF), adapted from the UM system developed under the UM Partnership, creates the surface initial condition (surface analysis) for the NCUM model. SURF system includes simplified Extended Kalman Filter (EKF) based Land Data Assimilation System (LDAS). The SURF system creates the surface initial condition of Snow (amount and depth), Sea Surface Temperature (SST), Sea Ice extent & depth and Soil Moisture for initializing the NCUM. Daily SST and Sea Ice analysis data obtained from UK Met Office, produced by Operational Sea surface Temperature and sea-Ice Analysis (OSTIA) system (Donlon et al., 2011), is interpolated and used in the NCUM system. Daily snow analysis (snow depth and amount) is produced at NCMRWF using "Interactive Multi-sensor Snow and Ice Mapping System" (IMS) snow cover product obtained from NOAA/NESDIS (National Environmental Satellite Data and Information Service). The IMS snow cover product combines ground observations and satellite data from microwave and visible sensors (using geostationary and polar orbiting satellites). For land surface analysis, simplified Extended Kalman Filter (EKF) based LDAS is used. In the new implementation, soil moisture observations from ASCAT onboard MetOp satellites as well as the surface (atmospheric) level analysis increments of moisture and temperatures (pseudo observation) are used for generating the soil moisture analysis at every 6 hourly interval (00, 06, 12 and 18 UTC).

2.5 Forecast Model

NCUM, adapted from Unified Model developed under "UM Partnership", has been used at NCMRWF since 2012 (Rajagopal et al., 2012) for NWP. The NCUM system is upgraded periodically to adapt new scientific and technological developments for improving the numerical weather predictions. 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. The "ENDGame" dynamical core (Even Newer Dynamics for General atmospheric modelling of the environment; Wood et al., 2014) is used in the new UM model. The major features of the model are listed below:

- Model Resolution: N1024 L70 (12 km horizontal resolution with 70 vertical levels reaching ~ 80 km height)
- Model time-step: 5.0 minutes

- Global Atmosphere GA7.2 version science configuration with ENDGame dynamical core
- GL8.1 land configuration.
- Forecast Range: 0 to 240 hours (10 days) based on 00 and 12 UTC analysis

Major improvement in this up-gradation is the use of the new version of Unified Model (UM11.2) with GA7.2 science configurations (Walters et al., 2019). There are many improvements in the model science. Notable changes are in the radiation, cloud and convection schemes, large-scale precipitation etc. compared to the previous version GA6. A number of changes are introduced in the treatment of snow, albedo, hydrology and roughness length in the Joint UK Land Environment Simulator (JULES) land surface model (Best et al., 2011). The inclusion of multi-layer snow is a major improvement in the land surface model (Burke et al., 2013). Table 3 summarizes the major changes between GA6 and GA7 science configurations.

2.6 Post-processing of Forecast Fields

The model produces user-defined prognostics and diagnostics fields which are written by the UM “STASH” (Spatial and Temporal Averaging and Storage Handling) system. These are written in the traditional UM formats called Fields File (ff) or Post Process (pp) format. Model outputs in ff/pp format needs to be converted into standard formats such as gridded binary (grib) or Network Common Data Form (NetCDF) before its distribution to the users. For this purpose, NCMRWF has developed a software named “UMRider” (Arulalan, 2020), which converts the UM outputs in ff/pp format to grib2, grib1 and netCDF formats (UMRider is available at https://github.com/NCMRWF/UMRider).

A common standard set of STASH variables are designed for operational global NCUM (NCUM-G). The prognostic and diagnostic fields are written in unit numbers 60-68 in NCUM-G, categorised based on different considerations like, single or multilevel fields, instantaneous or time-processed, pressure levels or native model levels or pseudo levels, fields used for daily operational visualisation or high frequency output requirements. For example, units 60 and 62 are written as single output files for the entire integration period (240 hours), with the extension of ‘.pp0’ and ‘.pp2’, which are outputs with daily frequency and are used for operational standard plots. All other units are used for restart files generated separately every day (or many segments in a day). These output files generally contain 3 hourly output records for global model and its file nomenclature follows the standard procedures of UM system. The high frequency outputs (also containing some variables at near-surface pressure levels) are written in unit 64 with the file names having extension of '_peXXX', where XXX denotes the starting hour of the diagnostics. Unit 61 (with extension '_pdXXX') contains single level fluxes, while Unit 63 contains the basic pressure level prognostics (instantaneous) and Unit 65 contains the time processed fluxes. Unit 66 and 67 stores the model native hybrid level fields and Unit 68 contains other multi-level or pseudo-level fields. Appendix-1 lists the details of the operational STASH files produced by the new global NCUM.

Table 3: Improvements in GA7 compared to GA6 science configuration

Model components	Changes/development areas	GA6	GA7
Dynamics	Semi-Lagrangian interpolation methods.	Qintic interpolation (in vertical)	Cubic Hermite.
	Advection of potential temperature	Non-conservative.	Optimised Conservative Filter (OCF) scheme.
	Solver tolerance in Helmholtz solver.	1×10−3.	1×10−4.
Physics Radiation	Treatment of gaseous absorptions.	Old correlated k-coefficients.	Newly derived k-coefficients and improved CO2 concentrations. Introduced N2O and CH4 absorption (SW).
Large-scale precipitation	Ice PSD, mass-diameter relationships and ice crystal fall speeds Warm rain microphysics	Data suffering from ice particle shattering effects. Significant evaporation of rain inside cloud and non–conservation of rain water.	Measurements using more accurate instruments. New scheme with improved auto-conversion and accretion parameterisations.
Large scale cloud	Radiative impact of the convective cores Treatment of phase change (PC2 scheme) Critical RH Cirrus spreading rate in PC2. Parameterisation for turbulent production of liquid water in mixed phase cloud.	Not included. Independent for convection and microphysics Constant 1×10^{-3} s^{-1}. Reduce the bias due to the lack of super cooled water in mixed phase.	Included. Consistent treatment for convection and microphysics. RHcrit based on sub-grid turbulence. 1×10^{-5} s^{-1}. Applied only for T < 0°C.
Orography drag scheme	Conversion of kinetic energy to frictional heating due to gravity wave dissipation.	Not included.	Included for both wave breaking and low level drag.
Boundary layer	Parameterisation of turbulent entrainment through the top of cloudy boundary layer. Parameterisation of BL entrainment flux in cumulus capped regions.	Abrupt decoupling process of surface-driven entrainment. Mixing across the cumulus cloud base is through the convection scheme.	Longer duration of decoupling process by linear weighting of surface-driven turbulence. Forced convective cloud and resolved mixing across the boundary-layer top.
Convection	Convection scheme.	5A (CAPE time scale fixed.	6A (w-based CAPE time scale).
Aerosol & chemistry	Aerosol scheme	CLASSIC	GLOMAP-mode
Land surface	Snow scheme and treatment of albedo, hydrology and roughness length	Simple (zero-layer)	Multi-layer snow and JULES modifications.

3. Workflow Management with *Rose* and *Cylc*

Complex cycling workflows are fundamental to operational NWP systems. Large numbers of jobs are executed at regular intervals to process new observations, produce new initial conditions and new forecasts. Dependencies between the data assimilation cycles within and that with the forecasts create a single never-ending workflow which needs to be efficiently managed in an operational NWP environment.

"*Rose*" is a group of utilities and specifications which provide a common way to manage the development and running of scientific application *suites* (collection of scientific application software for a common purpose) in both research and production environments. "*Cylc*" is the "*suite*" engine or workflow engine (tools for managing the workflows required by the "*Rose*") that drives "task submissions" and its continuous monitoring. "*Cylc*" is designed to manage infinite cycling workflows efficiently. "*Cylc*" has all the key features required for both operational and research job scheduling - including run, rerun, kill, poll, hold etc. as an individual task or a family of tasks.

All production jobs related to NCUM data assimilation system, from observation pre-processing to model forecasts (short forecast) are executed and managed through a single *suite* (Figure 2). Long forecast (10 day forecast) jobs (based on 00 UTC and 12 UTC analysis) are submitted and managed separately by another *suite*.

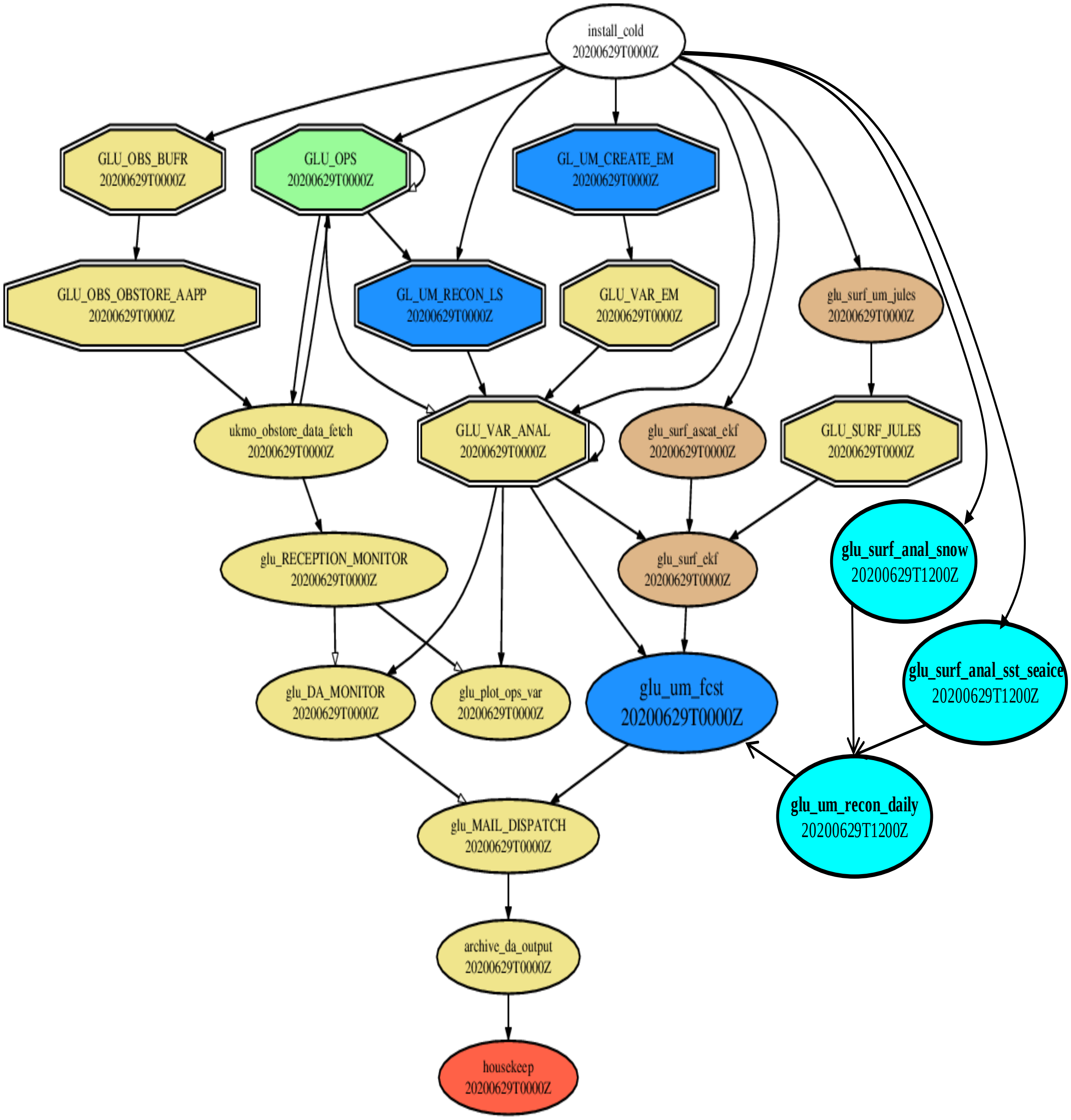

Figure 2: Workflow diagram of the NCUM Data Assimilation System (aqua color indicates jobs that are run only at 12 UTC)

4. Verification of Forecasts: NCUM-G:V5 v/s NCUM-G:V6

This section provides the forecast verification of NCUM-G:V6 during the month of May 2020 (test run period) against the observations. A comparison of standard verification scores of the new NCUM (NCUM-G:V6) forecast against previously operational forecasts (using NCUM-G:V5) during May, 2020 is also provided in following sub-sections. Two of the following subsections (4.1 and 4.2) summarize standard verification scores, while the next two subsections (4.3 and 4.4) are focuses on the forecast verification of Super Cyclone "Amphan".

4.1 Anomaly Correlation and RMSE of 850 hPa Wind

Verification of Mean Sea Level Pressure (MSLP) over tropics is given in Figure 3. The verification is carried out against the model analysis. A comparison between the two versions of the model shows no major differences in the forecast of all lead times during May, 2020. Forecast verification against radiosonde observations is presented for 850 hPa winds (Figure 4). The RMSE values of 850 hPa wind forecast over various regions (Indian region, NH, SH and tropics) show very marginal difference between NCUM-G:V5 and NCUM-G:V6 forecasts at all lead times during the comparison period.

4.2 Verification of Rainfall Forecast over India

Figure 5 shows the Mean Error (ME) in the rainfall forecasts over India. The verification is carried out against the IMD-NCMRWF merged (using Satellite and Rain Gauge) rainfall analysis over India at 0.25 x 0.25 Degree resolution. ME values of both NCUM-G:V5 and NCUM-G:V6 are very similar. The nature of errors are also similar with positive ME (wet bias) over NE India and negative ME (dry bias) over eastern India (Odisha and West Bengal). Categorical verification of rainfall forecasts is presented in Figure 6-8 for three lead times (Day-1, Day-3 and Day-5). It is found that for high rainfall thresholds NCUM-G:V6 shows an improvements in terms of higher POD (Figure 6), lower FAR (Figure 7) and higher values of PSS (Figure 8) compared to NCUM-G:V5. However it must be noted with caution that during the month of May the major part of Indian land region is relatively dry and there are very few rainy days. So result of the rainfall verification is based on a small sample size. The high rainfall amounts are mainly associated with the Super Cyclone "Amphan" that made landfall over West Bengal on 20th May 2020, which is discussed in the next sub-section.

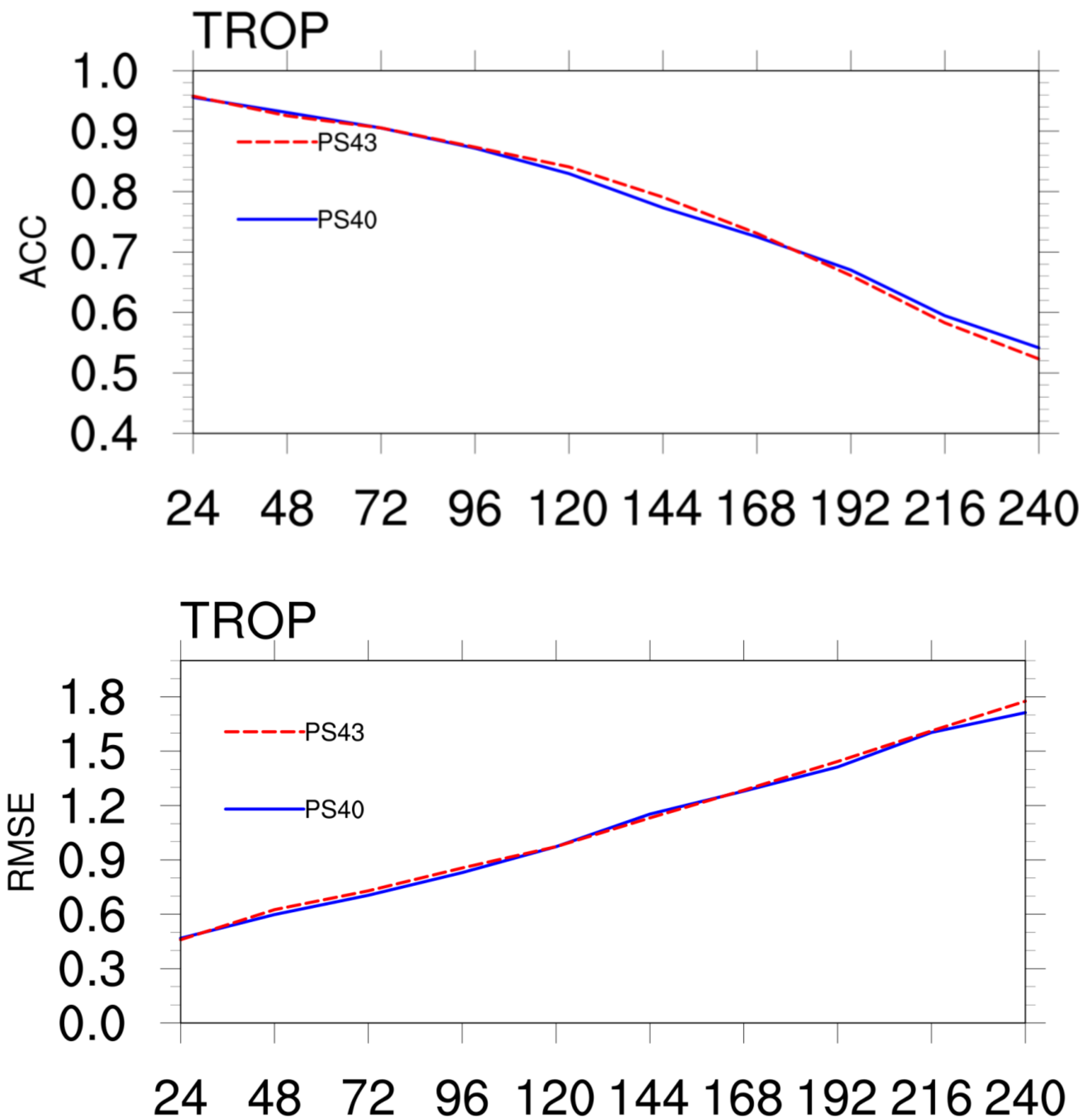

Figure 3: Verification of forecast MSLP against the analysis. Comparison of Anomaly Correlation (left) and Root Mean Squared Error (right) of MSLP forecast over the tropics during May 2020 in NCUM-G:V5 (PS40) and NCUM-G:V6 (PS43)

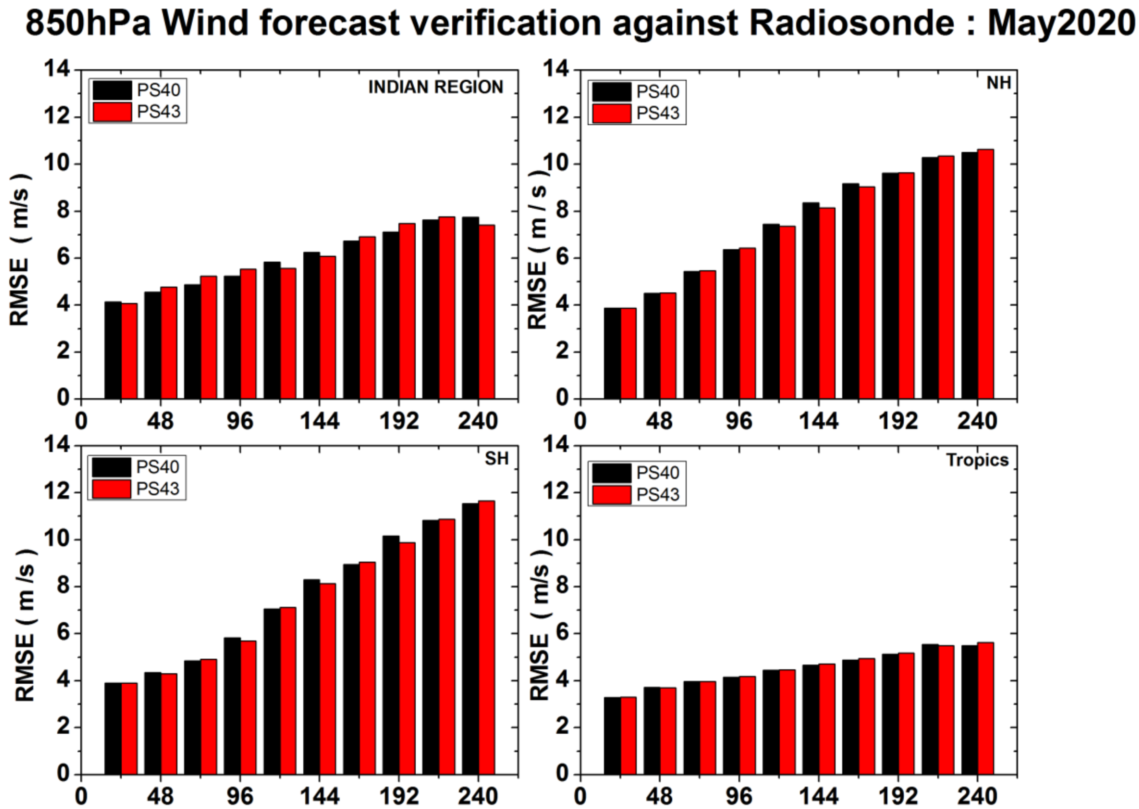

Figure 4: Verification of 850 hPa wind forecast against the Radiosonde observations. Comparison of Root Mean Squared Error (RMSE) in the forecast 850 hPa wind during May 2020 in NCUM-G:V5 (PS40) and NCUM-G:V6 (PS43)

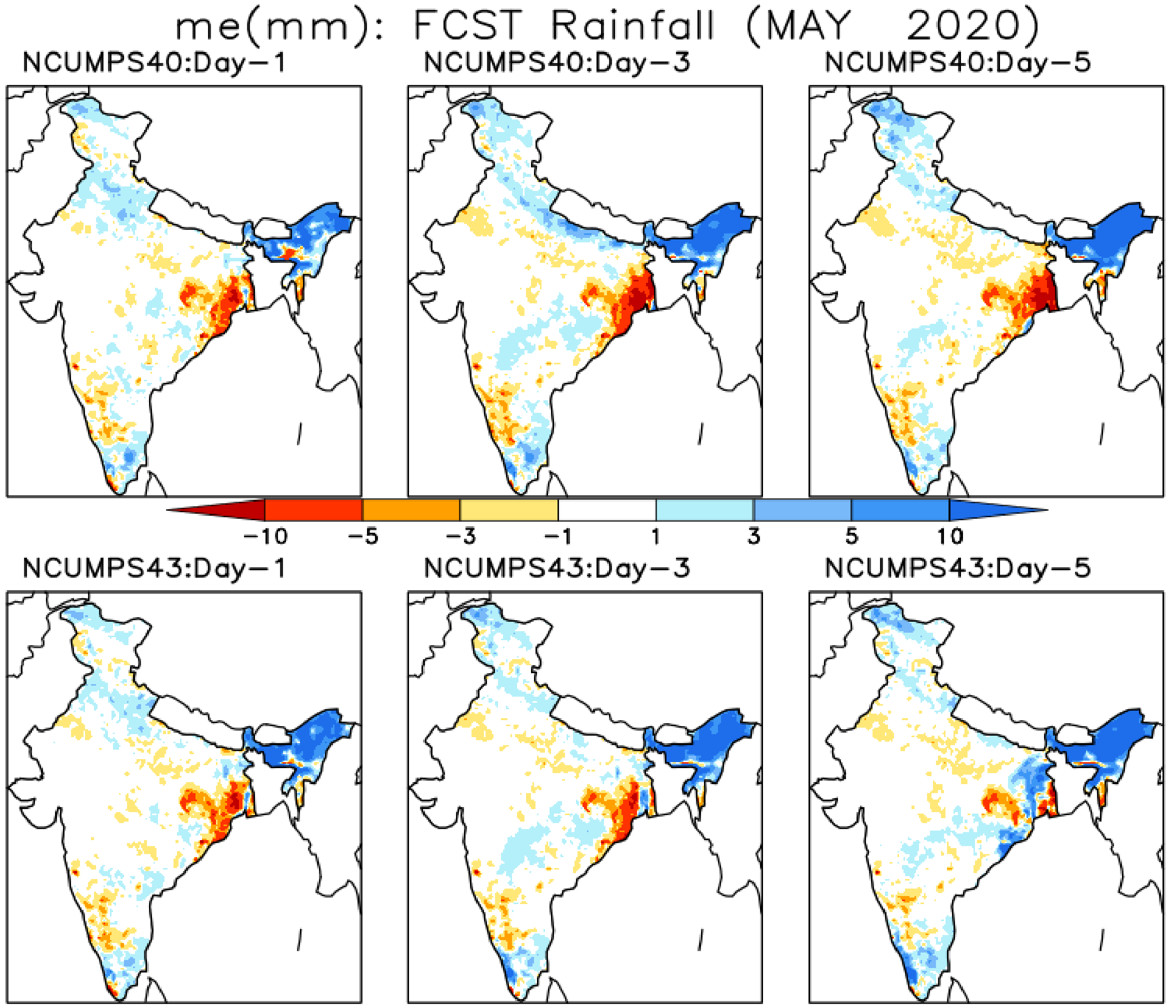

Figure 5: Mean Error (ME) in the forecast rainfall of NCUM-G:V5 [PS40] (top) and NCUM-G:V6 [PS43] (bottom) during May 2020

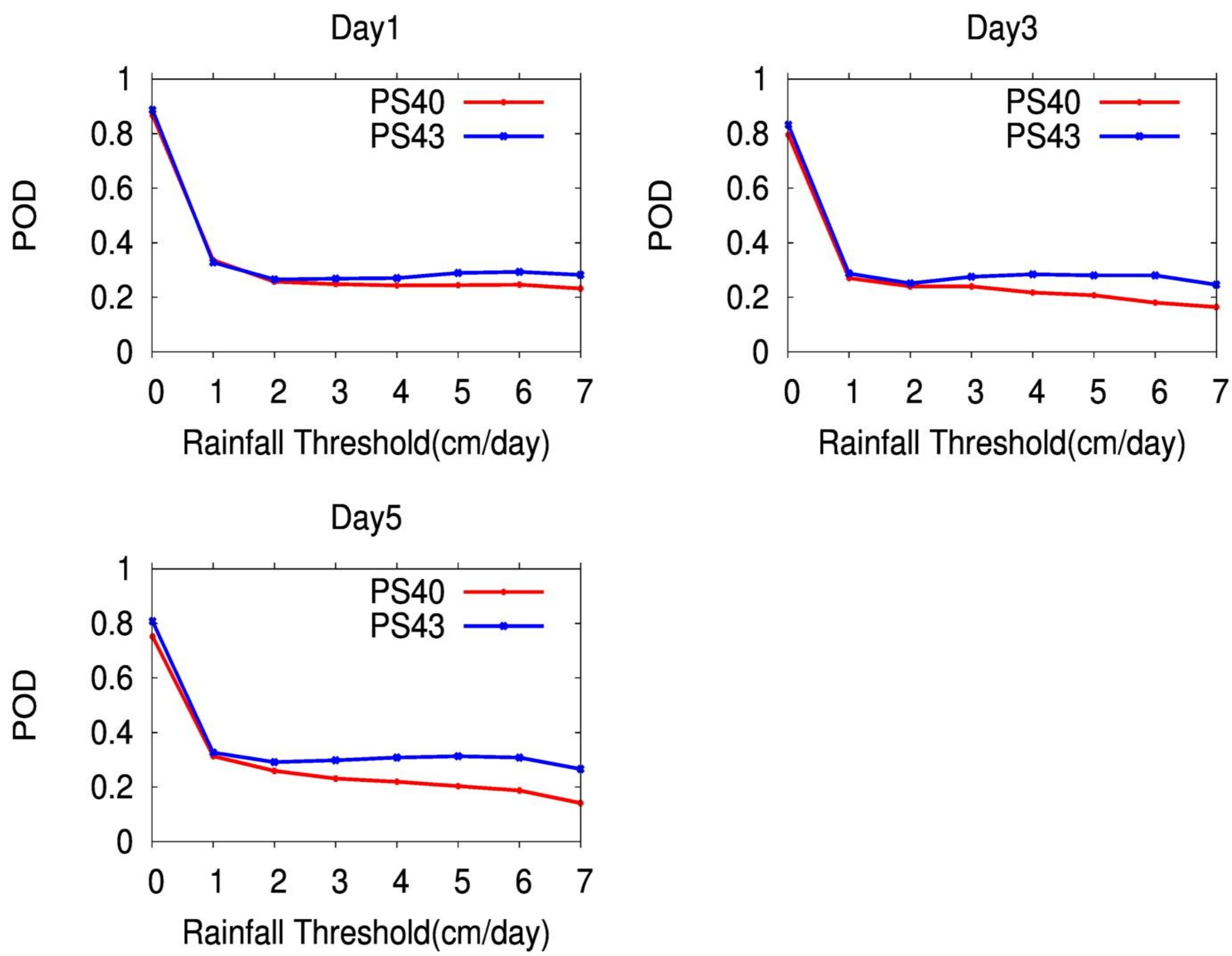

Figure 6: Probability of Detection (POD; Hit Rate) of Day-1, Day-3 and Day-5 rainfall forecasts from NCUM-G:V5 (PS40) and NCUM-G:V6 (PS43) for different rainfall thresholds.

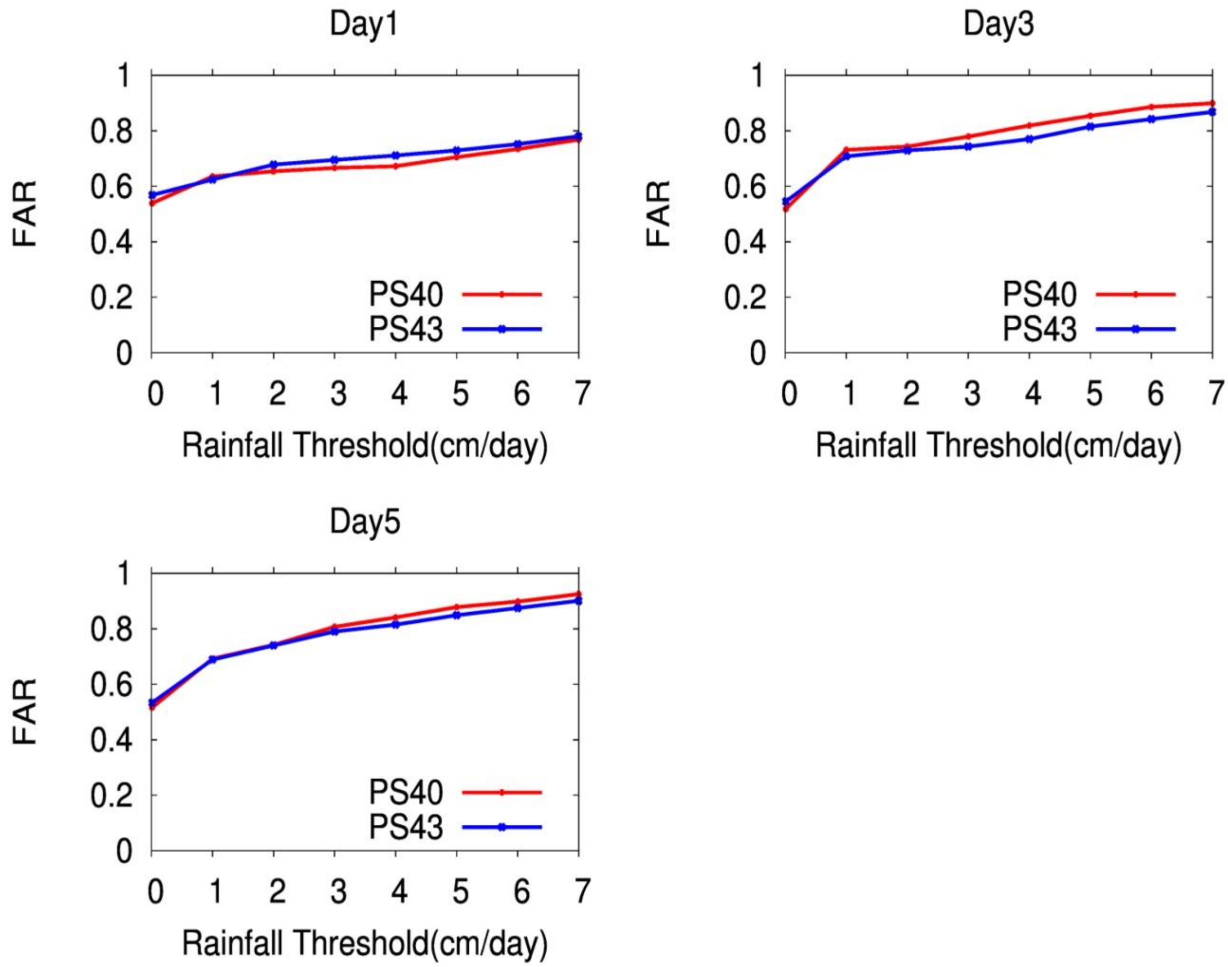

Figure 7: False Alarm Ratio (FAR) of Day-1, Day-3 and Day-5 rainfall forecasts from NCUM-G:V5 (PS40) and NCUM-G:V6 (PS43) for different rainfall thresholds.

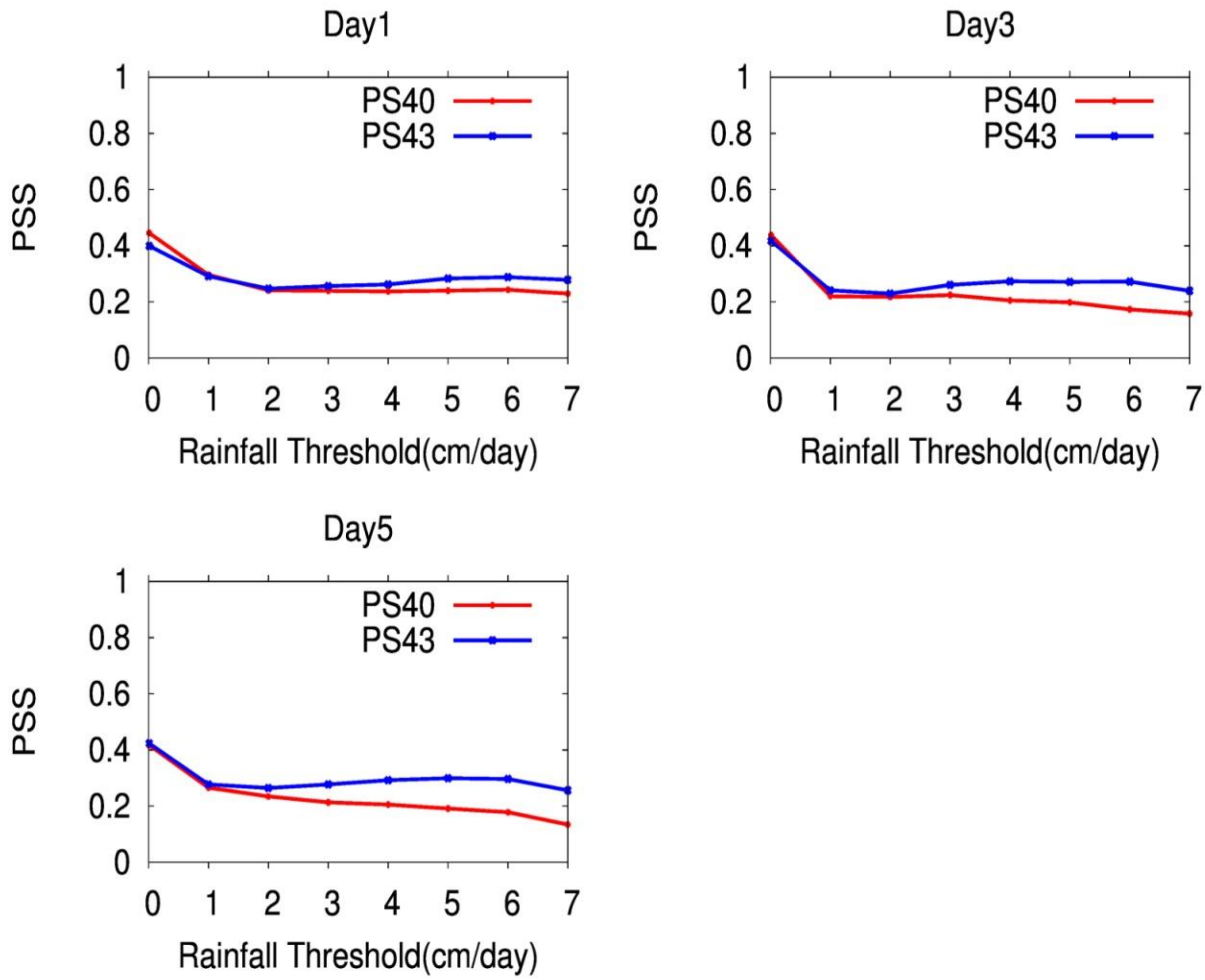

Figure 8: Peirce's skill score (PSS) of Day-1, Day-3 and Day-5 rainfall forecasts from NCUM-G:V5 (PS40) and NCUM-G:V6 (PS43) for different rainfall thresholds.

4.3 Forecast Verification for Super Cyclone "Amphan"

A brief summary of the verification and inter-comparison of forecasts by NCUM-G:V5 and NCUM-G:V6 is provided in this section for the recent Super Cyclone (SUCS) '***Amphan***' during 16-21 May2020. It was the strongest tropical cyclone formed in the Bay of Bengal after 1999 Odisha Super cyclone. The landfall of this cyclone occurred over West Bengal, causing widespread damage to life and property. Coastal areas in Odisha, especially Paradeep, received huge amounts (>200 mm) of 24 hr accumulated rainfall during 19-20 May 2020 (IMD tropical cyclone bulletin on 20 May 2020).

Figure 9 shows the observed and predicted tracks of Amphan based on NCUM-G:V5 and NCUM-G:V6 system on 16, 17, 18 and 19th May, 2020. The forecast tracks based on NCUM-G:V6 indicate a very good agreement with the observed track which is also reflected in the reduction of Direct Position Error (DPE) shown in Figure 10 for different forecast lead times. The errors in the initial position and forecast position on Day-1 seem to be higher in NCUM-G:V6 compared to NCUM-G:V5 but at all lead times, DPE is lower for NCUM-G:V6 compared to NCUM-G:V5. Similarly a comparison of observed and predicted 24 hour accumulated rainfall is shown in Figure 11 for 20th and 21st May 2020.

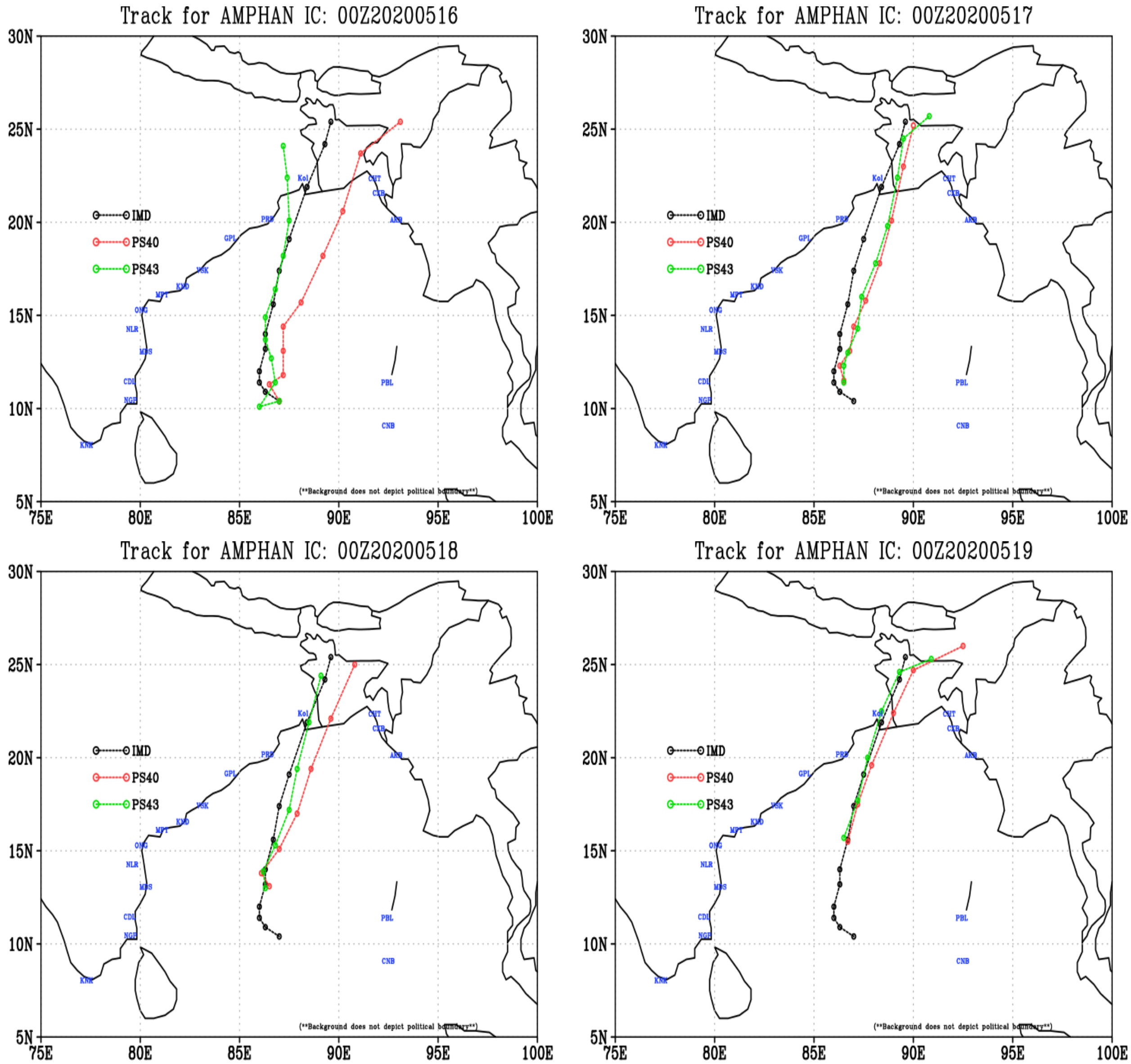

Figure 9: Observed and forecast tracks of the Super Cyclone Amphan on 16, 17, 18 and 19th May, 2020. A comparison of forecast tracks from NCUM-G:V5 (PS40) and NCUM-G:V6 (PS43) along with the Observed track.

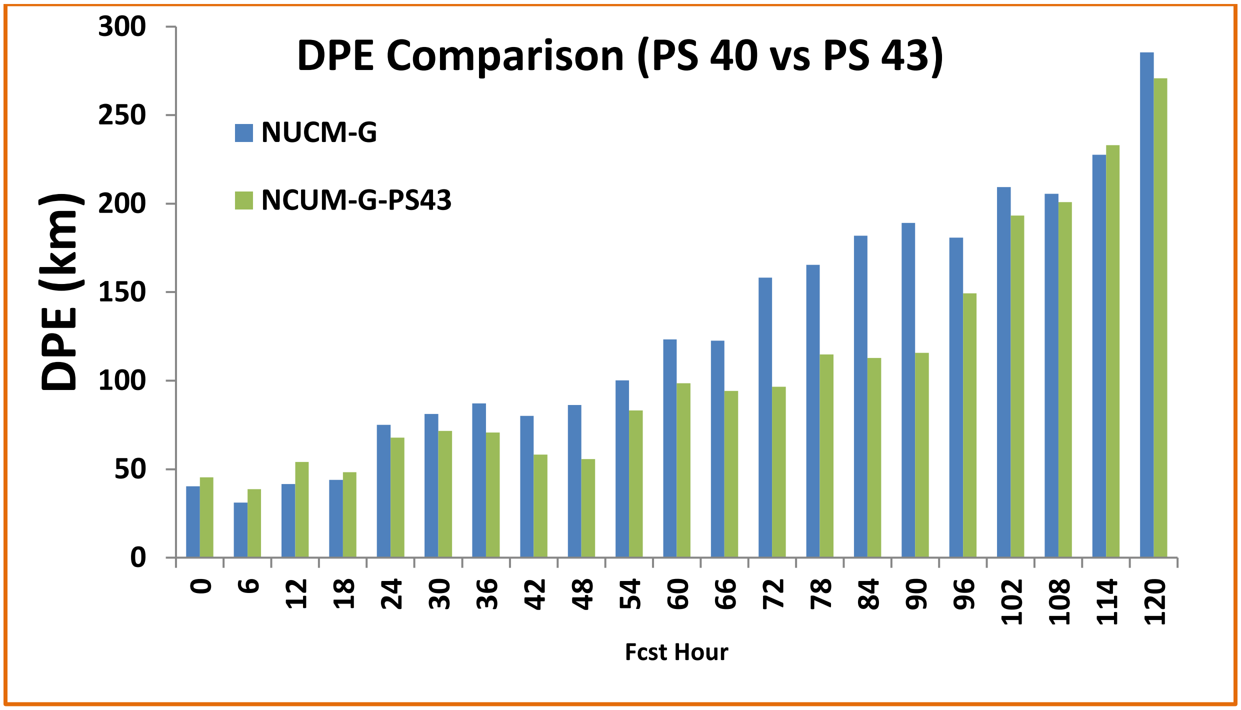

***Figure 10:** Direct Position Error (DPE) at different lead times for NCUM-G:V5 (*NCUM-G*) and NCUM-G:V6 (*NCUM-G-PS43*) for the Super Cyclone Amphan*

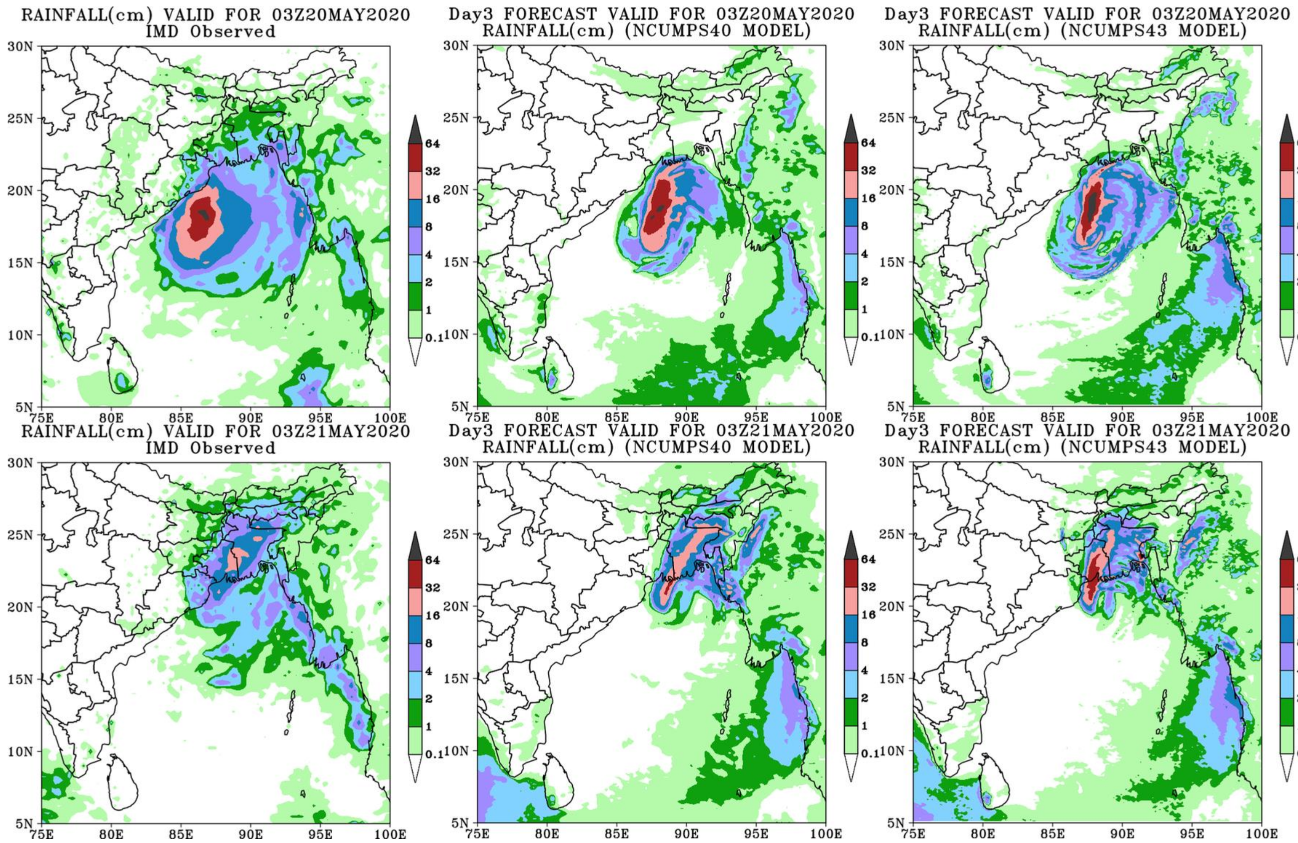

Figure 11: Observed and forecast rainfall in NCUM-G:V5 [PS40] (top) and NCUM-G:V6 [PS43] (bottom) on 20th May (before landfall) and 21st May (after landfall) of Super Cyclone Amphan

5. Summary

NCUM system has been upgraded periodically to absorb new scientific and technological advancements. During June 2020, the NCUM global NWP system has been upgraded with a latest UM components (based on Parallel Suite 43 of Met Office, PS43).The new version of the model (Unified Model Version 11.2) has improved model physics. Land surface of the model also has latest science configurations. Major improvements in the data assimilation system include the capability to assimilate cloud-affected microwave observations from ATOVS. Observation pre-processing system is enhanced with the capability to process latest satellite observations. The comparison of verification scores of NCUM-G:V5 and NCUM-G:V6 shows that the nature of errors are quite similar with positive ME (wet bias) over NE India, negative ME (dry bias) over eastern India (Odisha and West Bengal). Also, it is found that for high rainfall thresholds NCUM-G:V6 shows an improvements in terms of higher POD.

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Appendix

Standard lists of STASH diagnostics available in the operational global NCUM forecast output files

Unit: 60 (Daily, Instantaneous prognostics)

Filename: umgla00.pp0			
Sl. No.	***STASH Code***	***Field Name***	***Frequency***
1	33	OROGRAPHY	Daily
2	409	SURFACE PRESSURE	Daily
3	15242	W COMPNT (OF WIND) ON PRESSURE LEVELS	Daily
4	15243	U WIND ON PRESSURE LEVELS	Daily
5	15244	V WIND ON PRESSURE LEVELS	Daily
6	16202	GEOPOTENTIAL HEIGHT ON P LEVELS	Daily
7	16203	TEMPERATURE ON P LEVELS	Daily
8	16222	PRESSURE AT MEAN SEA LEVEL	Daily
9	16256	RH WRT WATER ON P LEVEL	Daily

Unit: 61 (Instantaneous, single-level diagnostics)

Filename: umglaa_pb000, ...			
Sl. No.	***STASH Code***	***Field Name***	***Frequency***
1	23	SNOW AMOUNT OVER LAND	3 Hourly (G)
2	24	SURFACE TEMPERATURE	3 Hourly (G)
3	25	BOUNDARY LAYER DEPTH	3 Hourly (G)
4	30	LAND MASK (No halo)	3 Hourly (G)
5	31	FRAC OF SEA ICE IN SEA	3 Hourly (G)
6	32	SEA ICE DEPTH (MEAN OVER ICE)	3 Hourly (G)
7	52	SNOW-FREE SURFACE ALBEDO#	3 Hourly (G)
8	53	DEEP-SNOW SURFACE ALBEDO#	3 Hourly (G)
9	95	SNOW AMOUNT OVER SEAICE#	3 Hourly (G)
10	376	SNOW DEPTH ON GROUND ON TILES#	3 Hourly (G))
11	3026	ROUGHNESS LEN. AFTER B.L. (SEE DOC)	3 Hourly (G)
12	3236	TEMPERATURE AT 1.5M (Tmax)	3 Hourly (G)
13	3236	TEMPERATURE AT 1.5M (Tmin)	3 Hourly (G)

14	3245	RELATIVE HUMIDITY AT 1.5M	3 Hourly (G)
15	3247	VISIBILITY AT 1.5M	3 Hourly (G)
16	3248	FOG FRACTION AT 1.5 M	3 Hourly (G)
17	3250	DEWPOINT AT 1.5M	3 Hourly (G)
18	3254	TL AT 1.5M	3 Hourly (G)
19	3255	QT AT 1.5M	3 Hourly (G)
20	3281	VIS AT 1.5M (including precipitation)	3 Hourly (G)
21	3341	LAND MEAN TEMPERATURE AT 1.5M	3 Hourly (G)
22	3342	LAND MEAN SPECIFIC HUMIDITY AT 1.5	3 Hourly (G)
23	3463	WIND GUST	3 Hourly (G)
24	3465	FRICTION VELOCITY	3 Hourly (G)
27	5207	PRESSURE AT CONVECTIVE CLD BASE###	3 Hourly (G)
28	5208	PRESSURE AT CONVECTIVE CLD TOP ###	3 Hourly (G)
29	5210	ICAO HT OF CONVECTIVE CLD BASE ###	3 Hourly (G)
30	5211	ICAO HT OF CONVECTIVE CLD TOP ###	3 Hourly (G)
31	5217	DILUTE CONVECTIVELY AVAIL POT E ###	3 Hourly (G)
32	5231	CAPE TIMESCALE (DEEP) ###	3 Hourly (G)
33	5275	MODEL FREEZING LEVEL ###	3 Hourly (G)
34	8208	SOIL MOISTURE CONTENT	3 Hourly (G)
36	9219	LOW CLOUD BASE (FT ASL)	3 Hourly (G)
37	9220	LOW CLOUD TOP (FT ASL)	3 Hourly (G)
39	30403	TOTAL COLUMN DRY MASS RHO GRID *	3 Hourly (G)
40	30404	TOTAL COLUMN WET MASS RHO GRID *	3 Hourly (G)
41	30405	TOTAL COLUMN QCL RHO GRID *	3 Hourly (G)
42	30406	TOTAL COLUMN QCF RHO GRID *	3 Hourly (G)
43	30451	Pressure at Tropopause Level	3 Hourly (G)
44	30452	Temperature at Tropopause Level	3 Hourly (G)
45	30453	Height at Tropopause Level	3 Hourly (G)
46	30454	ICAO HT OF TROP- NEED HT, TEMP, PRESS	3 Hourly (G)

Unit: 62 (Daily, time-processed, Prognostics)

Filename: umgla00.pp2			
Sl. No.	***STASH Code***	***Field Name***	***Frequency***
1	3236	TEMPERATURE AT 1.5M Tmax24	Daily
2	3236	TEMPERATURE AT 1.5M Tmin24	Daily
3	5226	TOTAL PRECIPITATION AMOUNT ###	Daily
4	4201	LARGE SCALE RAIN AMOUNT ***	Daily
5	4202	LARGE SCALE SNOW AMOUNT ***	Daily

*** Fields for mesoscale/cloud-resolving scales, when deep convection is switched off.

Available only if convection is on.

Unit: 63 (Instantaneous, multi-level, isobaric prognostics)

Filename: umglaa_pd000, ...			
Sl. No.	***STASH Code***	***Field Name***	***Frequency***
1	15201	U WIND ON PRESSURE LEVELS B GRID	3 Hourly (G)
2	15202	V WIND ON PRESSURE LEVELS B GRID	3 Hourly (G)
3	15242	W COMPNT (OF WIND) ON PRESSURE LEVELS	3 Hourly (G)
4	16202	GEOPOTENTIAL HEIGHT ON P LEVELS	3 Hourly (G)
5	16203	TEMPERATURE ON P LEVELS	3 Hourly (G)
6	16205	WET BULB POTENTIAL TEMPERATURE	3 Hourly (G)
7	16256	RH WRT WATER ON P LEVELS	3 Hourly (G))
8	30205	SPECIFIC HUMIDITY ON P LEV/UV GRID	3 Hourly (G)

Unit: 64 (High frequency diagnostics)

Filename: umglaa_pe000, ...			
Sl. No.	***STASH Code***	***Field Name***	***Frequency***
1	25	BOUNDARY LAYER DEPTH	1 Hourly (G)
2	238	SURFACE DOWN LW RADIATION	1 Hourly (G)
3	409	SURFACE PRESSURE	1 Hourly (G)
4	1235	TOTAL SURFACE DOWN SW RADIATION	1 Hourly (G)
5	3225	10 METRE WIND U-COMP B GRID	1 Hourly (G)

6	3226	10 METRE WIND V-COMP B GRID	1 Hourly (G)
7	3229	EVAP FROM SOIL SURF: AMOUNT	1 Hourly (G)
8	3236	TEMPERATURE AT 1.5M	1 Hourly (G)
9	3237	SPECIFIC HUMIDITY AT 1.5M	1 Hourly (G)
10	3245	RELATIVE HUMIDITY AT 1.5M	1 Hourly (G)
11	3247	VISIBILITY AT 1.5M	1 Hourly (G)
12	4201	LARGE SCALE RAIN AMOUNT	1 Hourly (G)
13	4202	LARGE SCALE SNOW AMOUNT	1 Hourly (G)
14	5201	CONV RAIN AMOUNT	1 Hourly (G)
15	5202	CONV SNOW AMOUNT	1 Hourly (G)
16	5226	TOTAL PRECIPITATION AMOUNT	1 Hourly (G)
17	5233	UNDILUTE CAPE	1 Hourly (G)
18	5234	UNDILUTE PARCEL CIN	1 Hourly (G)
19	9202	VERY LOW CLOUD AMOUNT	1 Hourly (G)
20	9203	LOW CLOUD AMOUNT	1 Hourly (G)
21	9204	MEDIUM CLOUD AMOUNT	1 Hourly (G)
22	9205	HIGH CLOUD AMOUNT	1 Hourly (G)
23	9216	TOTAL CLOUD AMOUNT - RANDOM OVERLAP	1 Hourly (G)
24	9217	TOTAL CLOUD AMOUNT MAX/RANDOM OVERLAP	1 Hourly (G)
25	15201	U WIND ON PRES LEVEL B GRID **DP9XX	1 Hourly (G)
26	15202	V WIND ON PRES LEVEL B GRID**DP9XX	1 Hourly (G)
27	15212	50 METRE WIND U COMPNT (B GRID)	1 Hourly (G)
28	15213	50 METRE WIND V COMPNT (B GRID)	1 Hourly (G)
29	16202	GEOPOTENTIAL HEIGHT ON P LEV**DP9XX	1 Hourly (G)
30	16222	PRESSURE AT MEAN SEA LEVEL	1 Hourly (G)

**DP9XX: Pressure levels 1000, 995, 990, 985, 980, 975, 960 and 925 hPa.

Unit: 65 (Time-averaged, single level diagnostics)

Filename: umglaa_pf000,...			
Sl. No.	***STASH Code***	***Field Name***	***Frequency***
1	238	SURFACE DOWNWARD LW RADIATION	3 Hourly (G)
2	239	TOA - SURF UPWARD LW RADIATION	3 Hourly (G)
3	1202	NET DOWN SURFACE SW FLUX	3 Hourly (G)
4	1205	OUTGOING SW RAD FLUX (TOA)	3 Hourly (G)
5	1207	INCOMING SW RAD FLUX (TOA)	3 Hourly (G)
6	1209	CLEAR-SKY (II) UPWARD SW FLUX	3 Hourly (G)
7	1210	CLEAR-SKY (II) DOWN SURFACE SW FLUX	3 Hourly (G)
8	1211	CLEAR-SKY (II) UP SURFACE SW FLUX	3 Hourly (G)
9	1215	DIRECT SURFACE SW FLUX	3 Hourly (G)
10	1216	DIFFUSE SURFACE SW FLUX	3 Hourly (G)
11	1235	TOTAL DOWNWARD SURFACE SW FLUX	3 Hourly (G)
12	1408	OUTGOING SW RAD FORCING (TOA)	3 Hourly (G)
13	2201	NET DOWN SURFACE LW RAD FLUX	3 Hourly (G)
14	2205	OUTGOING LW RAD FLUX (TOA)	3 Hourly (G)
15	2206	CLEAR-SKY (II) UPWARD LW FLUX (TOA)	3 Hourly (G)
16	2207	DOWNWARD LW RAD FLUX: SURFACE	3 Hourly (G)
17	2208	CLEAR-SKY (II) DOWN SURFACE LW FLUX	3 Hourly (G)
18	3201	HT FLUX THROUGH SEAICE:SEA MEAN	3 Hourly (G)
19	3202	HT FLUX FROM SURF TO DEEP SOIL LEV	3 Hourly (G)
20	3217	SURFACE SENSIBLE HEAT FLUX	3 Hourly (G)
21	3228	SFC SH FLX FROM OPEN SEA:SEA MN	3 Hourly (G)
22	3232	EVAP FROM OPEN SEA: SEA MEAN	3 Hourly (G)
23	3234	SURFACE LATENT HEAT FLUX	3 Hourly (G)
24	3296	EVAP OVER SOIL SURF: RATE	3 Hourly (G)
25	3297	EVAP OVER CANOPY: RATE	3 Hourly (G)
28	5214	TOTAL RAINFALL RATE: LS+CONV	3 Hourly (G)
29	5215	TOTAL SNOWFALL RATE: LS+CONV	3 Hourly (G)
30	5216	TOTAL PRECIPITATION RATE	3 Hourly (G)
31	5277	DEEP CONV PRECIP RATE	3 Hourly (G)
32	5278	SHALLOW CONV PRECIP RATE	3 Hourly (G)

33	5279	MID LEVEL CONV PRECIP RATE	3 Hourly (G)
34	8234	SURFACE RUNOFF RATE	3 Hourly (G)
35	8235	SUB-SURFACE RUNOFF RATE	3 Hourly (G)

Unit: 66 (Instantaneous, hybrid-level prognostics)

Filename: umglaa_pg000, ...			
Sl. No.	***STASH Code***	***Field Name***	***Frequency***
1	2	U COMPNT OF WIND	3 Hourly (G)
2	3	V COMPNT OF WIND	3 Hourly (G)
3	4	THETA	3 Hourly (G)
4	10	SPECIFIC HUMIDITY	3 Hourly (G)
5	12	QCF	3 Hourly (G)
6	33	OROGRAPHY	3 Hourly (G)
7	150	W COMPNT OF WIND	3 Hourly (G)
8	253	DENSITY*R*R	3 Hourly (G)
9	254	QCL	3 Hourly (G)
10	255	EXTNR PRESS(rho) AFTER TIMESTEP	3 Hourly (G)
11	256	ADVT COMPNT OF U WIND#	3 Hourly (G)
12	257	ADVT COMPNT OF V WIND#	3 Hourly (G)
13	258	ADVT COMPNT OF W WIND#	3 Hourly (G)
14	272	RAIN AFTER TIMESTEP	3 Hourly (G)
15	407	PRESSUER AT RHO LEVELS	3 Hourly (G)
16	408	PRESSUER AT THETA LEVELS	3 Hourly (G)
17	431	DUST DIV 1 MASS MIXING RATIO	3 Hourly (G)
18	432	DUST DIV 2 MASS MIXING RATIO	3 Hourly (G)
19	16004	TEMPERATURE ON THETA LEVELS	3 Hourly (G)
20	16207	TOTAL SPECIFIC HUMIDITY (qT)	3 Hourly (G)

#Availability depends on UM version.

Unit: 67 (Instantaneous, hybrid-level prognostics)

Filename: umglaa_ph000,...			
Sl. No.	***STASH Code***	***Field Name***	***Frequency***
1	406	EXNER PRESSURE AT THETA LEVELS	3 Hourly (G)
2	1212	DIRECT UV FLUX	3 Hourly (G)
3	2261	TOTAL CLOUD AMT IN THETA LEVELS	3 Hourly (G)
4	9222	WET BULB TEMPERATURE	3 Hourly (G)
5	15217	PV ON MODEL THETA LEVELS	3 Hourly (G)
6	16201	GEOPOTENTIAL HEIGHT ON THETA LEVELS	3 Hourly (G)
7	16206	CLOUD WATER CONTENT (qc)	3 Hourly (G)
8	17257	TOTAL DUST CONC ##	3 Hourly (G)

Available only if dust is incorporated.

Unit: 68 (Multi-level/Pseudo-level diagnostics)

Filename: umglaa_pi000,...			
Sl. No.	***STASH Code***	***Field Name***	***Frequency***
1	2422	DUST OPTICAL DEPTH (time-mean)##	3 Hourly (G)
2	3238	DEEP SOIL TEMPERATURE AFTER B.LAYER*	3 Hourly (G)
4	8223	SOIL MOISTURE CONTENT IN A LAYER*	3 Hourly (G)

*4 soil levels.

Available only if dust is incorporated (6 pseudo-levels).

5 pseudo levels.