Impact of Satellite Data on limited area model analysis and forecast System in India Meteorological Department

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ABSTRACT
The India Meteorological Department (IMD) is the nodal agency for providing weather forecasts/ warnings to all sectors of activity. IMD's short range forecast system is based on synoptic method. However, the forecast products available from various numerical models available from with in IMD and other global forecasting centers, all satellite observations such as CMVs, cloud imageries available from INSAT and METEOSAT and other satellite products are taken into consideration. IMD's operational Numerical Weather Prediction (NWP) system is based on a limited area analysis and forecasting system (LAFS), which consists of real time processing of data received on Global Telecommunication system (GTS), objective analysis by 3-D multivariate optimum interpolation (OI) scheme and limited area forecast model. In the present study, the impact of Indian satellite KALPANA-I derived CMVs and also ATOVS humidity profile data for some of the major synoptic systems over the Indian region are discussed. Method for assimilation of the additional data as pseudo observations in the analysis scheme has been developed and implemented in the regional analysis scheme. Verification analysis and forecast fields with this additional data have shown substantial improvement in the initial analysis and model predicted rainfall.

Key words: KALPANA-I CMVs, ATOVS humidity profile, Impact study, Numerical model

1. Introduction

Difficulties and inaccuracies in numerical weather prediction over low latitudes are mainly attributed to data problems and thus to the overall treatment of diabatic processes. Tropical general circulation is mainly governed by convective heating. Thus NWP over low latitudes is sensitive to the four dimensional structure of parameterized convective heating. In the initial fields, there is a greater degree of uncertainty in the quality of the divergence and moisture fields on which this convective heating depends. In spite of the use of vast amount of a synoptic and non-conventional data, large data gaps are evident over both land and ocean areas of tropics. The use of various satellite data in numerical weather prediction (NWP) has advanced substantially in the last decade. Several operational NWP centers are now assimilating satellite data of many different types with clear positive impact over the data sparse regions, particularly over tropical regions. However, currently available data are far from being exploited to their full potential. There has been a continuous operational demand for development of suitable assimilation procedure consistent with the analysis and forecast system for utilization of these data.

The India Meteorological Department (IMD) is the nodal agency for providing weather forecasts/ warnings to all sectors of activity. IMD's short range forecast system is based on synoptic method. However, the forecast products available from various numerical models available from with in IMD and other global forecasting centers, all satellite observations such as CMVs, cloud imageries available from INSAT and METEOSAT and surface wind from NASA QuikSCAT satellite (QSCT) are taken into consideration. IMD's operational Numerical Weather Prediction (NWP) system is based on a limited area analysis and forecasting system (LAFS), which consists of real time processing of data received on Global Telecommunication system (GTS), objective analysis by 3-D multivariate optimum interpolation (OI) scheme and limited area forecast model.

Some experiments are conducted earlier for assimilation of INSAT derived humidity and TOVS temperature-humidity profile data to study the impact of these additional data in IMD's operational NWP forecast system (Bhatia et al, 1999, Rama Rao et al, 2001). In the present study we are presenting the impact of Indian satellite KALPANA-I derived CMVs and also ATOVS humidity profile data for some of the major synoptic systems over the Indian region. Method for assimilation of the additional data as pseudo observations in the analysis scheme has been developed and implemented in the regional analysis scheme.

2 IMD's operational NWP system

2.1 Input data

The grid point fields for running the model are prepared from the conventional and non-conventional data received through GTS. The data consists of the surface SYNOP/SHIP, upper air TEMP/PILOT, SATEM, SATOB, AIREP, DRIBU and AMDAR, which are extracted and decoded from the raw GTS data sets. The synthetic observations such as cyclone bogusing data and ATOVS temperature and humidity profile data also included as per requirement. All the data are quality controlled and packed into a special format for objective analysis.

2.2 Analysis procedure

The objective analysis is carried out by three dimensional multivariate optimum interpolation procedures. The variables analysed are the geopotential, u and v components of wind and specific humidity. Temperature fields are derived from the geopotential fields hydrostatically. Analysis is carried out on 12 sigma surfaces from 1.0 to 0.05 in the vertical and at 1^0x1^0 horizontal lat/long. grid for limited area domain of 30^0S to 70^0N ; 0^0 to 150^0E. The generated ATOVS temperature and relative humidity data are included into the regional OI scheme as additional observations. While the direct assimilation of radiances from sounding instruments on polar orbiting satellites in 3DVAR has shown a positive impact in global and regional models, however, because of limitations in OI scheme, the finally derived temperature and relative humidity data are included as observations. The observations are generally horizontally consistent over synoptic scales, and very few are rejected by the analysis system.

2.3 Forecast Model

The IMD limited area forecast model is a semi-implicit semi-Lagrangian multilayer primitive equation model based on sigma co-ordinate system and Arakawa C-grid in the horizontal. The present version of the model has a horizontal resolution of 0.75^0x0.75^0 lat/long (domain 30^0S to 50^0N and 25^0E to 130^0E) in horizontal and 16 sigma levels (1.0 to 0.05) in vertical. The detailed description of model formulation, horizontal and vertical descretization and time integration scheme used in the experiment are given in Prasad et al (1997), Krishnamurti et al (1990). The lateral boundary conditions are obtained from the T-80 global forecasts of the National Centre for Medium Range Weather Forecasting (NCMRWF), New Delhi, India.

3. The impact study

3.1 Case-I: Impact of KALPANA-I CMVs data

In this study, the impact of KALPANA-I derived Cloud Motion Vector (CMVs) are examined during the Arabian Sea Monsoon Experiment (ARMEX) observational program. The KALPANA-I satellite was launched in 2003. The real-time CMV products are not available during the ARMEX Intense Observation Period (IOP) 07 - 12 June 2003 due to testing/validation of the products. The ARMEX IOP also coincided with the onset of Indian monsoon over Kerala (southern part of peninsular India). Using additional data available from ARMEX observational program, namely SYNOP, upper air and CMVs from KALPANA-I satellite, the impact of these data in the IMD's operational limited area forecast system during the onset phase of monsoon 2003 has been investigated.

3.1.1 Onset of Indian monsoon 2003

The Indian southwest monsoon reaches the Kerala, the southeastern part of India by 1st June. During 2003, the monsoon advanced into Kerala and adjoining parts of Tamil Nadu on 8th June with a delay of about a week. It advanced into parts of coastal and south interior Karnataka and some more parts of Tamil Nadu on 10^{th}. In the present study the performance of the limited area model during the onset phase of the monsoon was investigated. The model forecasts are produced with the additional ARMEX data and compared with the operational real-time forecasts produced without these additional data.

The 850 hPa analysis for 6, 7, 8 and 9^{th} June are given in Fig.1.It shows wind speed of 20-30 knots over Somali coast and north Bay of Bengal on 6^{th} and further strengthening on 7^{th} with northward extension into Arabian Sea. On 8^{th} the southwesterly flow over Arabian Sea increased to 30-40 kts. On 9^{th} these westerlies extended to more eastwards and a weak trough off Kerala-Karnataka-Goa coast was observed. The 200 hPa analysis for 6, 7, 8 and 9^{th} June are given in Fig.2. It shows on 6^{th} and 7^{th} the strength of westerly jet stream is of the order 100-120 kts, which weakened to 80-100 kts by 8^{th}, whereas the upper tropospheric easterlies over peninsular parts of India showed strengthening by about 10 knots from 6 to 9^{th}. Based on the 7^{th} analysis, the 24 hours forecast 850 hPa wind in respect of experiment and control run and the change in zonal and meridional wind component with the additional data are given in Fig.3 and rainfall in Fig.4. It shows, with additional data positive impact was observed over Arabian Sea where the wind speed increased by 2-3 kts. The 24 hours forecast rainfall based on the experiment for 8^{th} June showed slight northward propagation in the rainfall belt compared to the control run (Fig.4) that agrees better with the observations. Verification analysis and forecast fields with this additional data have shown substantial improvement in the analysis and model predicted rainfall.

3.2 Impact of ATOVS data during winter season - January 2004

Until recently (A)TOVS data have mainly been assimilated into global numerical weather models, but the study of their impact on a regional model is of great relevance for many weather services, especially if data can be made available with sufficiently short delay. India Meteorological Department (IMD) installed High Resolution Picture Transmission (HRPT) Direct Readout ground receiving station at Delhi to receive the NOAA satellite (K, L and M) ATOVS data in real time. The AMSU temperature and moisture data are received over the pass area from Equator to lat. 40^{o}N and long. 60^{o} to 100^{o}E at the resolution of 50 km in the horizontal and 10 pressure levels in the vertical (from 1000 hPa to 200 hPa). Due to the presence of uneven terrain with snow and desert, only few upper air observations are available over northwest and extreme northern region of India. In view of this, using this data several experiments were undertaken to examine the impact of these data sets on some of the important weather systems such as active monsoon conditions during monsoon 2003 and also during the winter season, January 2004. The preliminary studies reveal that these additional data have a positive impact on rainfall prediction of the limited area model. In the present case, the data impact during the winter season, January 2004 will be discussed.

3.2.1 Synoptic conditions

Western Disturbances (WDs) are low pressure systems observed in the midlatitude westerlies over the sub-tropical regions of Asia. They move from west to east in all seasons, but most prominent during winter months of December to March. In winter, over northern India, generally a high pressure at the surface level is observed and the associated weather is clear and dry. This situation is altered due to passage of trough in the middle and upper air westerlies, which cause cloudy conditions and light to heavy precipitation over northern parts of India. In addition, the southern part of India is effected by the easterly waves, which moves from east to west and produces rainfall over the peninsular India. During the January 2004, five Western Disturbances (WD) affected over the region. However, out of five WDs, four of which moved northeast as an upper-air systems which effected the weather over Western Himalayan region and only one system with its associated induced cyclonic circulation over northwest plains affected the weather over the plains of north India and also parts of central India. During the January 2004, 13 subdivisions reported excess, 6 normal except Tamil Nadu, Orissa and West Bengal where deficient rainfall was reported. The all India area weighted rainfall was 23% excess during the month.

3.2.2 Model Forecast

The monthly rainfall prediction by the model based on day-1 (24 hours) control and experimental forecasts are given in Fig.6. The 850 hPa relative humidity (%) analysis of January 2004 shown (fig. not shown) an increase of 5-10 % over northern parts of India where the ATOVS data was assimilated. The model predicted day-1 rainfall (cm) with additional data (experiment) for the month of January 2004 (Fig.6) shows the extension of rainfall belt further northwest and increased rainfall over north of Delhi region compared to the control run (without additional data) which was close to observed features.

4.Concluding remarks

The sensitivity experiments with KALPANA-I satellite CMVs data has shown positive impact on the model predicted 24 hours forecast wind fields and rainfall. The forecast model runs to study the impact of the additional ATOVS derived humidity data on the rainfall predictions during the winter 2004 has shown a considerable improvement over northwestern parts of India, as seen from the corresponding observed rainfall. Maximizations of use of such satellite-based observations are expected to considerably improve the initial humidity analysis and subsequent forecasts produced by NWP models. Recently some efforts are made to assimilate sea surface wind from NASA QuikSCAT satellite (QSCT) in operational NWP forecast system to improve the tropical cyclone track and intensity prediction over Indian Seas. However, due to limitations in the present IMD's OI analysis scheme, the model shown only marginal improvement. Efforts are in the process to improve the present data assimilation system to assimilate the various satellite data products in the NWP system.

Acknowledgement

The authors are thankful to Director General of Meteorology, India Meteorological Department, New Delhi for providing the necessary facilities.

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Legend of Figures:

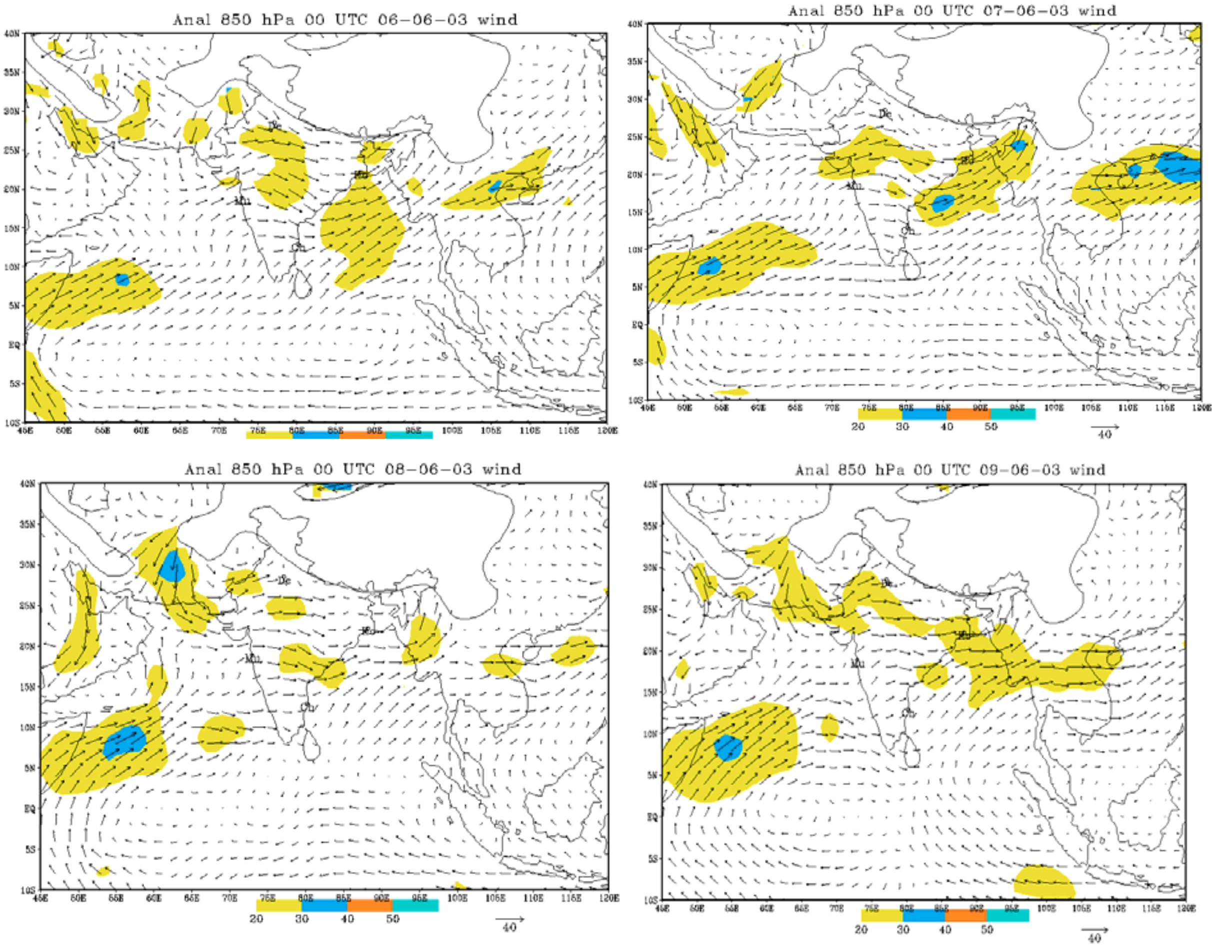
Fig.1 Analysis 850 hPa - wind (kt) and contour height (gpm) for 00 UTC of 06, 07, 08 and 09 June 2003

Fig.2. Analysis 200 hPa - wind (kt) and contour height (gpm) for 00 UTC of 06, 07, 08 and 09 June 2003

Fig.3 Forecast (24 hrs) 850 hPa wind (kt) and change of U & V components for 00 UTC of 08 June 2003 Left: Control, Right: Experiment

Fig.4 Forecast (24 hrs) Rainfall (mm) for 03 UTC of 08 June 2003 Left: Control, Right: Experiment

Fig.5 Day-1 Forecast (24 hrs) Rainfall (cm) for the month of January 2004 Left: Control, Right: Experimen**t**



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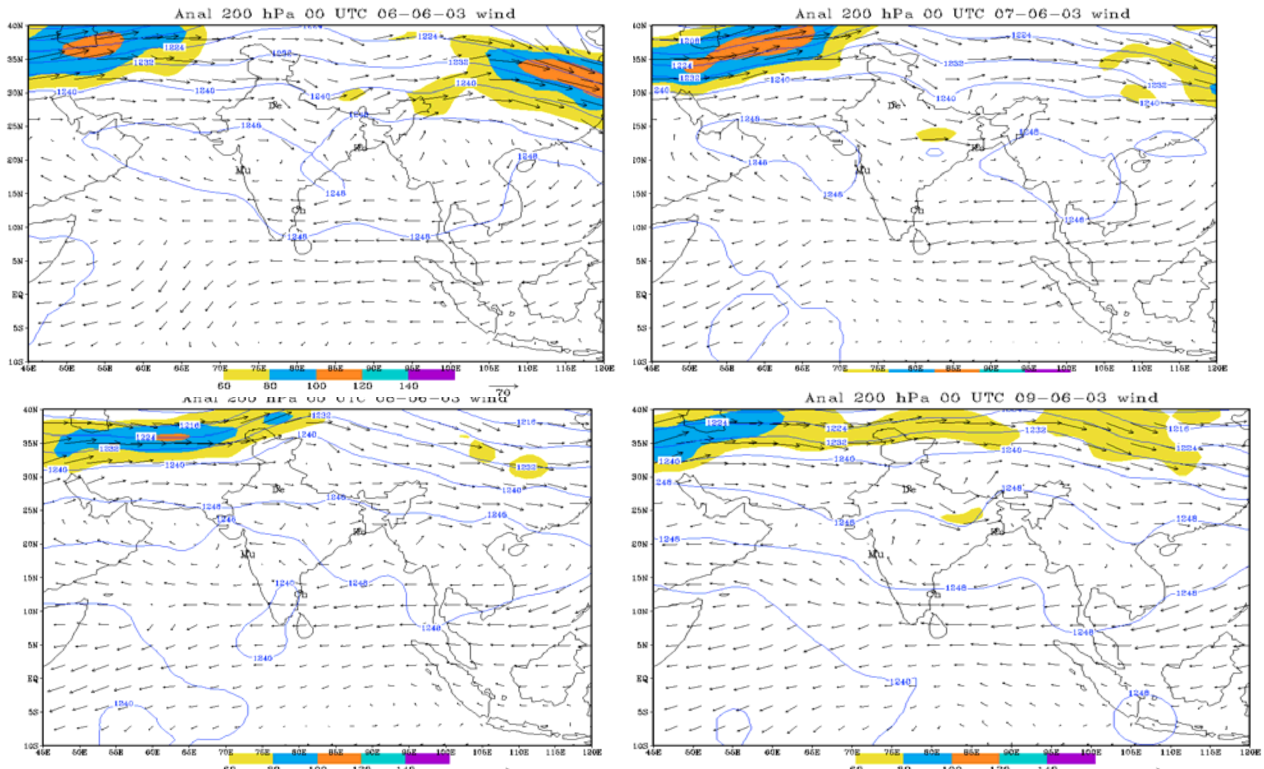
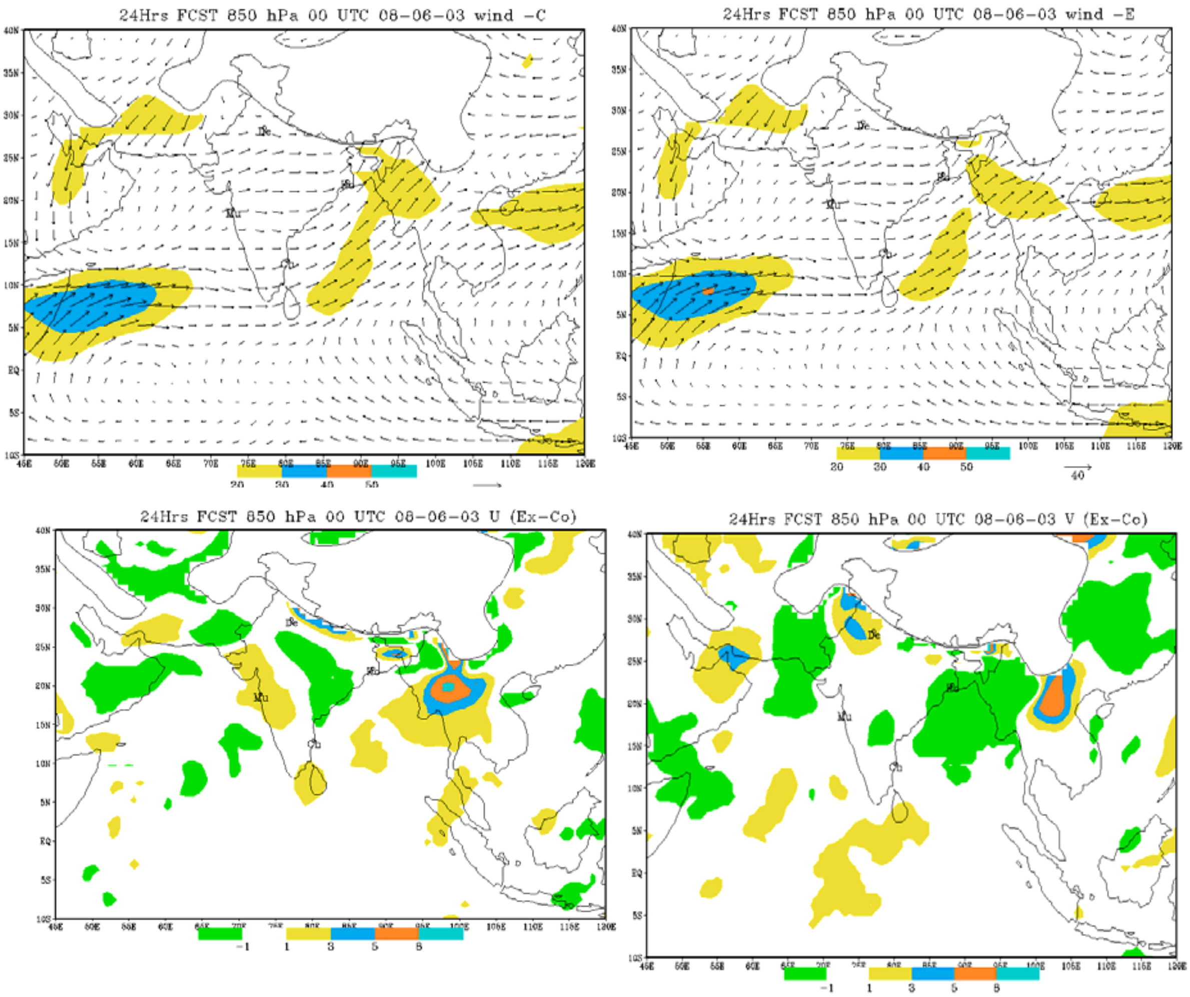


Fig.2. Analysis 200 hPa - wind (kt) and contour height (gpm) for 00 UTC of 06, 07, 08 and 09 June 2003



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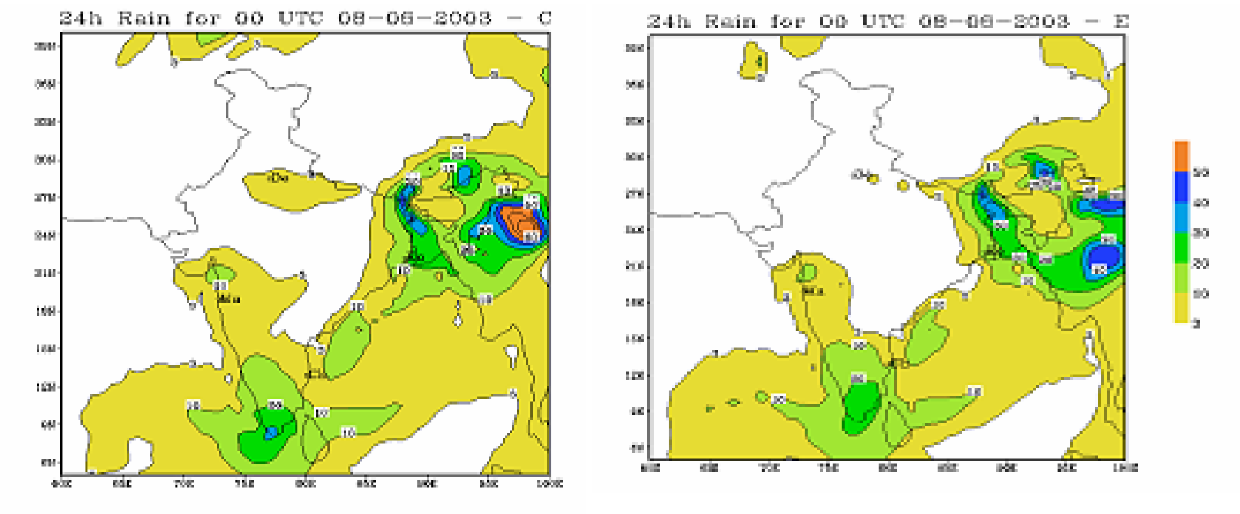

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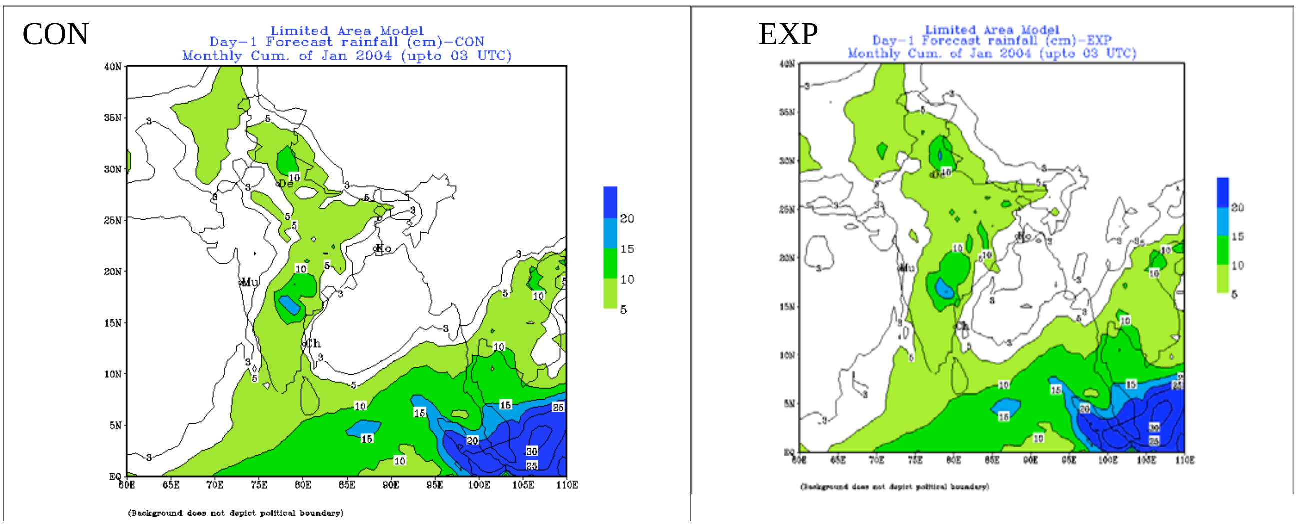

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