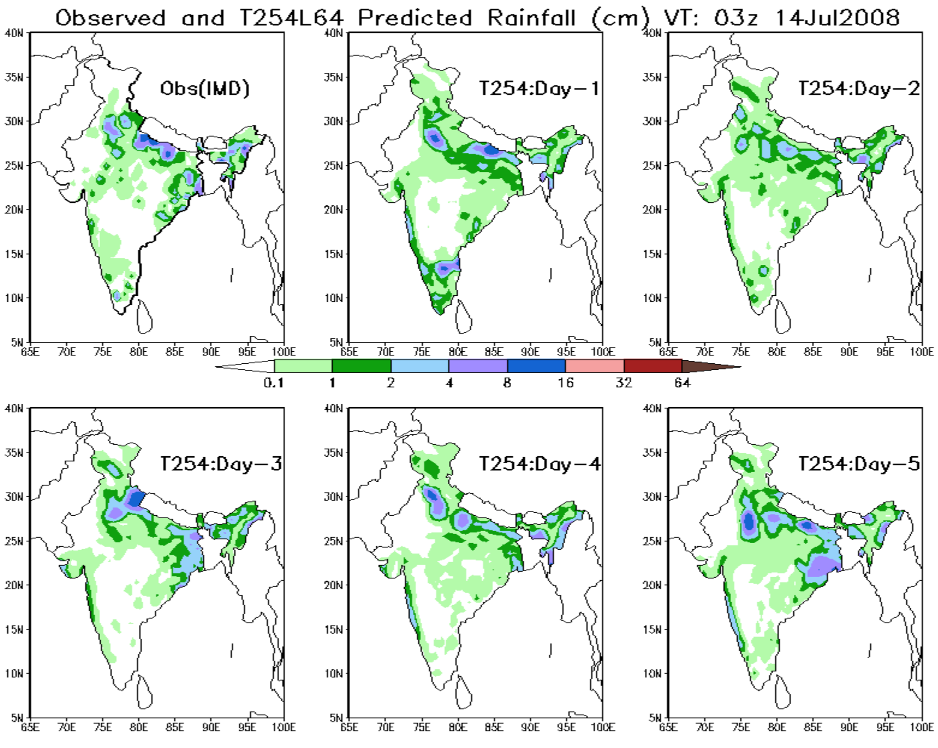
NCMRWF

NMRF / MR / 01 /2009

MONSOON REPORT

Monsoon-2008:

Performance of T254L64 Global Assimilation–Forecast System



February 2009

National Centre for Medium Range Weather Forecasting
Ministry of Earth Sciences, Government of India
A-50, Sector-62, NOIDA, India 201 307

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Disclaimer:

The geographical boundaries shown in this report do not necessarily correspond to political boundaries.

Front Cover:

Front cover shows global T254L64 model predicted rainfall valid for 03UTC of 14 July 2008 (a typical weak monsoon condition) along with observation.

This report was compiled and produced by:

Ashis K. Mitra , Munmun Das Gupta and Gopal. R. Iyengar, NCMRWF/MoES

Acknowlwdgement:

Acknowledgement is also due to NCEP/NOAA for providing the GFS assimilation-forecast system codes and their support for its implementation. Observed rainfall was taken from IMD.

For other details about NCMRWF see the website **www.ncmrwf.gov.in**

* * *

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FOREWORD

Asian Monsoon is one of the major components of the earth climate system. Realistic modeling, simulation and prediction of monsoon are challenging scientific tasks for the world earth system science community. For India, the monsoon rain is of enormous importance giving shape to agriculture, economy and rhythms of life. The science pertaining to monsoon has progressed significantly in the last two decades due to an increased wealth of new data from satellite observations and enhanced computing power. Numerical models have been further improved at all major international centers across the globe. 'NCMRWF' a Center of Excellence in modeling has generated vast experience in global/regional modeling and data assimilation. Proper evaluation, verification and diagnosis of the numerical modeling systems for monsoons is one of the most important tasks which provides feedback to model improvements and keeps the users / forecasters aware about the current capabilities and limitations of such numerical models. Performance evaluation reports are of immense importance for inter-comparison studies in relation to the skill of other modeling systems of the major leading international centers.

During 2007, NCMRWF had implemented and tested a higher resolution global model T254L64 with its assimilation system. This makes use of direct assimilation of radiances from satellites. I am happy that NCMRWF has brought out a detailed performance verification report with title "*Monsoon-2008: Performance of the* T254L64 *Global Assimilation-Forecast System* ". This is the second consecutive year that different components of the monsoon system have been evaluated from this higher resolution global modelling system. This report will provide useful information to both scientists and operational personnel engaged in monsoon prediction using numerical models as the tool. I take this opportunity to congratulate the NCMRWF team for bringing out this useful report.

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GOVERNMENT OF INDIA
(Ministry of Earth Sciences)
National Centre for Medium Range Weather Forecasting (NCMRWF)
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15 February 2009

Foreword

At NCMRWF we strive constantly to imbibe the latest technologies in terms of data, assimilation and modelling techniques to capture the monsoon system in a realistic way. Proper scientific verification of model simulation is of immense value to model developers and forecasters. This is the second time we are verifying the performance of a high resolution global model for the monsoon system. During 2007 monsoon we had noticed that with enhanced horizontal and vertical resolution of the new modelling system the global model errors were reduced considerably. However, we need to improve the model performance further in terms of its skill and reliability for severe and high impact weather events. Improvement in model dynamics, model physics, further enhancement of model resolution, incorporating 4-D variational data assimilation for tropics including moist physics are the priority items at NCMRWF for coming years. A variety of new data from MoES coordinated modern observing systems are going to become available in coming months and years. More useful data from Nation's satellite programme are also likely to become available during 2009-10. NCMRWF is gearing up to make use of the new useful satellite data.

With increased amount of data from the higher resolution global models, we are planning to adopt new strategies to handle the model verification and diagnostics. The NCMRWF team has worked very efficiently to bring out this report. I am sure for coming monsoon years the quality of the report and the scientific content will improve further and will be found more useful by research and forecasting communities in India and abroad.

(A. K. Bohra)

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Overview of Global Data Assimilation - Forecast System

E. N. Rajagopal, M. Das Gupta and V.S. Prasad

1. Introduction

The global high-resolution assimilation-forecast system T254L64 (T254 spectral waves in horizontal and 64 layers in vertical) was implemented at NCMRWF in January 2007 (Rajagopal et al., 2007). In this report an attempt is made to verify and compare the evolutions of various weather systems and semi-permanent monsoon features during June-September 2008, in the T254L64 analysis-forecast system. The salient features of T254L64 global data assimilation-forecast system are presented briefly in this chapter.

Global Forecast System (GFS) is the operational numerical weather analysis-forecast system of National Centers for Environmental Prediction (NCEP), USA. This system was acquired by NCMRWF under a USAID training programme. The GFS was implemented on CRAY-X1E and Param Padma (IBM P5 cluster) in 2007. GFS has capabilities to assimilate various conventional as well as satellite observations including radiances from different polar orbiting and geostationary satellites.

2. Data Pre-Processing and Quality Control

The meteorological observations from all over the globe and from various observing platforms are received at Regional Telecommunication Hub (RTH), New Delhi through Global Telecommunication System (GTS) and the same is made available to NCMRWF through a dedicated link at half hourly interval.

In decoding step, all the GTS bulletins are decoded from their native format and encoded into NCEP BUFR format using the various decoders. Satellite radiances (level 1b) from AMSU-A, AMSU-B/MHS & HIRS on board NOAA-15, 16, 18, Metop-A and SBUV ozone profiles from NOAA-16 & 17 are downloaded from NOAA/NESDIS ftp server. The same are processed and encoded in NCEP BUFR.

Global data assimilation system (GDAS) of T254L64 access the observational database at a set time each day (i.e., the data cut-off time, presently set as 6 hour), four times a day. Observations of a similar type [e.g., satellite-derived winds ("satwnd"), surface land reports ("adpsfc")] are dumped into individual BUFR files in which, duplicate reports are removed, and upper-air report parts (i.e. AA,BB,CC,DD) are merged.

Last step of conventional data processing is the generation of "prebufr" files. This step involves the execution of series of programs designed to assemble observations dumped from a number of decoder databases, encode information about the observational error for each data type as well the background (first guess) interpolated to each data location, perform both rudimentary multi-platform quality control and more complex platform-specific quality control. Quality control of satellite radiance data is done within the global analysis scheme.

3. Global Analysis Scheme

The global analysis scheme in GFS framework is based on Spectral Statistical Interpolation (SSI) (Parrish and Derber, 1992 and Derber et al. 1991). The analysis problem is to minimize the equation

$$J = J_b + J_o + J_c \qquad (1)$$

where, J_b is the weighted fit of the analysis to the six hour forecast (background or first guess), J_o is the weighted fit of the analysis to the observations and J_c is the weighted fit of the divergence tendency to the guess divergence tendency. J_c also includes a constraint to limit the number of negative and supersaturated moisture points.

Horizontal resolution of the analysis system is in spectral triangular truncation of 254 (T254). The quadratic T254 Gaussian grid has 768 grid points in the zonal direction and 384 grid points in the meridional direction. The resolution of the quadratic T254 Gaussian grid is approximately 0.5 x 0.5 degree. The analysis is performed directly in the model's vertical coordinate system. This sigma ($\sigma = p/p_s$) coordinate system extends over 64 levels from the surface (~997.3 hPa) to top of the atmosphere at about 0.27hPa. This domain is divided into 64 layers with enhanced resolution near the bottom and the top, with 15 levels is below 800 hPa, and 24 levels are above 100 hPa.

Meteorological observations from various types of observing platform, assimilated in T254L64 global analysis scheme at NCMRWF are shown Table I.

Table I: Observations currently used in T254L64

Observation type	***Variables***
Radiosonde	U,v,T,q, P_s
Pibal winds	U,v
Wind profilers	U,v
Surface land observations	P_s
Surface ship and buoy observations	U,v,T,q, P_s
Conventional Aircraft observations (AIREP)	U,v,T
AMDAR Aircraft observations	U,v,T
ACARS Aircraft observations	U,v,T
GMS/MTSAT AMV (BUFR)	U,v,T
INSAT AMV (SATOB)	U,v,T
METEOSAT AMV (BUFR)	U,v,T
GOES (BUFR)	U,v,T
SSM/I	Surface wind speed
Scatterometer (QSCAT)	10m u, v
AMSU-A radiance	Bright. Temp.
AMSU-B radiance	Bright. Temp.
HIRS radiance	Bright. Tem
SBUV ozone	Total Ozone

The analysis procedure is performed as series of iterative problems. There are two main external iterations, which take care of the non-linearities in the objective function J (Eqn. 1). In this external iteration, some parts of the transformation of the analysis variables into the pseudo-observations are linearized around the current solution. In the first external iteration, the current solution is the 6- hour forecast (guess). In the later iterations, the current solution is the result from the previous external iteration.

Each external iteration comprise of several operations for generating the analysis. First, The difference between the current solution and the observations is found by interpolating the 3, 6 (or the current solution after the first external iteration) and 9 hour forecasts of the model variables to the observation time. The model variables are then transformed to the pseudo-observation variables. For satellite-measured radiances, the model predicted profile of temperature, moisture and ozone along with various surface quantities are transformed into pseudo-radiances. These pseudo-observations are then compared to the actual observations and an observational increment is created. The final analysis is generated by modifying the background with the help of observational increments.

The NOAA level 1b radiance data sets obtained from NESDIS/NOAA contain raw instrument counts, calibration coefficients and navigation parameters. The data is in a packed format and all the band data exists in a 10 bit format. The data product, in addition to video data, contains ancillary information like Earth Location Points (ELPs), solar zenith angle and calibration.. The raw counts in the level 1b files are transformed using the calibration coefficients in the data file to antenna temperatures and then to brightness temperatures (for AMSU-A data) using the algorithm of Mo (1999). The geometrical and channel brightness temperature data extracted from orbital data are then binned in 6 hour periods (+/-3hrs) of the analysis time for use in the assimilation system. The use of the level 1b data requires the application of quality control, bias correction, and the appropriate radiative transfer model (Derber & Wu, 1998; McNally et al., 1999). The radiative transfer model (CRTM) uses the OPTRAN transmittance model to calculate instrument radiances and brightness temperatures and their Jacobians.

4. Forecast Model

The forecast model is a primitive equation spectral global model with state of art dynamics and physics (Kanamitsu 1989, Kanamitsu et al. 1991, Kalnay et al. 1990). Model horizontal and vertical resolution & representation are same as described in analysis scheme. The main time integration is leapfrog for nonlinear advection terms. Semi-implicit method is used for gravity waves and for zonal advection of vorticity and moisture. An Asselin (1972) time filter is used to reduce computational modes. The model time step for T254 is 7.5 minutes for computation of dynamics and physics. The full calculation of longwave radiation is done once every 3 hours and shortwave radiation every hour (but with corrections made at every time step for diurnal variations in the shortwave fluxes and in the surface upward longwave flux). Mean orographic heights on the Gaussian grid are used. Negative atmospheric moisture values are not filled for moisture conservation, except for a temporary moisture filling that is applied in the radiation calculation. Various physical parameterization schemes used in the model are summarized briefly in Table II.

Table II: Physical Parameterization schemes in T254L64 & T80 Models

Physics	Scheme
Surface Fluxes	Monin-Obukhov similarity
Turbulent Diffusion	Non-local Closure scheme (Hong and Pan (1996))
SW Radiation	Based on Hou et al. 2002 –invoked hourly
LW Radiation	Rapid Radiative Transfer Model (RRTM) (Mlawer et al. 1997). – invoked 3 hourly
Deep Convection	SAS convection (Pan and Wu (1994))
Shallow Convection	Shallow convection Following Tiedtke (1983)
Large Scale Condensation	Large Scale Precipitation based on Zhao and Carr (1997)
Cloud Generation	Based on Xu and Randall (1996)
Rainfall Evaporation	Kessler's scheme
Land Surface Processes	NOAH LSM with 4 soil levels for temperature & moisture Soil soisture values are updated every model time step in response to forecasted land-surface forcing (precipitation, surface solar radiation, and near-surface parameters: temperature, humidity, and wind speed).
Air-Sea Interaction	Roughness length determined from the surface wind stress (Charnock (1955)) Observed SST, Thermal roughness over the ocean is based on a formulation derived from TOGA COARE (Zeng et al., 1998).
Gravity Wave Drag	Based on Alpert et al. (1988)

5. Computational Performance

One cycle of analysis (SSI) takes about 70 minutes of computing time in 112 SSPs (Single-Streaming Processor) on Cray X1E compared to 10 minutes for T80L18 SSI on Cray-SV1. The forecast model takes about 100 minutes of computation time in 28 MSPs (Multi-Streaming Processors) of Cray X1E for a 168-hr model forecast compared to 30 minutes for T80L18 model on Cray-SV1.   Due to this large computational time required for T256L64, analysis-forecast system runs 4 times a day for four assimilation cycle (i.e. 0000, 0600,1200,1800 UTC) with a strict data-cut off of 6 hours.

References

Alpert, J.C., S-Y Hong and Y-J Kim, 1996: Sensitivity of cyclogenesis to lower troposphere enhancement of gravity wave drag using the Environmental Modeling Center medium range model. *Proc. 11th Conference. on NWP, Norfolk, 322-323.*

Asselin, R., 1972: Frequency filter for time integrations. *Mon. Wea. Rev., 100*, 487-490.

Charnock, H., 1955: Wind stress on a water surface. *Quart. J. Roy. Meteor. Soc., 81*, 639-640.

Derber, J. C. and W.-S. Wu, 1998: The use of TOVS cloud-cleared radiances in the NCEP SSI analysis system. Mon. Wea. Rev., 126, 2287 - 2299

Derber, J. C., D.F. Parrish and S. J. Lord, 1991: The new global operational analysis system at the National Meteorological Center. *Weather and Forecasting, 6*, 538-547.

Hong, S.-Y. and H.-L. Pan, 1996: Nonlocal boundary layer vertical diffusion in a medium-range forecast model. *Mon. Wea. Rev., 124,* 2322-2339.

Hou, Y-T, K. A. Campana and S-K Yang, 1996: Shortwave radiation calculations in the NCEP's global model. *International Radiation Symposium, IRS-96, August 19-24, Fairbanks, AL.*

Kalnay, M. Kanamitsu, and W.E. Baker, 1990: Global numerical weather prediction at the National Meteorological Center. *Bull. Amer. Meteor. Soc., 71*, 1410-1428.

Kanamitsu, M., 1989: Description of the NMC global data assimilation and forecast system. *Weather and Forecasting, 4,* 335-342.

Kanamitsu, M., J.C. Alpert, K.A. Campana, P.M. Caplan, D.G. Deaven, M. Iredell, B. Katz, H.-L. Pan, J. Sela, and G.H. White, 1991: Recent changes implemented into the global forecast system at NMC. *Weather and Forecasting, 6,* 425-435.

McNally, A. P., J. C. Derber, W.-S. Wu and B.B. Katz, 2000: The use of TOVS level-1 radiances in the NCEP SSI analysis system. *Quart.J.Roy. Metorol. Soc.* , 129**,** 689-724

Mlawer, E.J., S.J. Taubman, P.D. Brown, M.J. Iacono, and S.A. Clough, 1997: Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave. *J. Geophys. Res., 102,* 16663-16682.

NCMRWF, Ministry of Earth Sciences (MoES), Government of India (January 2008): Monsoon-2007:Performance of the NCMRWF Global Assimilation Forecast System , Report No. NMRF/MR/01/2008, 143 pages, Published by NCMRWF (MoES), A-50, Sector-62, NOIDA, UP, INDIA 201307.

Parrish, D.E. and J.C. Derber, 1992. The National Meteorological Center's spectral statistical-interpolation analysis system. Mon. Wea. Rev., 120, 1747-1763.

Pan, H.-L. and W.-S. Wu, 1995: Implementing a Mass Flux Convection Parameterization Package for the NMC Medium-Range Forecast Model. *NMC Office Note, No. 409*, 40 pp.

Rajagopal, E.N., M. Das Gupta, Saji Mohandas, V.S. Prasad, John P. George, G.R. Iyengar and D. Preveen Kumar, 2007: Implementation of T254L64 Global Forecast System at NCMRWF, *NMRF/TR/1/2007,* 42 pp.

Tiedtke, M., 1983: The sensitivity of the time-mean large-scale flow to cumulus convection in the ECMWF model. *ECMWF Workshop on Convection in Large-Scale Models, 28 November-1 December 1983, Reading, England*, pp. 297-316.

Xu, K. M., and D. A. Randall, 1996: A semiempirical cloudiness parameterization for use in climate models. *J. Atmos. Sci., 53*, 3084-3102.

Zeng, X., M. Zhao, and R.E. Dickinson, 1998: Intercomparison of bulk aerodynamical algorithms for the computation of sea surface fluxes using TOGA COARE and TAO data. *J. Climate, 11,* 2628-2644.

Zhao, Q. Y., and F. H. Carr, 1997: A prognostic cloud scheme for operational NWP models. *Mon. Wea. Rev., 125,* 1931-1953.

Mean Circulation Characteristics of the Summer Monsoon

G. R. Iyengar

1 Introduction

The Indian summer monsoon circulation has some characteristic features like the cross-equatorial flow and the low level westerly jet over the Arabian Sea, anti-cyclone over the Tibet and the tropical easterly jet to its south. These features are connected in the vertical by a Hadley type direct circulation (known as the reverse Hadley cell) with the upward limb over the monsoon trough region and the downward limb over the Indian ocean region.

In this chapter, mean circulation characteristics of the summer monsoon- and their anomalies are examined. The anomalies are calculated from the archived mean analysis fields of NCMRWF (1994-2003).

2. Wind Fields

The geographical distribution of the mean NCMRWF (T254) wind field for the months of June, July, August and September at 850, 700, 500 and 200hPa and their monthly anomalies are shown in Fig. 1(a-b) to Fig. 16(a-b) respectively. The anomalous features identified from the mean circulation of each month of monsoon- 2008 are listed below.

2.1 June

At 850hPa level, an anomalous a cyclonic circulation was seen over the northern Arabian Sea and adjoining parts of Gujarat. This anomalous cyclonic circulation was also observed at 700 hPa level. Anomalous easterlies were observed over the northern plains of India at 850 and 700 hPa levels. At 500 hPa level an anomalous east west cyclonivc circulation is seen over the eastern and central parts of India. These features resulted in a stronger than normal monsoon trough. The central and northern parts of India received more than normal rainfall. At 200 hPa level, the Tibetan anti-cyclone was stronger than normal.

2.2 July

In the lower tropospheric levels (850 and 700hPa) an anomalous anti-cyclonic circulation was seen over the southern peninsula and adjoining areas, resulting in a weakening of the low-level westerly flow. The observed rainfall was deficient over the west coast and central parts of India. Westerly anomalies were seen over the plains of India in the lower tropospheric levels. At 200hPa level there was the tropical easterly jet was weaker than the normal.

2.3 August

In the lower tropospheric levels (850 and 700hPa) anomalous anti-cyclonic circulations were seen over the central Arabian Sea and the central Bay of Bengal. Anomalous easterlies were seen over the northern parts of peninsular India in the lower tropospheric levels. The observed rainfall was in excess over most parts of peninsular India.

2.4 September

In the lower tropospheric levels (850 and 700hPa) anomalous cyclonic circulation was seen over the western parts of India and adjoining areas. An anomalous cyclonic circulation was seen over the eastern parts of India. The observed rainfall was in excess over Gujarat and adjoining areas, the west coast and Orissa. An anomalous anti-cyclonic circulation was seen over the southern Bay of Bengal in the lower tropospheric levels.

Legends for figures:

Figure 1: Geographical distribution of mean wind field (a) and anomaly (b) at 850hPa; for June 2008. Anomalies are departures from the 1994-2003 base period. [Units: m/s, Contour interval: 5m/s for analyses and 3m/s for anomalies]

Figure 2: Same as in Figure 1, but for 700hPa.

Figure 3: Same as in Figure 1, but for 500hPa.

Figure 4: Same as in Figure 1, but for 200hPa. [Units: m/s, Contour interval: 10m/s for analyses and 5m/s for anomalies]

Figure 5: Same as in Figure 1, but for July 2008.

Figure 6: Same as in Figure 2, but for July 2008.

Figure 7: Same as in Figure 3, but for July 2008.

Figure 8: Same as in Figure 4, but for July 2008.

Figure 9: Same as in Figure 1, but for August 2008.

Figure 10: Same as in Figure 2, but for August 2008.

Figure 11: Same as in Figure 3, but for August 2008.

Figure 12: Same as in Figure 4, but for August 2008.

Figure 13: Same as in Figure 1, but for September 2008.

Figure 14: Same as in Figure 2, but for September 2008.

Figure 15: Same as in Figure 3, but for September 2008.

Figure 16: Same as in Figure 4, but for September 2008.

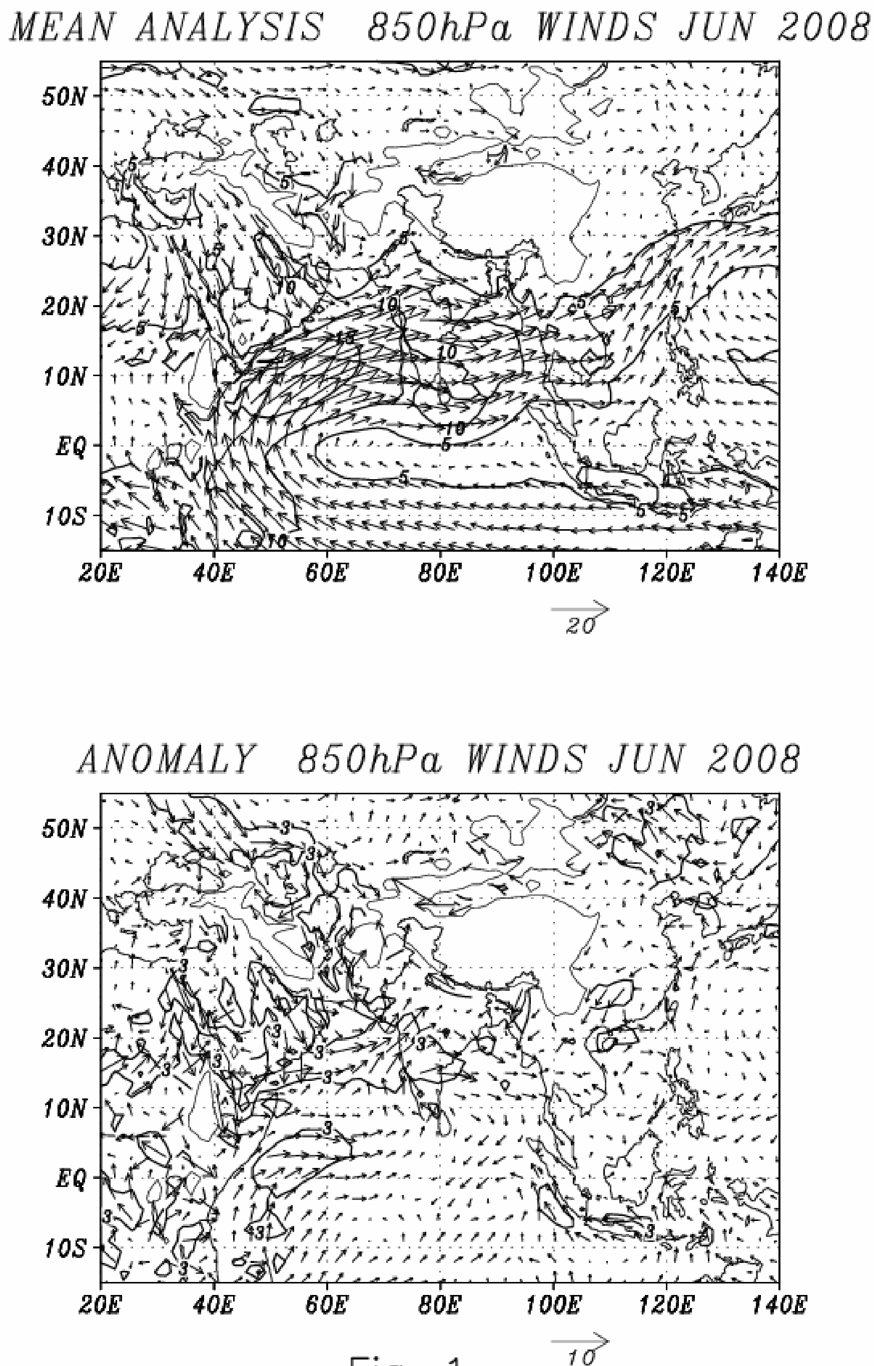
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Fig. 1

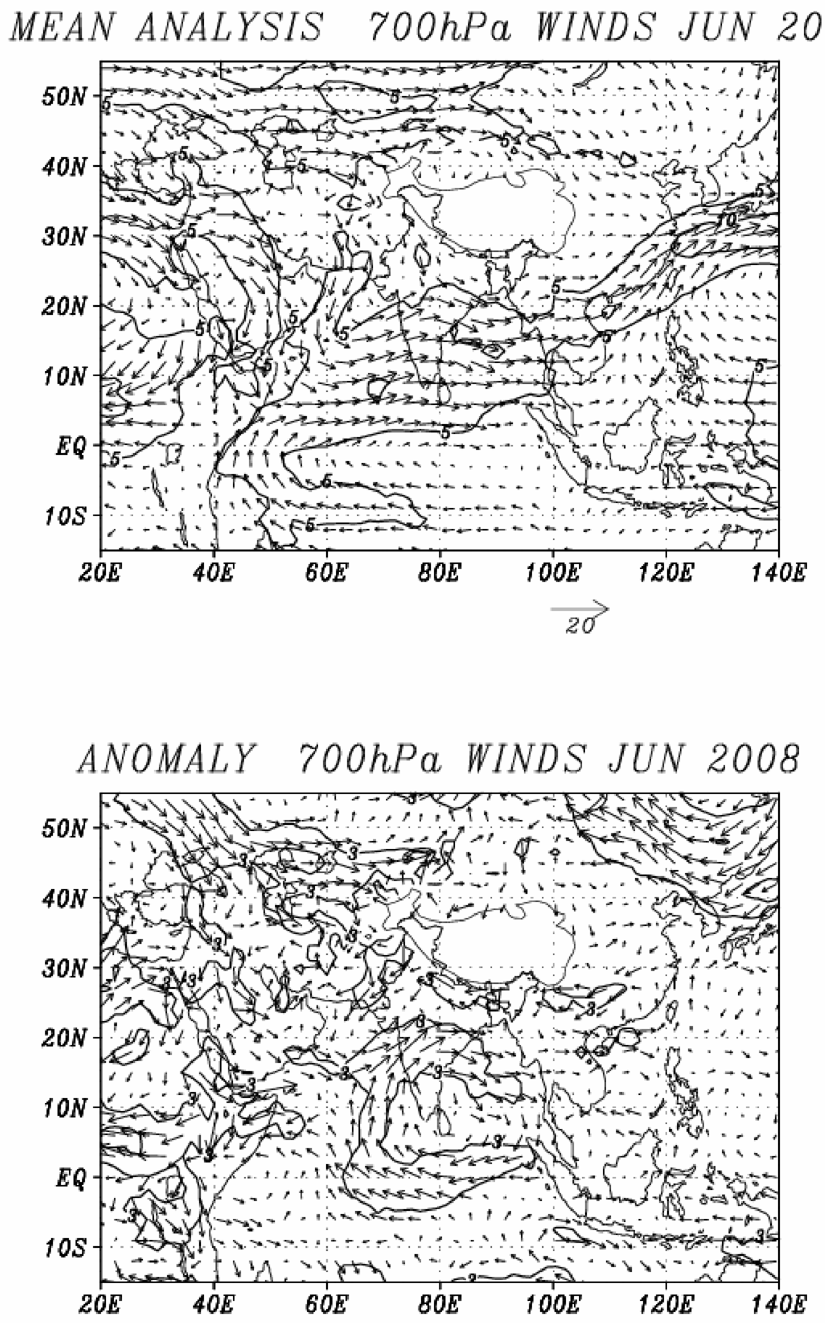
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Fig. 2

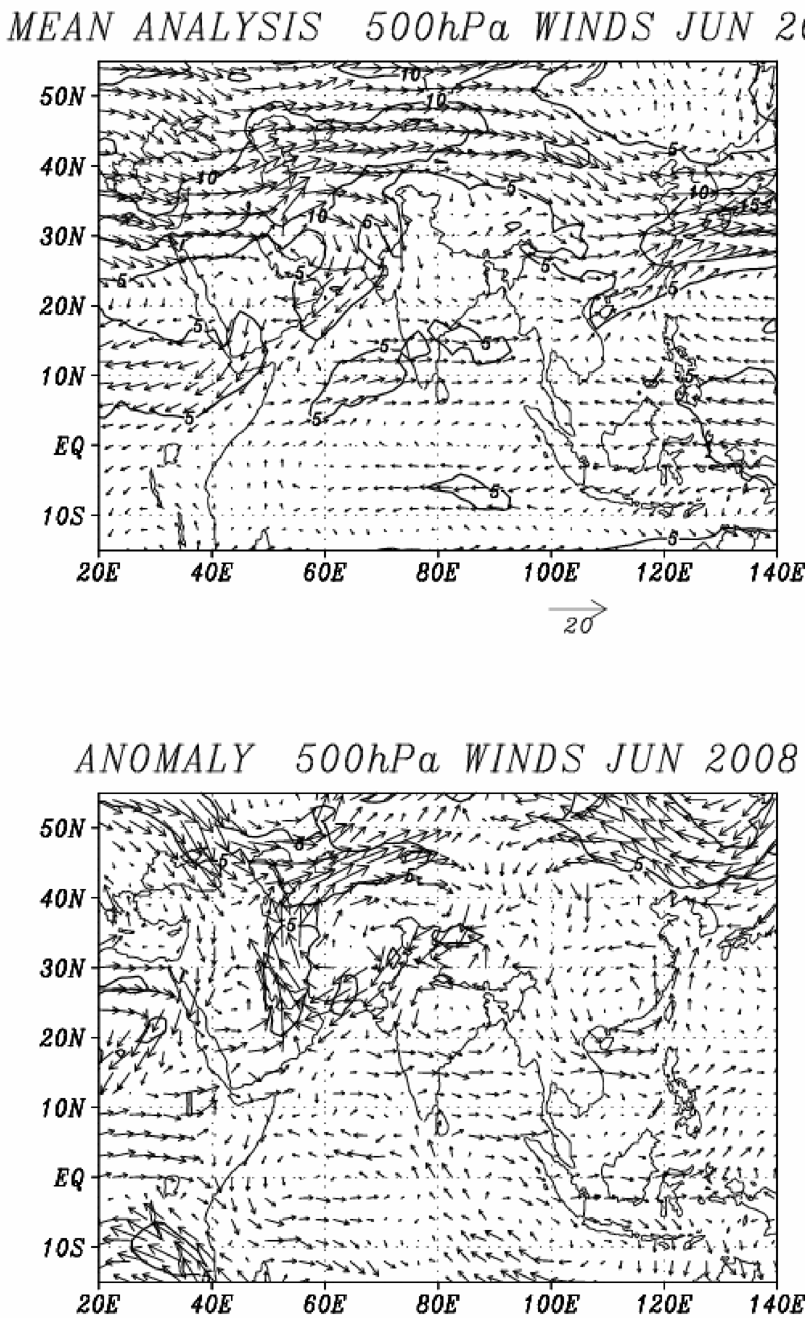
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Fig. 3

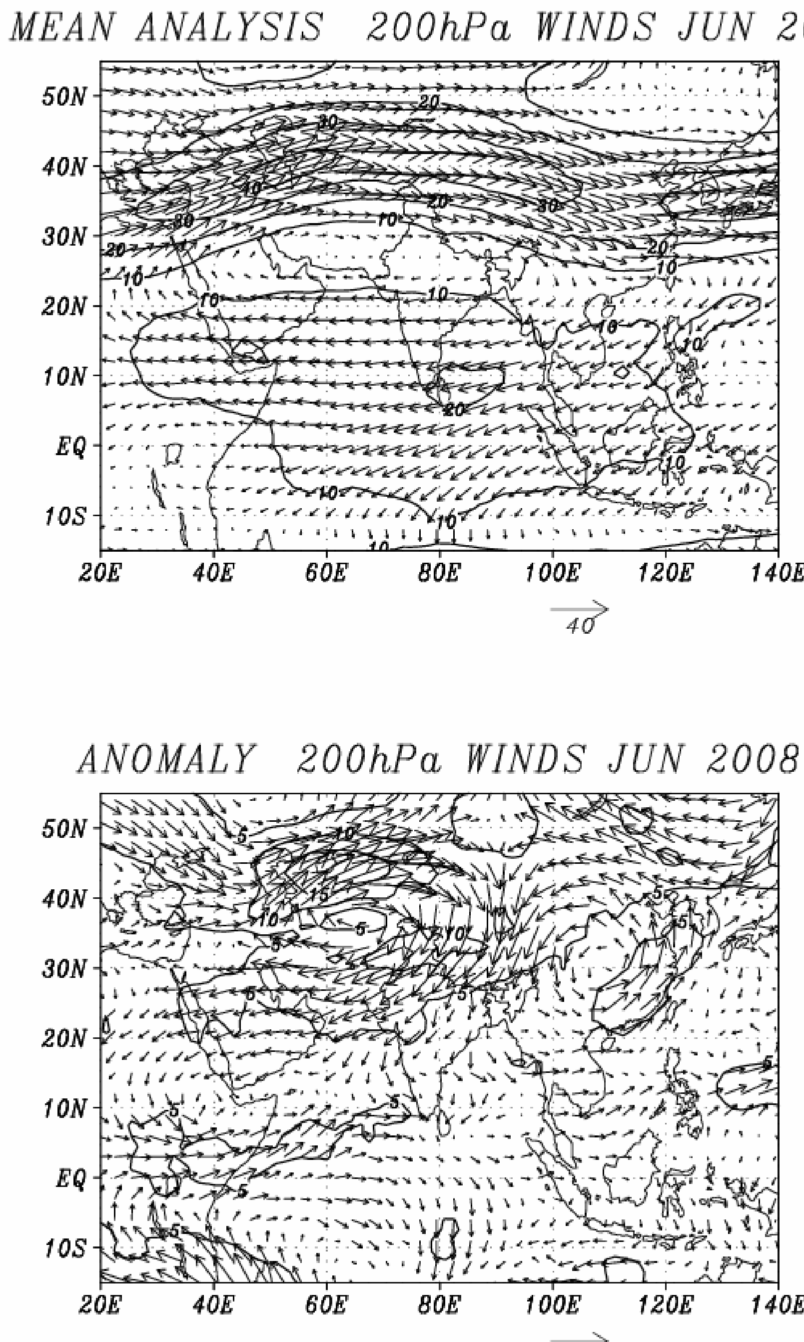
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Fig. 4

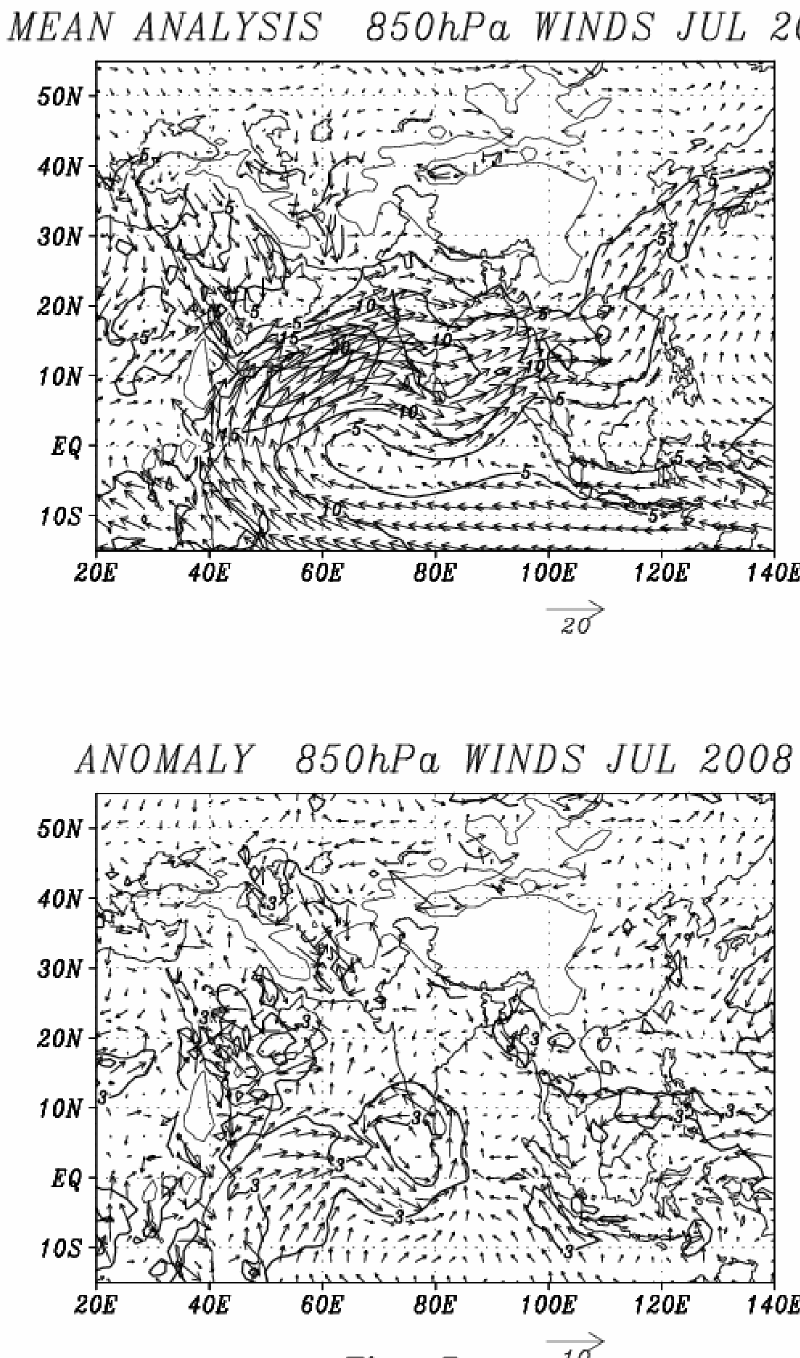
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Fig. 5

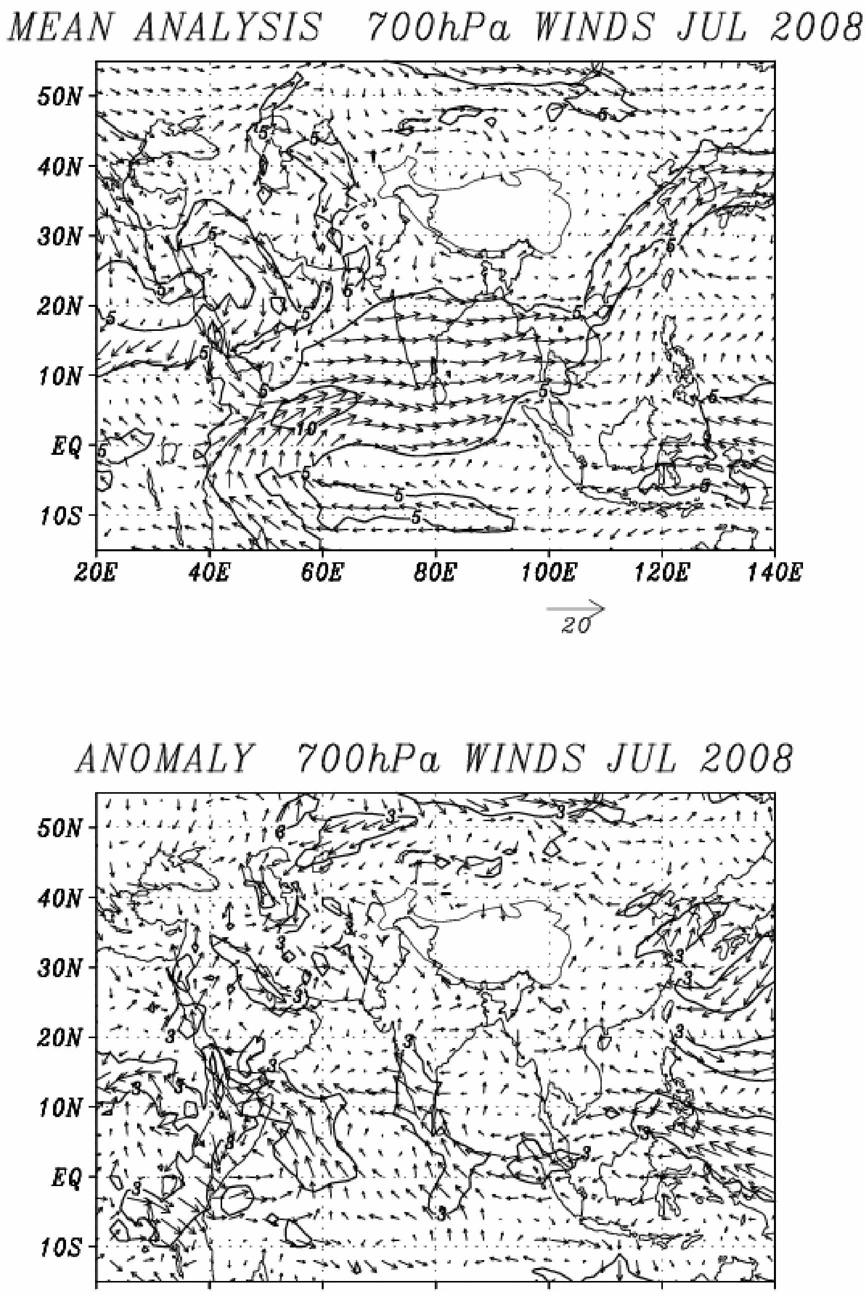

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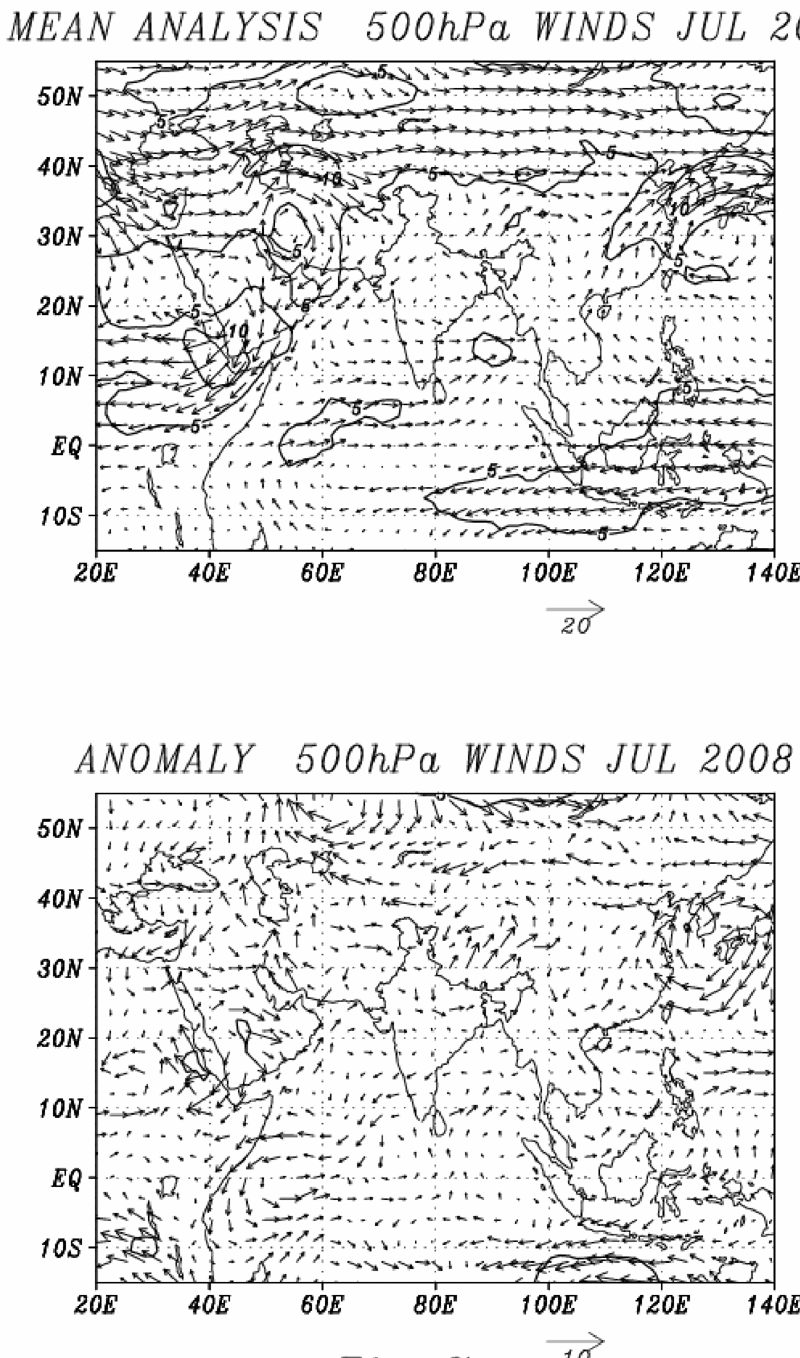
Fig. 6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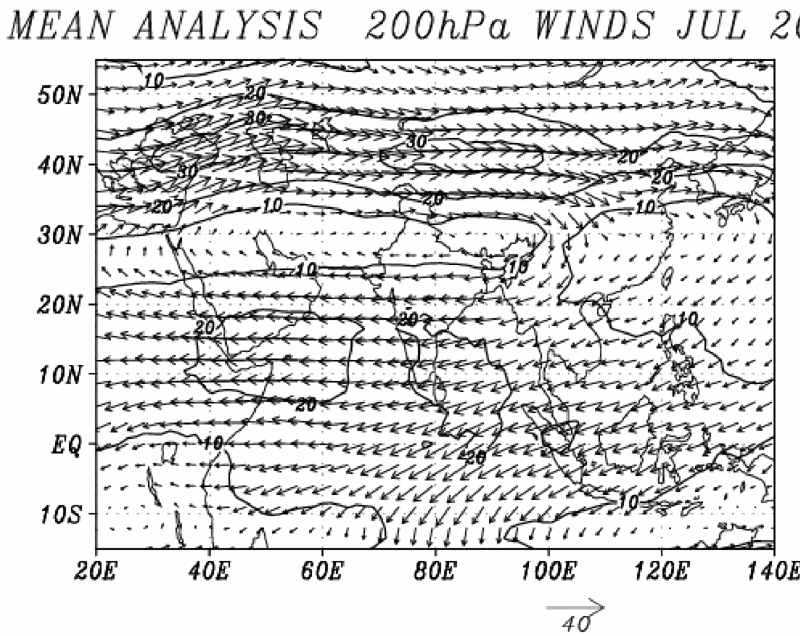
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
20
ANOMALY 500hPa WINDS JUL 2008
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
10

Fig. 7


MEAN ANALYSIS 200hPa WINDS JUL 2008
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
40

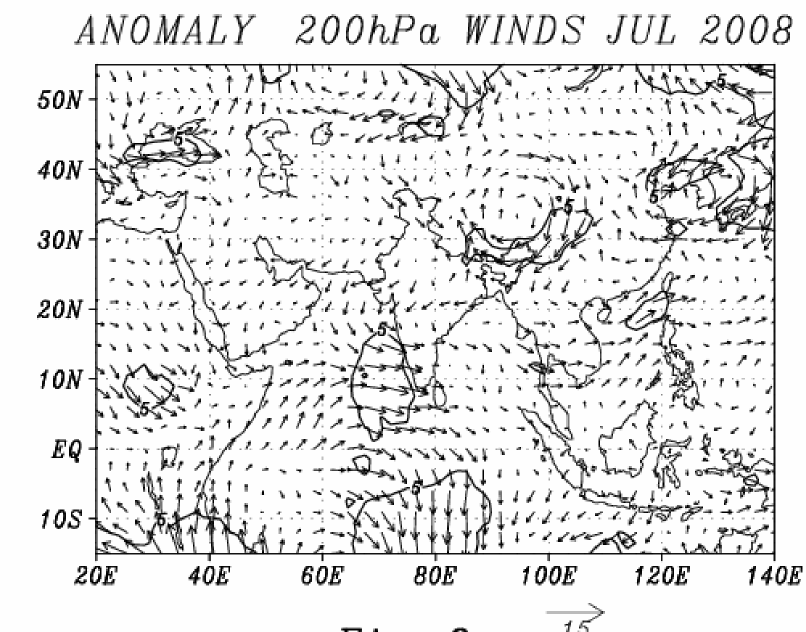
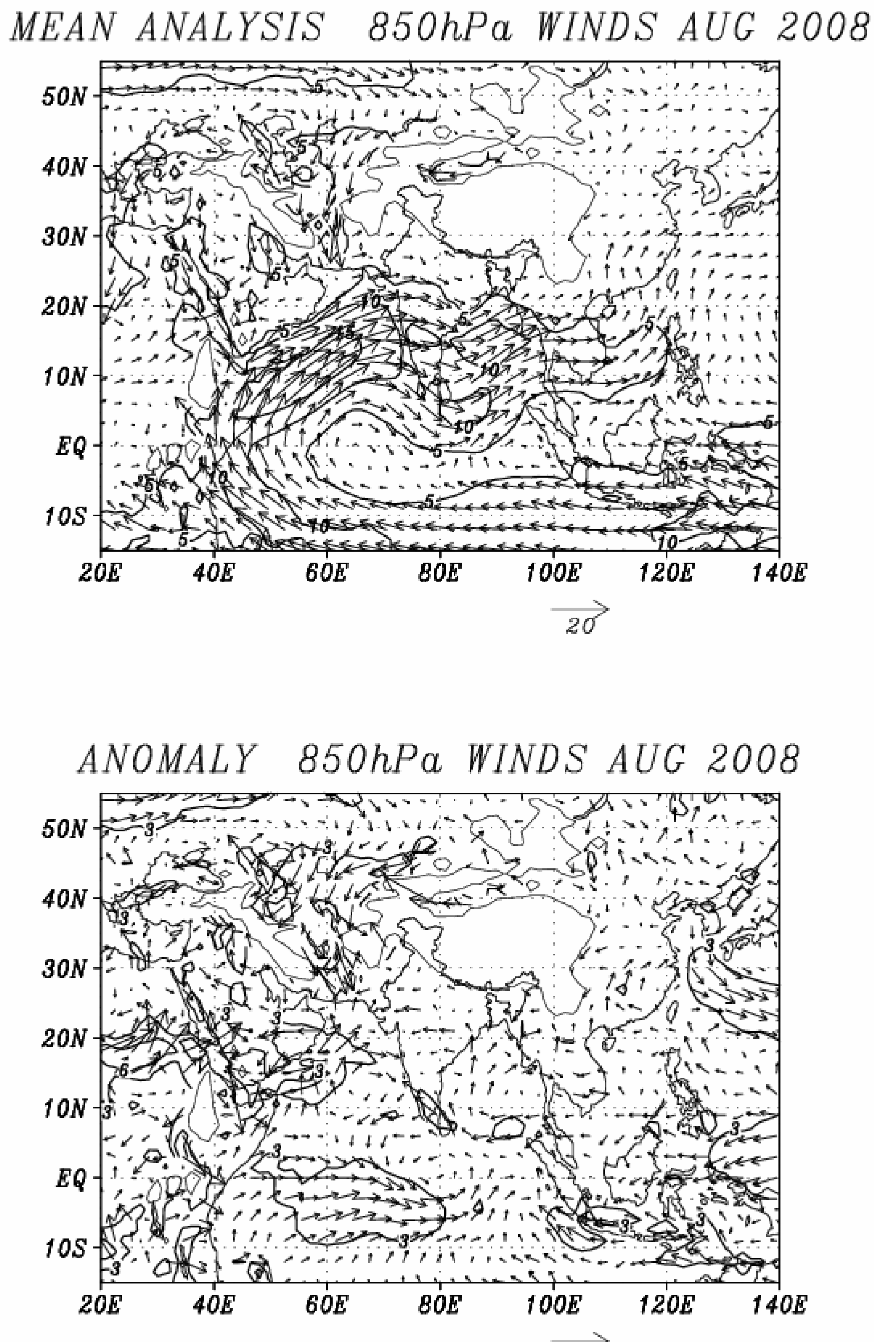

ANOMALY 200hPa WINDS JUL 2008
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
15

Fig. 8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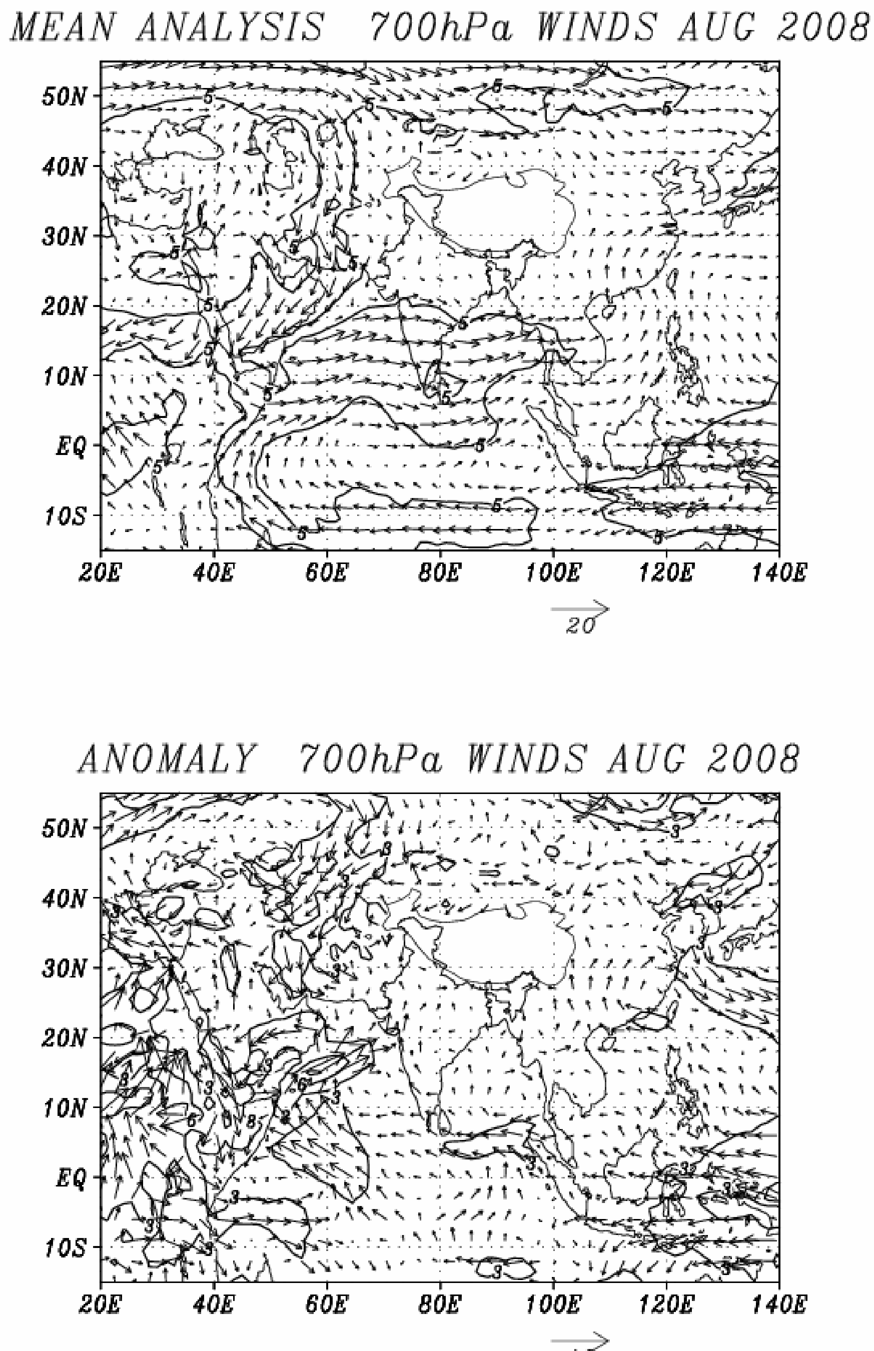
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
20
ANOMALY 850hPa WINDS AUG 2008
10

Fig. 9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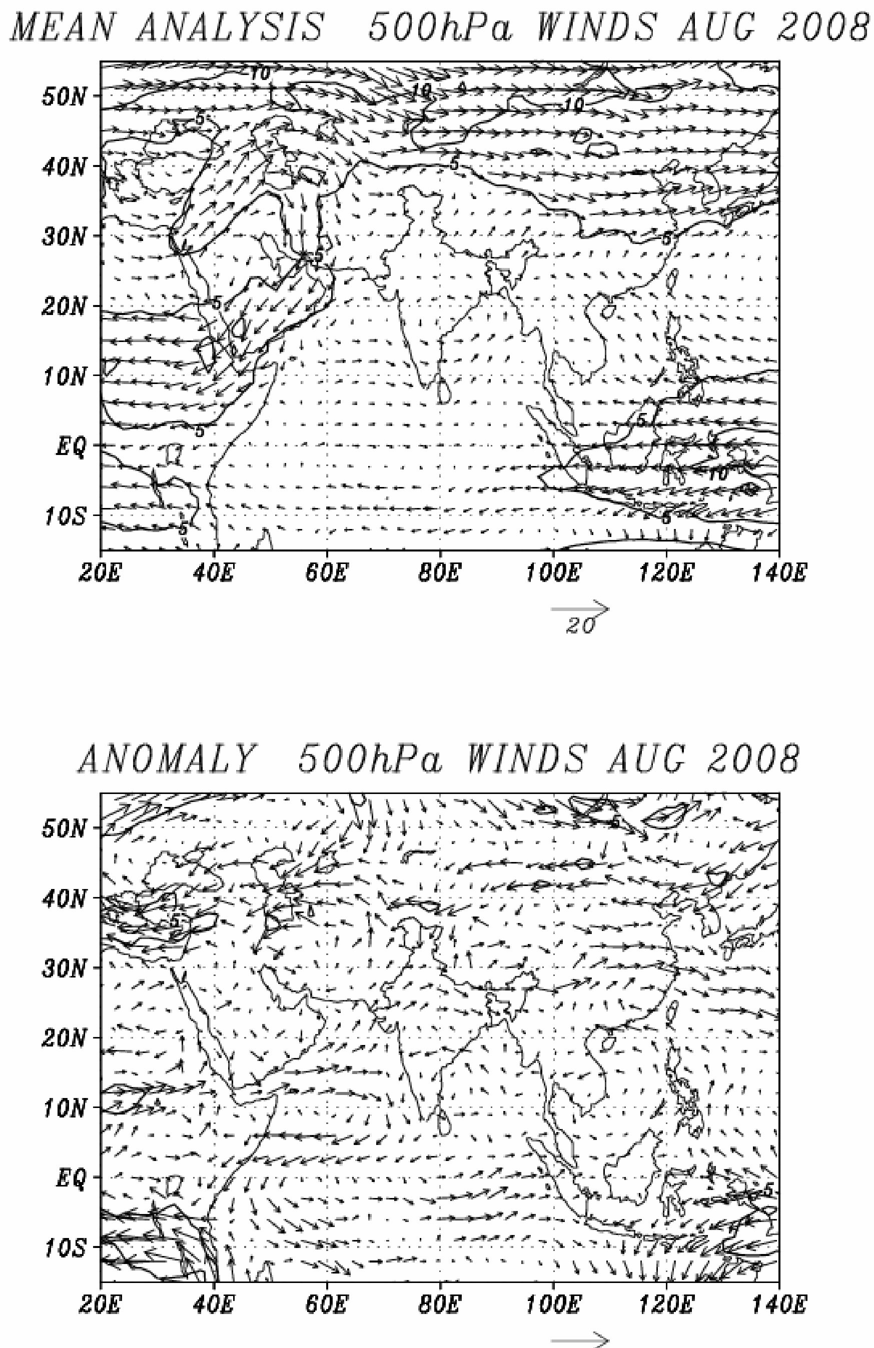
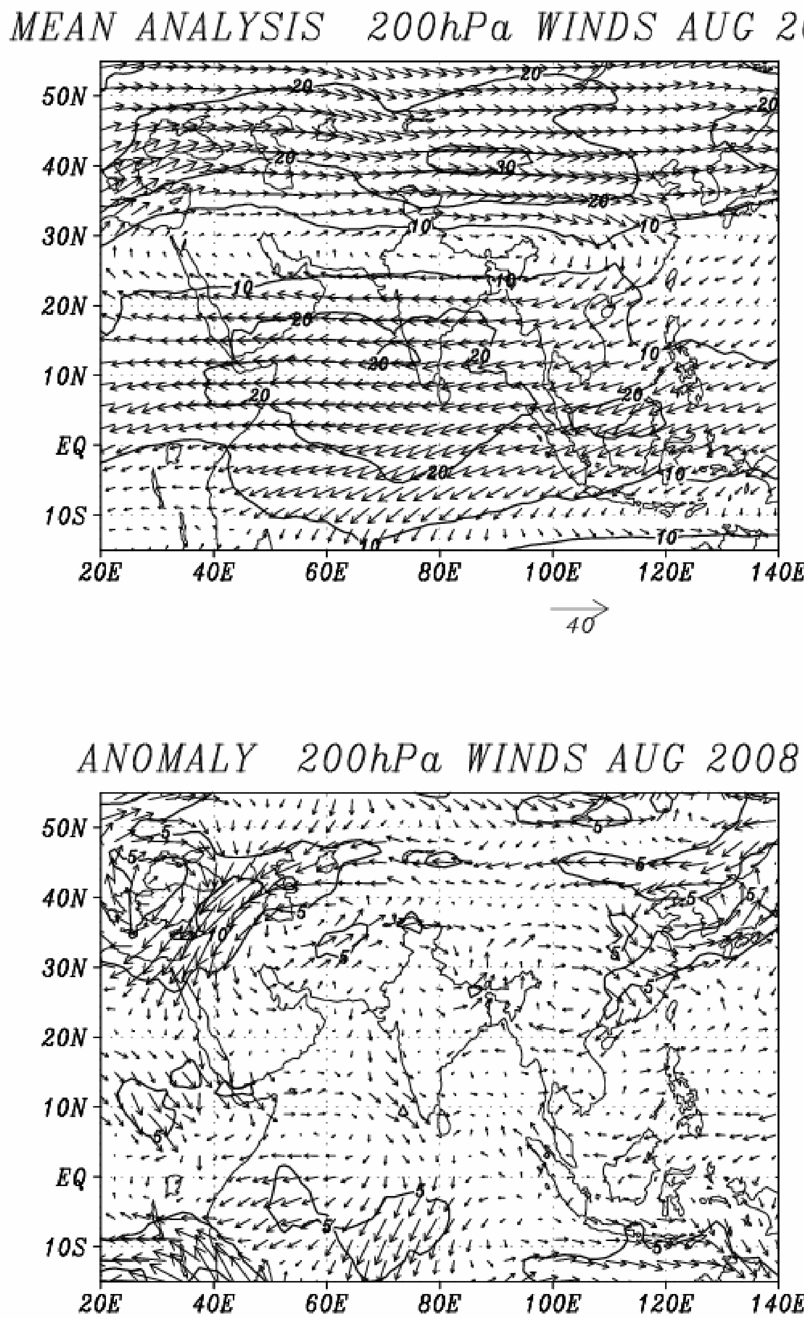
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
20
ANOMALY 700hPa WINDS AUG 2008
10

Fig. 10



MEAN ANALYSIS 500hPa WINDS AUG 2008
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
20
ANOMALY 500hPa WINDS AUG 2008
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
10

Fig. 11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50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
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120E
140E
40
ANOMALY 200hPa WINDS AUG 2008
50N
40N
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20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
15

Fig. 12

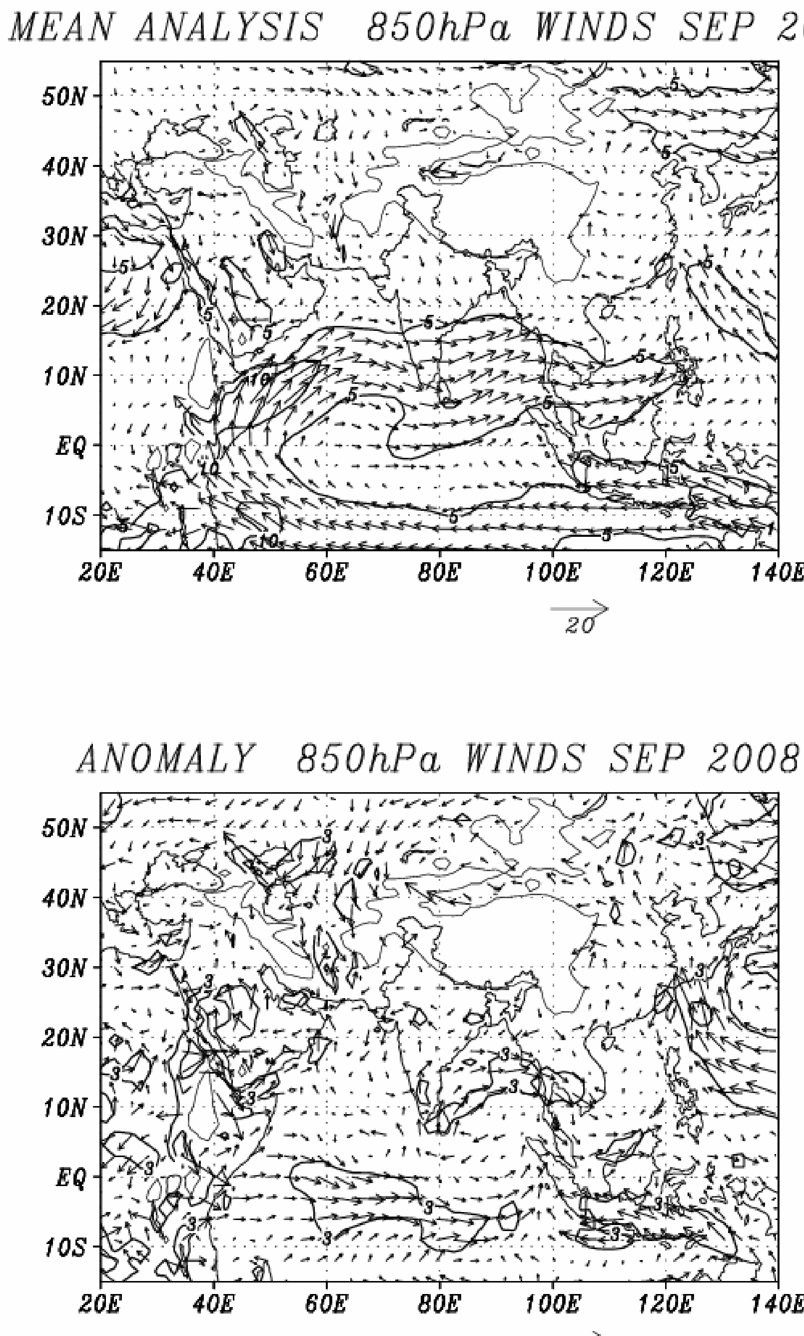
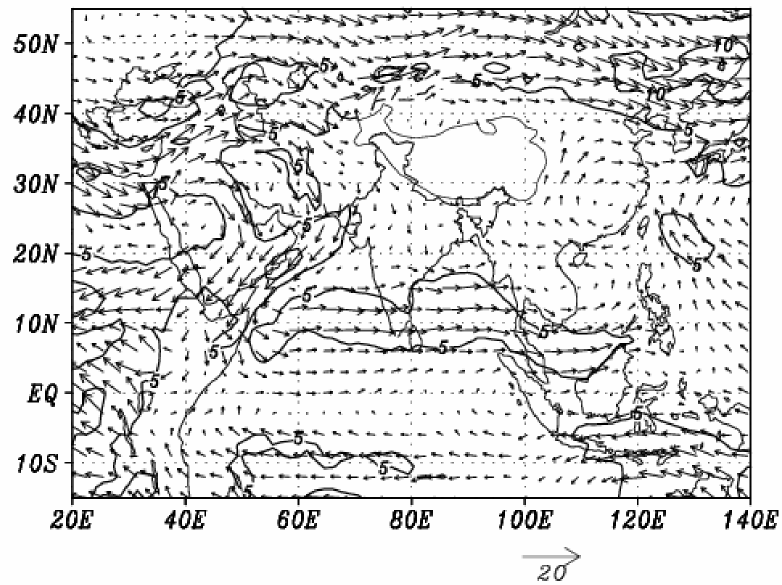

MEAN ANALYSIS 850hPa WINDS SEP 2008
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
20
ANOMALY 850hPa WINDS SEP 2008
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
10

Fig. 13

MEAN ANALYSIS 700hPa WINDS SEP 2008



ANOMALY 700hPa WINDS SEP 2008

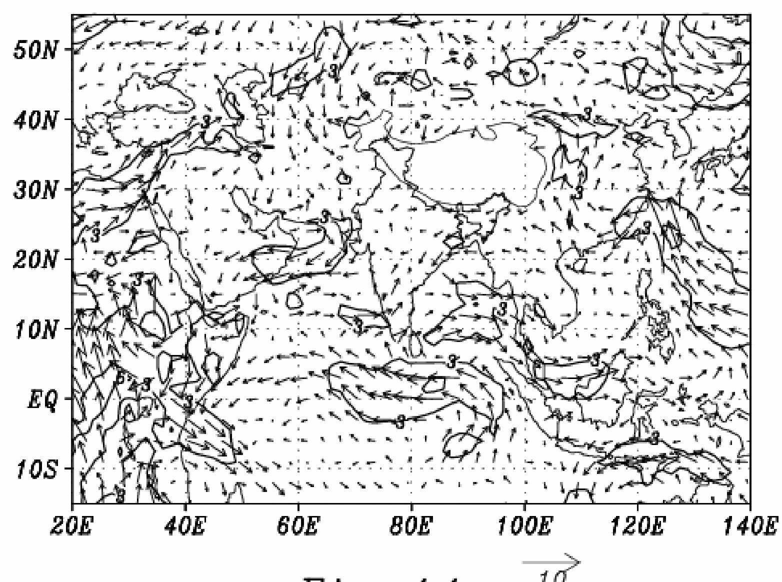
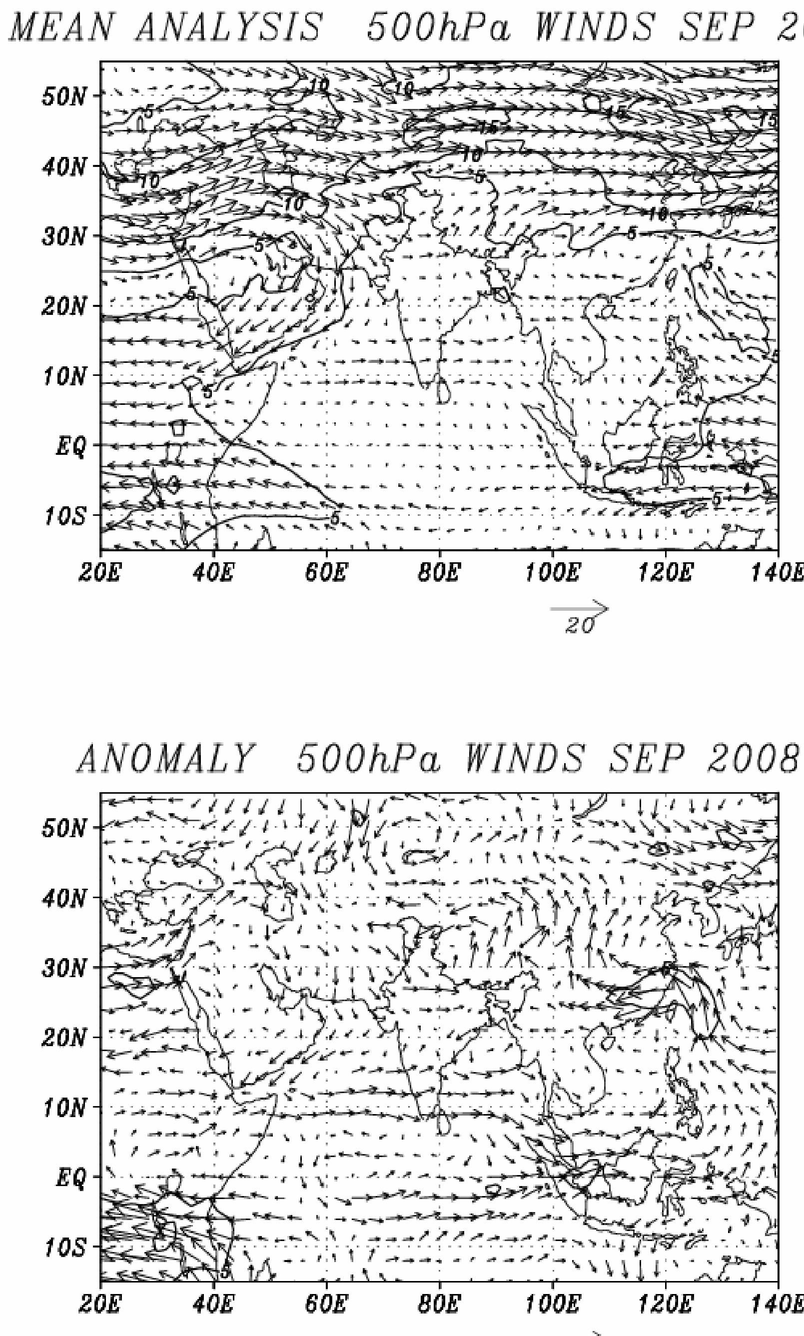


Fig. 14


MEAN ANALYSIS 500hPa WINDS SEP 2008
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
20
ANOMALY 500hPa WINDS SEP 2008
50N
40N
30N
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10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
10

Fig. 15

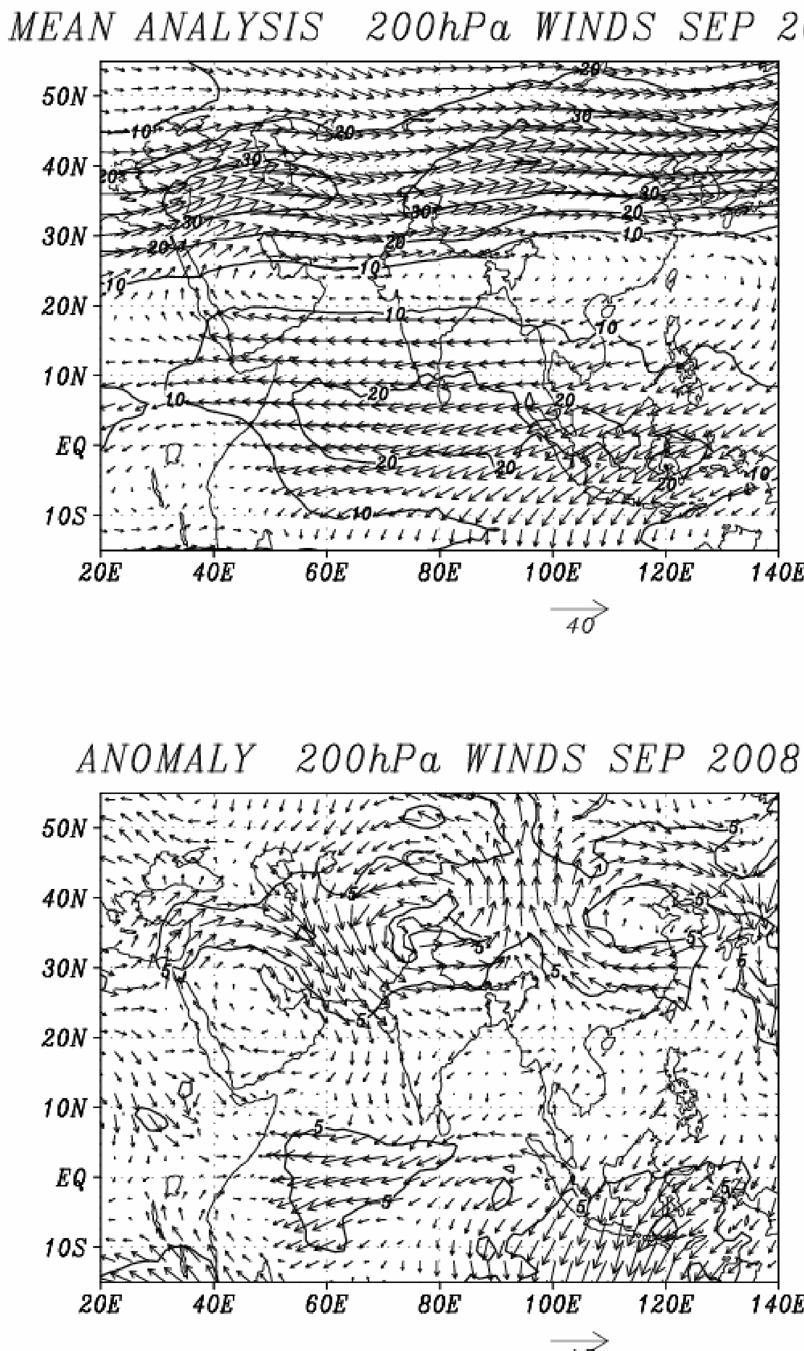

MEAN ANALYSIS 200hPa WINDS SEP 2008
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
40
ANOMALY 200hPa WINDS SEP 2008
50N
40N
30N
20N
10N
EQ
10S
20E
40E
60E
80E
100E
120E
140E
15

Fig. 16

Systematic Errors in the Medium Range Prediction of the Summer Monsoon

G. R. Iyengar

1 Introduction

Model forecast errors are a combination of systematic (time mean) errors and the random errors. The systematic errors are largely due to the deficiencies in the model formulation. The diagnosis of model systematic errors, play an important role in identifying the model deficiencies and improving the skill of model forecasts. The nature and distribution of systematic errors seen in the NCMRWF global T254 model forecasts are discussed in this chapter using the seasonal (June-September) means of analyses and medium range (Day-1 through Day-5) forecasts.

2 Circulation Features:

Geographical distribution of the mean analysed wind field and the systematic forecast errors for the T254 model at 850hPa, 700hPa, 500hPa and 200hPa are shown in figures 1(a-d) - 4(a-d) respectively. The notable features seen in the systematic errors of the 850hPa flow pattern are the anomalous easterlies over eastern & central parts of India. This feature is also seen at 700 and 500hPa levels. An anomalous cyclonic circulation is also seen over the north-west parts of India and adjoining Pakistan at 850hPa level.. The incursion of dry air could be reason for the scanty rainfall observed in the model forecasts over the northwest parts of India. The low level jet strength seen in the mean analysis is maintained throughout the forecast period. At 200hPa, the most significant feature in the systematic errors is the weakening of the Tropical Easterly Jet.

The strong cross-equatorial low level jet stream with its core around 850 hPa is found to have large intraseasonal variability. Figure 5 shows the Hovmoller diagram of zonal wind (*U*) of 850 hPa averaged over the longitude band 60–70E and smoothed by a 5-day moving average for the period 1 June–30 September 2008. The top panel shows the analysis and the middle and the lower panel depict the day-3 and day-5 forecasts respectively. The active monsoon spells are characterized by strong cores of zonal wind.

The monsoon set in over Kerala on 31 May, one day ahead of its normal date. The monsoon advanced over most parts of India by 16^{th} June. As seen from the analysis panel the zonal wind flow was quite weak in the second fortnight of June. The low level westerly flow picked up strength again in the first week of July. The monsoon covered the entire country by 10^{th} of July. Another spell of strong core of zonal wind of about 20 ms^{-1} was seen in the first fortnight of August. This was followed by a spell of weak core of zonal wind for a period of two weeks. The last of a relatively strong core of zonal wind of about 15 ms^{-1} is seen in the analyses in the third week of September.. The day-3 and day-5 forecasts agree reasonably well with the analyses and are able to depict the active and weak spells of the monsoon flow. Figure 6 shows the Hovmoller diagram of zonal wind (*U*) of 850 hPa averaged over the longitude band 75–80E and smoothed by a 5-day moving average for the period 1 June–30 September 2008. The top panel shows the analyses and the middle and the lower panel depict the day-3 and day-5 forecasts respectively. The analyses show the northward movement of the core of zonal wind during the third week of June to second week of July. Two other such spells are seen from the third week of July and second week of September respectively. The day-3 forecasts compare well with the analyses and are able to depict the northward movement of the core of zonal wind.

3 Temperature:

Geographical distribution of the mean systematic forecast temperature errors for the T254 model at 850hPa and 200hPa level are shown in figures 7(a-d) and 8(a-d) respectively. The T254 model forecasts also show a warm bias in the lower troposphere over the continents in general, and a cold bias over the oceans. Over the north-west parts of India, at 850hPa level a warm bias is seen which is associated with the cyclonic wind errors described in the earlier section. In the upper troposphere, the T254 model also shows a cold bias over the northern parts of India and a warm bias over the central & peninsular India.

4 Verification of wind and temperature forecasts:

Objective verification scores against the analysis and observations are computed every day valid for 00UTC at standard pressure levels for different areas as recommended by the WMO. Monthly averages are then computed form the daily values of all forecasts verifying within the relevant month.

Figure 9 shows the rmse of winds for the NCMRWF operational model day 03 forecasts against the radiosonde observations over the Indian region since January 1999.The errors of the T254 model during monsoon 2008 were less as compared to monsoon 2007.

Figures10 (a-d) and 11 (a-d) show the rmse of winds for the T254, NCEP, UKMO and ECMWF model forecasts against the radiosonde observations over the Asian region (25º - 65º N & 60º -145º E) for June, July, August and September 2008 at 850 & 200hPa levels respectively. . These figures show that ECMWF model forecasts have the least rmse among the four models.

Legends for figures:

Figure 1. Mean T254 analysed wind field (a) and systematic forecast errors for Day-1 (b), Day-3 (c) and Day-5 (d) at 850 hPa. [Units: m/s, Contour interval: 5m/s for analyses and 2m/s for forecast errors]

Figure 2. Mean T254 analysed wind field (a) and systematic forecast errors for Day-1 (b), Day-3 (c) and Day-5 (d) at 700 hPa. . [Units: m/s, Contour interval: 10m/s for analyses and 5m/s for forecast errors]

Figure 3. Mean T254 analysed wind field (a) and systematic forecast errors for Day-1 (b), Day-3 (c) and Day-5 (d) at 500 hPa. [Units: m/s, Contour interval: 5m/s for analyses and 2m/s for forecast errors]

Figure 4. Mean T254 analysed wind field (a) and systematic forecast errors for Day-1 (b), Day-3 (c) and Day-5 (d) at 200 hPa. . [Units: m/s, Contour interval: 10m/s for analyses and 5m/s for forecast errors]

Figure 5. Hovmoller diagram of zonal wind (*U*) of 850 hPa averaged over the longitude band 60–70E and smoothed by a 5-day moving average for the period 1 June–30 September 2008.

Figure 6. Hovmoller diagram of zonal wind (*U*) of 850 hPa averaged over the longitude band 75–80E and smoothed by a 5-day moving average for the period 1 June–30 September 2008.

Figure 7. Mean T254 analysed temperature field (a) and systematic forecast errors for Day-1 (b), Day-3(c) and Day-5 (d) of temperature at 850 hPa.: [Units: K, Contour interval: 2 K for analyses and 1 K for forecast errors]

Figure 8. Mean T254 analysed temperature field (a) and systematic forecast errors for Day-1 (b), Day-3(c) and Day-5 (d) of temperature at 200 hPa.: [Units: K, Contour interval: 2 K for analyses and 1 K for forecast errors]

Figure 9. Mean T254 analysed specific humiduty field (a) and systematic forecast errors for Day-1 (b), Day-3(c) and Day-5 (d) of specific humidity at 850 hPa.: [Units: gm/kg, Contour interval: 2 for analyses and 1 for forecast errors]

Figure 10. RMSE of wind (m/s) against the radiosonde observations for the NCMRWF operational model forecasts at 850hPa level over the India region The blue line corresponds to T80L18 model and the red line corresponds to the T254L64 model.

Figure 11. RMSE of wind (m/s) against the radiosonde observations for the T254 , UKMO, NCEP and ECMWF model forecasts at 850hPa level over the Asian region for June(a), July(b), August(c) and September(d)

Figure 12. RMSE of wind (m/s) against the radiosonde observations for the T254 , UKMO, NCEP and ECMWF model forecasts at 200hPa level over the Asian region for June(a), July(b), August(c) and September(d)

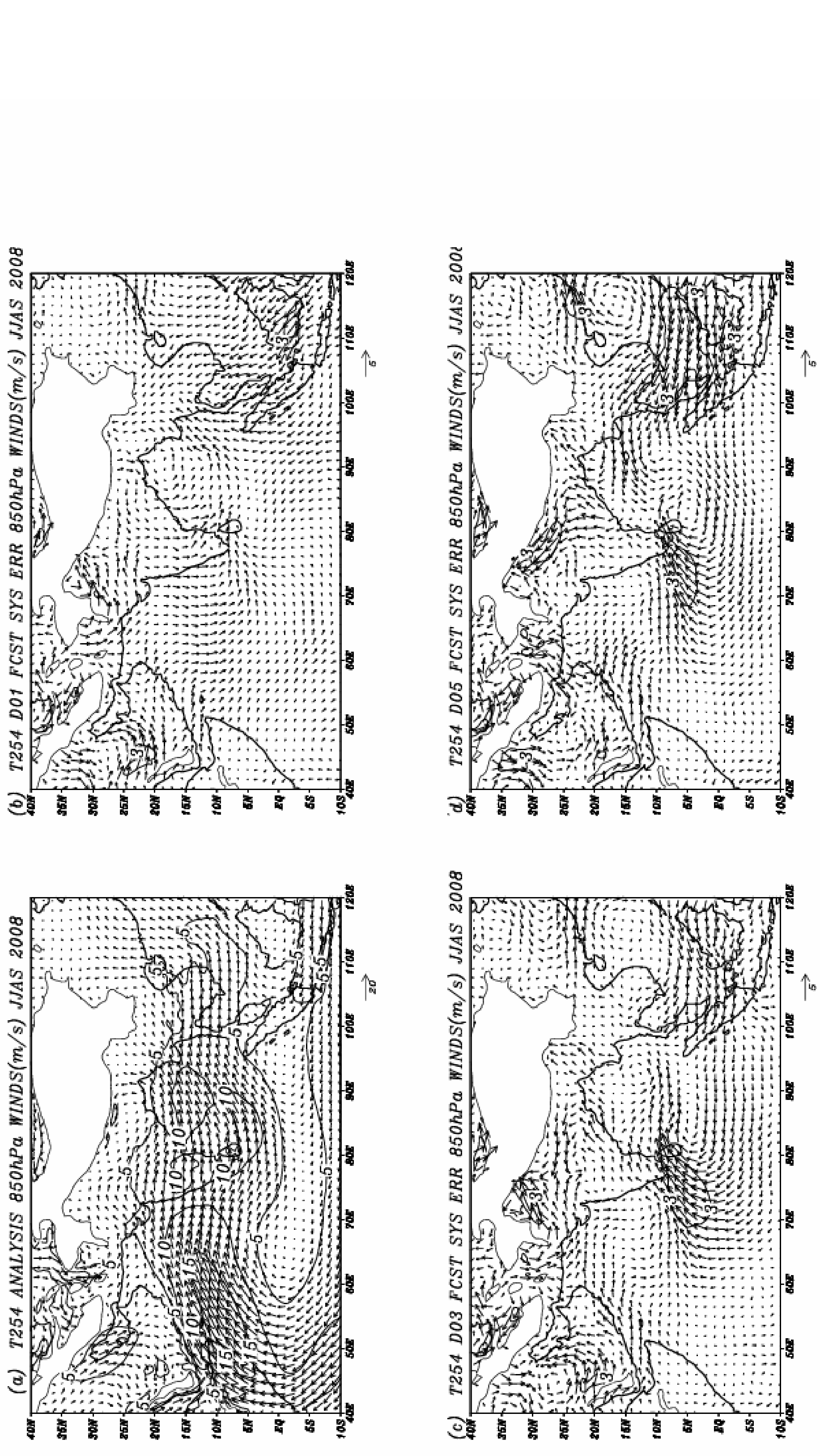

(a) T254 ANALYSIS 850hPa WINDS(m/s) JJAS 2008
(b) T254 D01 FCST SYS ERR 850hPa WINDS(m/s) JJAS 2008
(c) T254 D03 FCST SYS ERR 850hPa WINDS(m/s) JJAS 2008
(d) T254 D05 FCST SYS ERR 850hPa WINDS(m/s) JJAS 200

Fig. 1

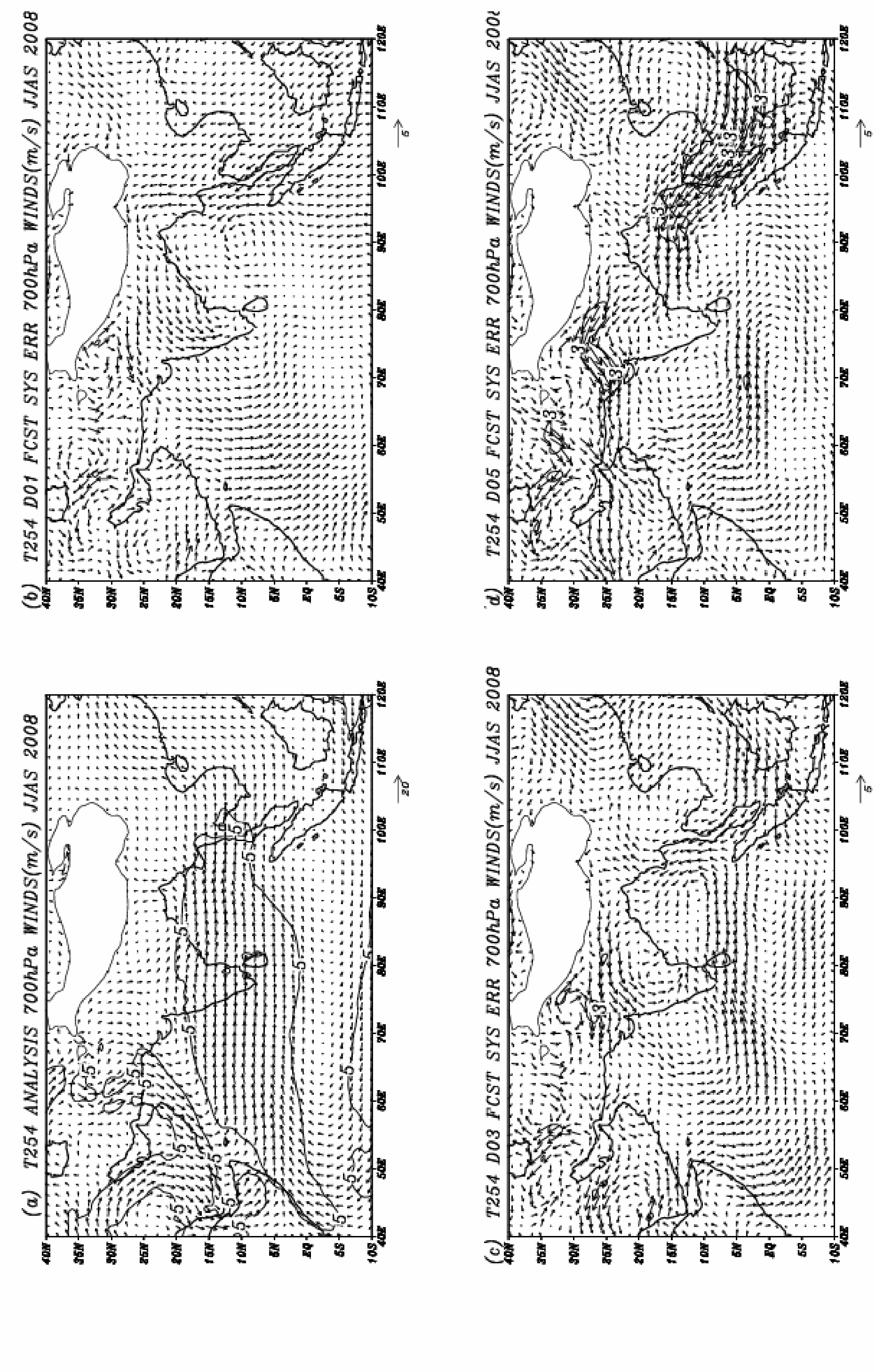

(a) T254 ANALYSIS 700hPa WINDS(m/s) JJAS 2008
(b) T254 D01 FCST SYS ERR 700hPa WINDS(m/s) JJAS 2008
(c) T254 D03 FCST SYS ERR 700hPa WINDS(m/s) JJAS 2008
(d) T254 D05 FCST SYS ERR 700hPa WINDS(m/s) JJAS 200

Fig. 2

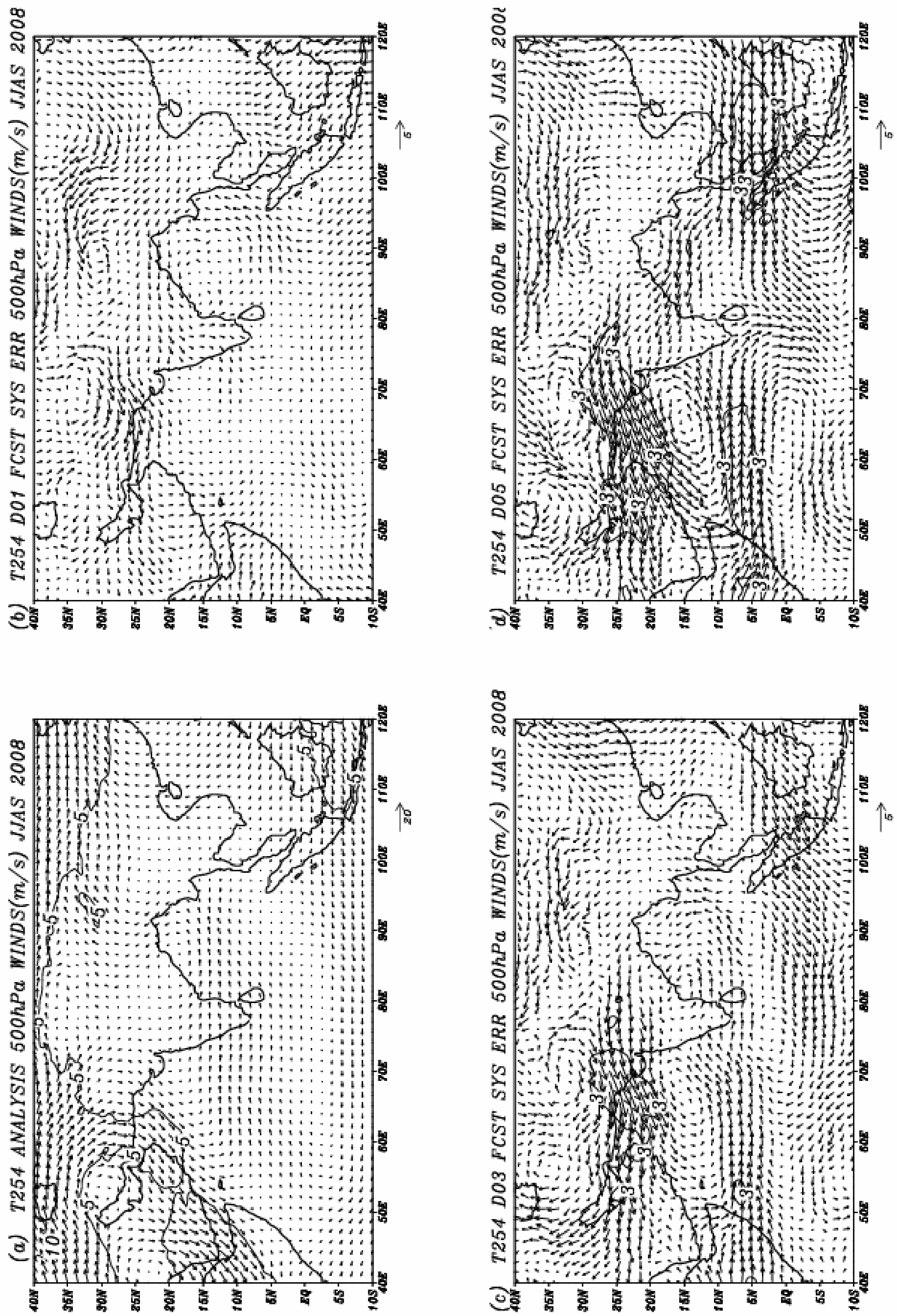

(a) T254 ANALYSIS 500hPa WINDS(m/s) JJAS 2008
(b) T254 D01 FCST SYS ERR 500hPa WINDS(m/s) JJAS 2008
(c) T254 D03 FCST SYS ERR 500hPa WINDS(m/s) JJAS 2008
(d) T254 D05 FCST SYS ERR 500hPa WINDS(m/s) JJAS 2008

Fig. 3

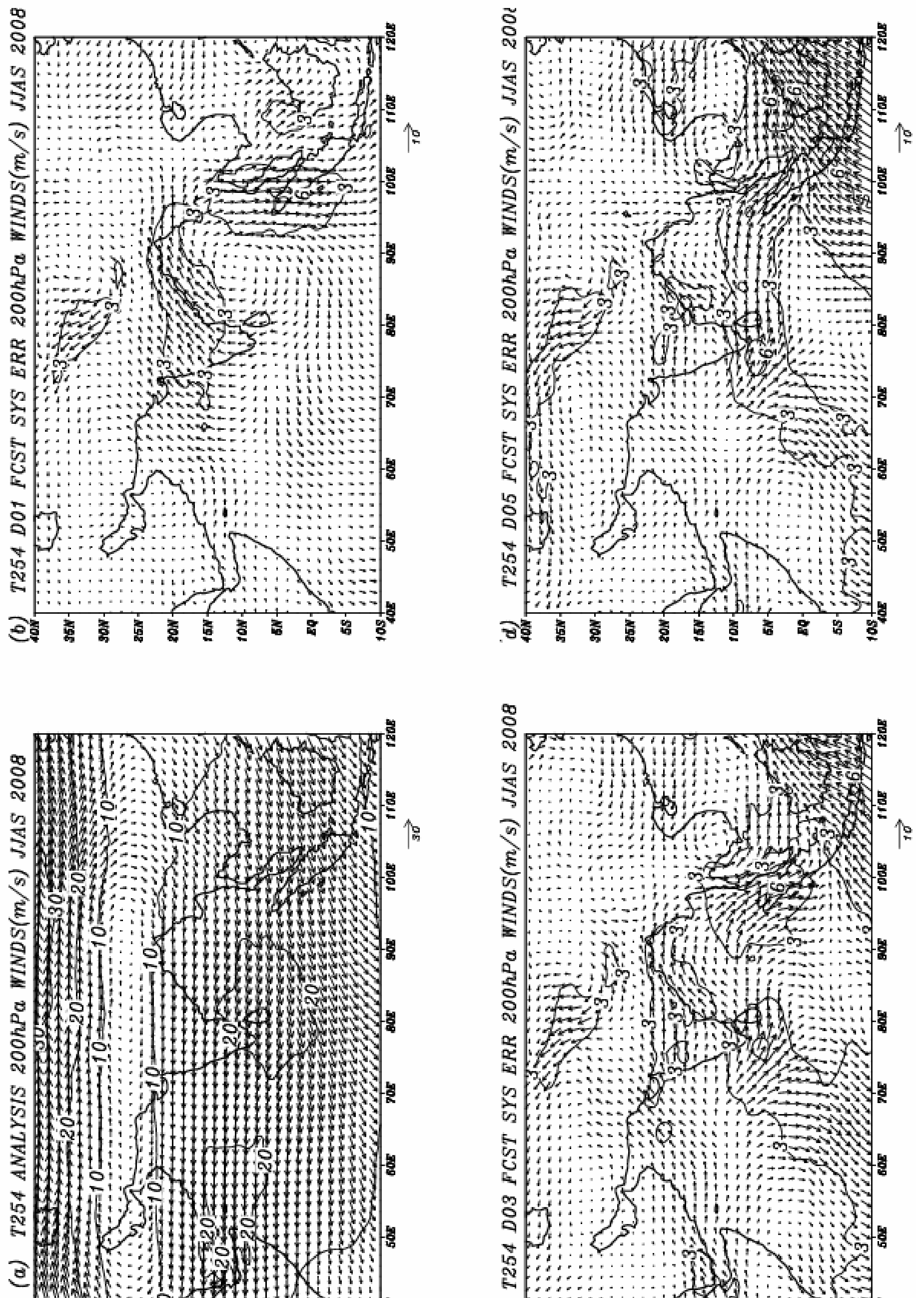
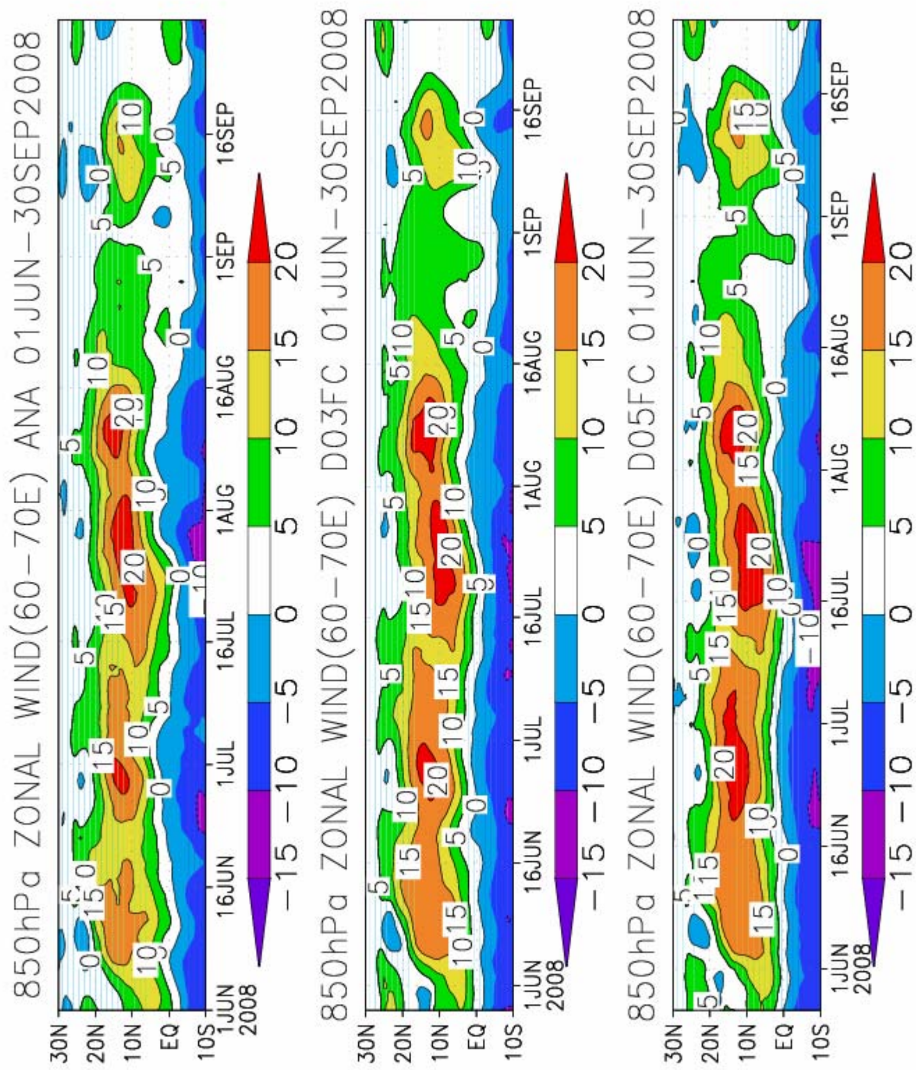

(a) T254 ANALYSIS 200hPa WINDS(m/s) JJAS 2008
(b) T254 D01 FCST SYS ERR 200hPa WINDS(m/s) JJAS 2008
(c) T254 D03 FCST SYS ERR 200hPa WINDS(m/s) JJAS 2008
(d) T254 D05 FCST SYS ERR 200hPa WINDS(m/s) JJAS 200

Fig. 4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850hPa ZONAL WIND(60-70E) D03FC 01JUN-30SEP2008
850hPa ZONAL WIND(60-70E) D05FC 01JUN-30SEP2008
30N
20N
10N
EQ
10S
1JUN 2008
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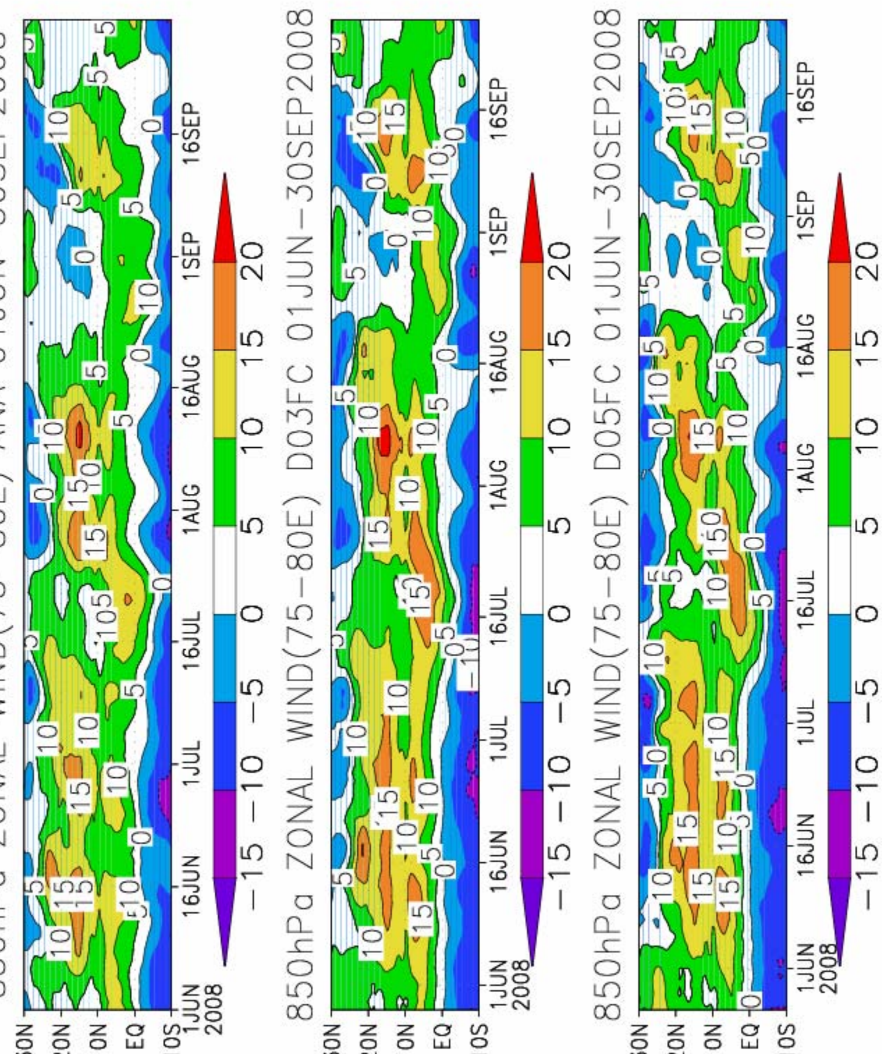
1JUL
16JUL
1AUG
16AUG
1SEP
16SEP
−15 −10 −5 0 5 10 15 20

Fig. 5


850hPa ZONAL WIND(75-80E) ANA 01JUN-30SEP2008
850hPa ZONAL WIND(75-80E) D03FC 01JUN-30SEP2008
850hPa ZONAL WIND(75-80E) D05FC 01JUN-30SEP2008
30N
20N
10N
EQ
10S
1JUN 2008
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1SEP
16SEP
-15 -10 -5 0 5 10 15 20

Fig. 6

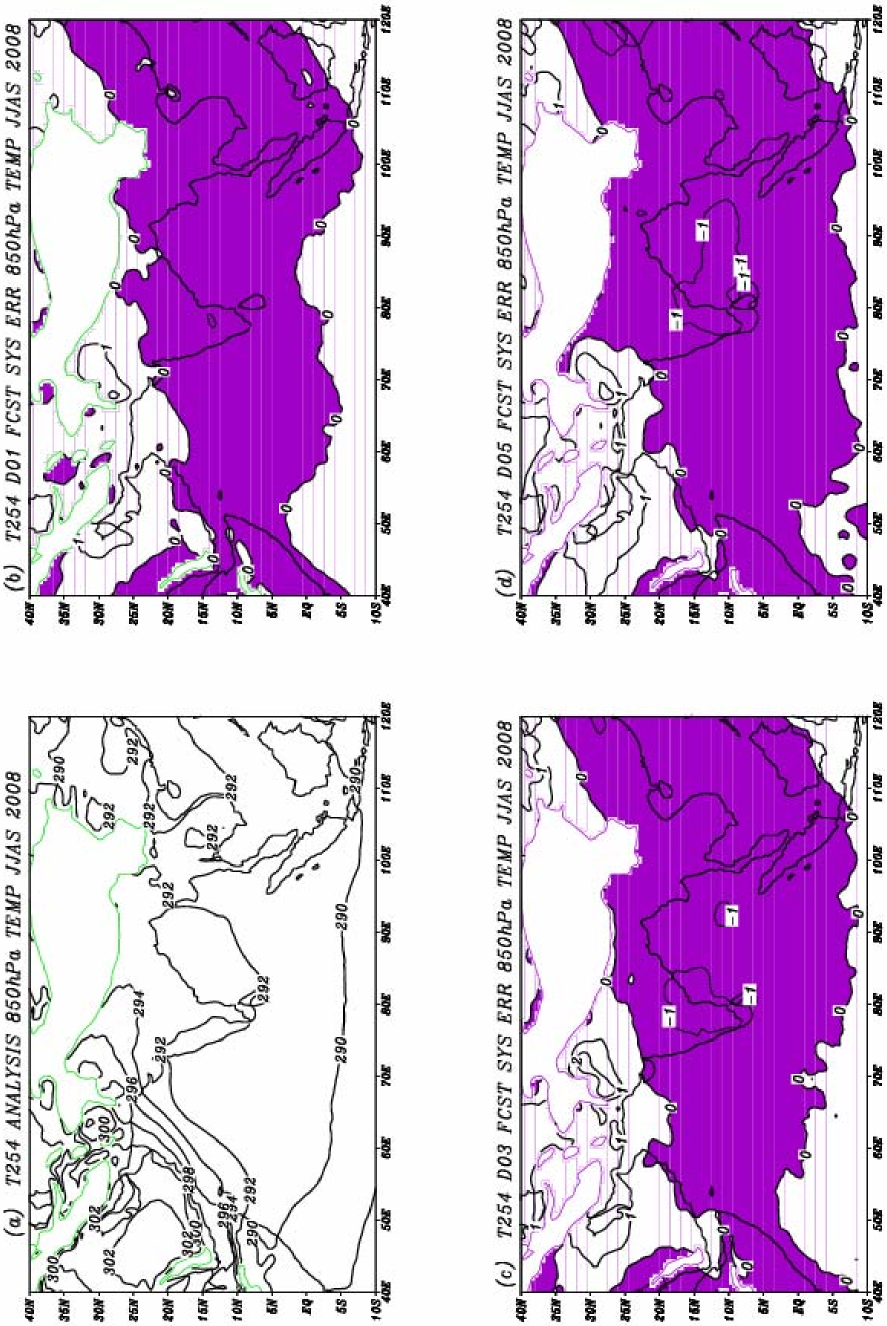

(a) T254 ANALYSIS 850hPa TEMP JJAS 2008
(b) T254 D01 FCST SYS ERR 850hPa TEMP JJAS 2008
(c) T254 D03 FCST SYS ERR 850hPa TEMP JJAS 2008
(d) T254 D05 FCST SYS ERR 850hPa TEMP JJAS 2008

Fig. 7

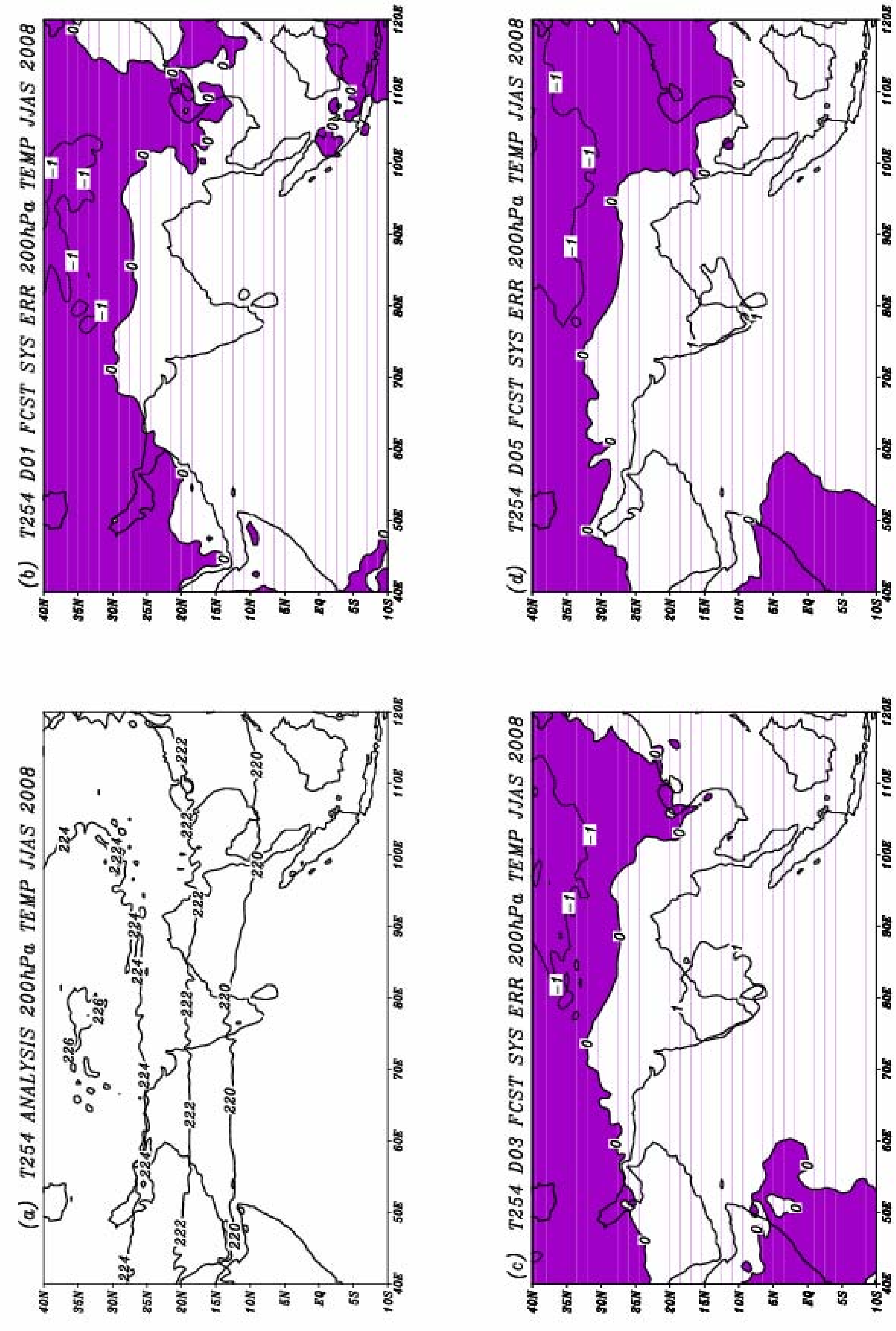

(a) T254 ANALYSIS 200hPa TEMP JJAS 2008
(b) T254 D01 FCST SYS ERR 200hPa TEMP JJAS 2008
(c) T254 D03 FCST SYS ERR 200hPa TEMP JJAS 2008
(d) T254 D05 FCST SYS ERR 200hPa TEMP JJAS 2008

Fig. 8

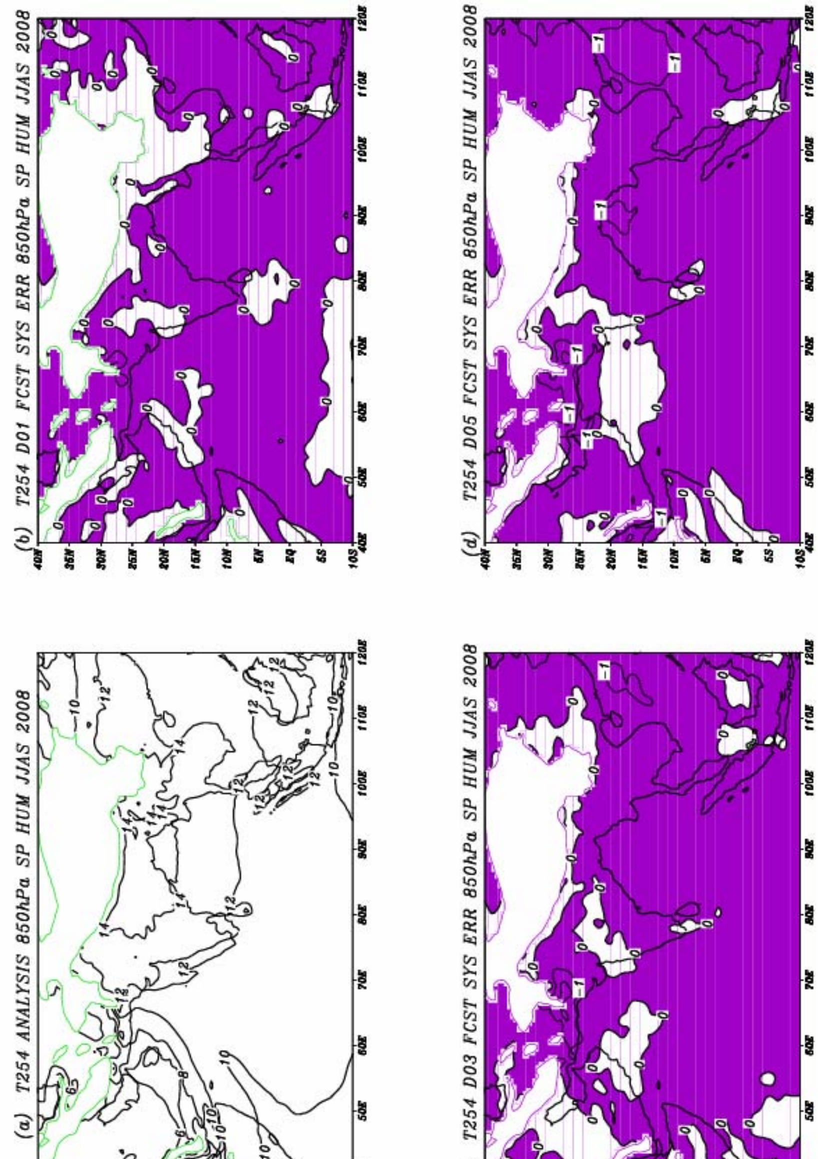
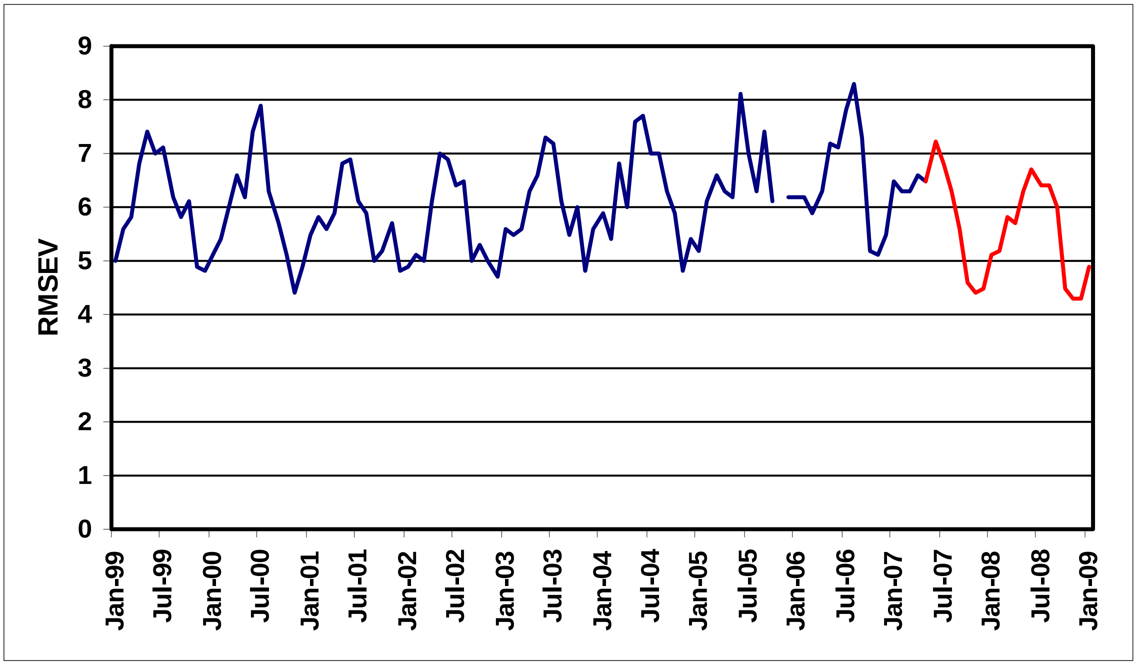

(a) T254 ANALYSIS 850hPa SP HUM JJAS 2008
(b) T254 D01 FCST SYS ERR 850hPa SP HUM JJAS 2008
(c) T254 D03 FCST SYS ERR 850hPa SP HUM JJAS 2008
(d) T254 D05 FCST SYS ERR 850hPa SP HUM JJAS 2008

Fig. 9



RMSEV
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8
7
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Jan-99
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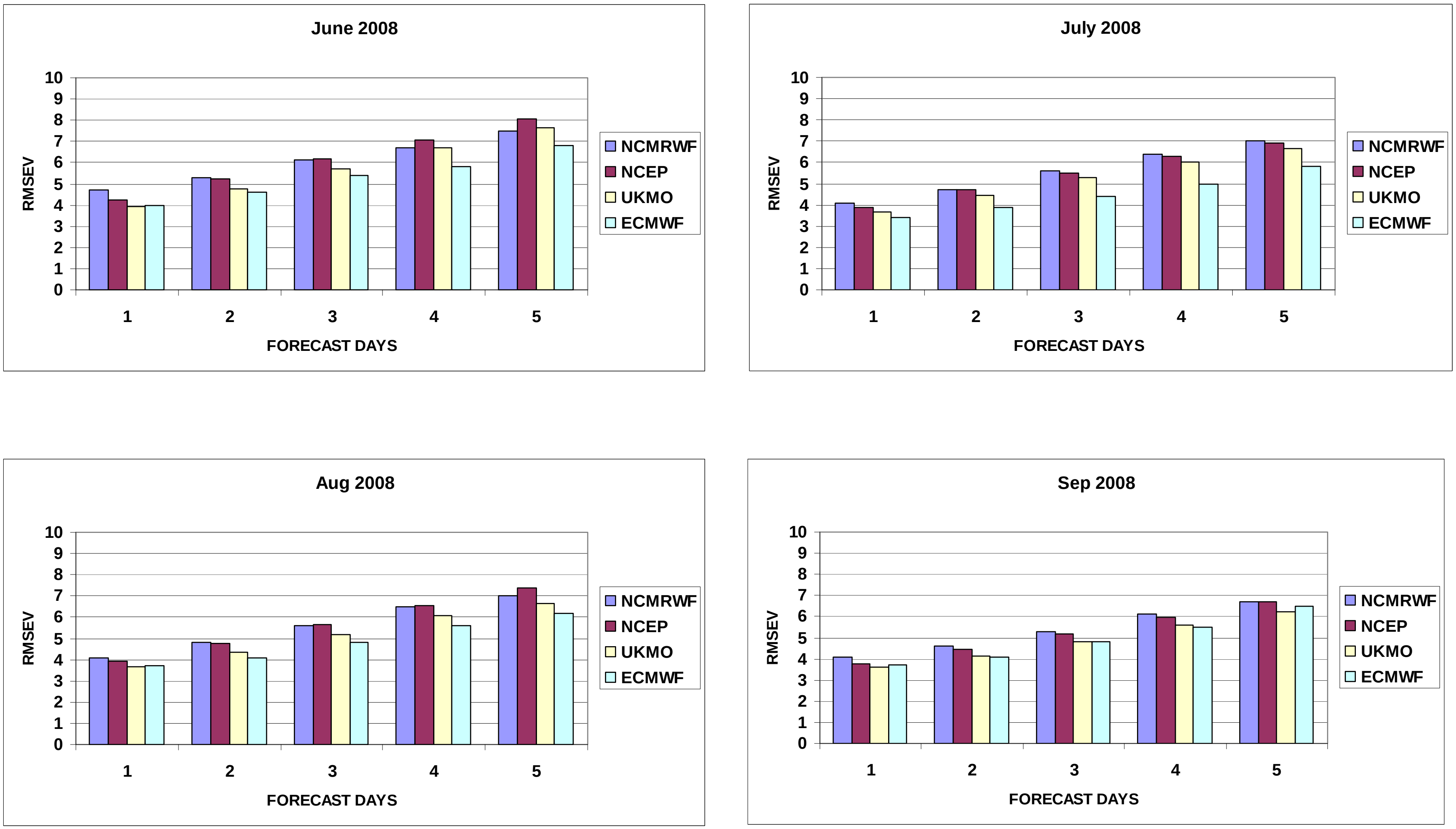
Jan-09

Figure 10


June 2008
July 2008
Aug 2008
Sep 2008
RMSEV
FORECAST DAYS
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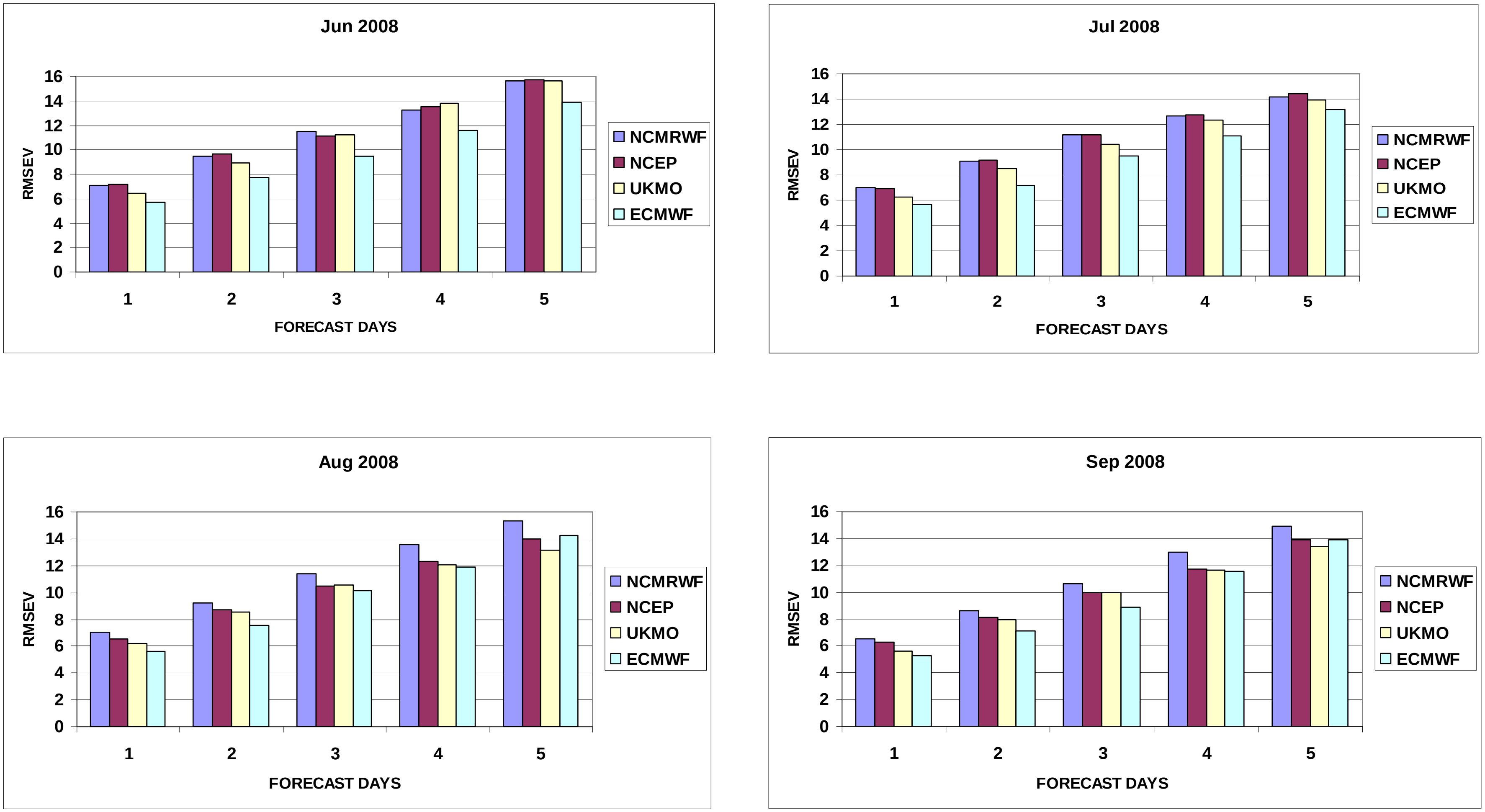
1 2 3 4 5
NCMRWF
NCEP
UKMO
ECMWF

Figure 11


Jun 2008
RMSEV
16
14
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10
8
6
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3
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5
FORECAST DAYS
NCMRWF
NCEP
UKMO
ECMWF
Jul 2008
Aug 2008
Sep 2008

Figure 12

Verification of Model Rainfall Forecasts

A. K. Mitra, G. R. Iyengar, R. G. Ashrit and Saji Mohandas

In this section the performance of the global T254L64 high resolution model in terms of medium range rainfall forecasts are discussed. Mostly the reference observed rain is the daily gridded merged satellite (meteosat-7) and gauge data for the Indian region produced by NCMRWF. For the all India rainfall (AIR) comparisons the AIR values provided by IMD are used. Panels in figure 1 shows the seasonal total rainfall amounts from observations and model forecasts. Broadly it shows that the model is able to represent the monsoon rain well. However, on closer examination we see different amounts in observations and the model predictions. For example, in the monsoon trough region, the model forecasts are good only for day-1. Day-3 and day-5 amounts and regions of maximum rainfall in monsoon trough zone are different compared to observations. The differences of forecasts (day-1 , day-3 and day-5) minus the observations for the season are shown in figure 2, where the anomalies are seen more clearly. Over central India region the error increases with time from day-1 through day-5. The region of the error also moves towards west. Another region with high positive error values are the Arakan Coastal bordering the north eastern Bay of Bengal.

Different threshold based skill scores for rainfall for the season are shown in figure 3 to figure 6. These calculations are based on collecting points above a certain intended rainfall threshold amount. We have considered six thresholds of 1 to 6 cm per day. Different skill scores like equitable threat score, hit rate and bias scores are computed from observed and model rainfall data. Equitable threat score (ETS) is a measure of relative accuracy of the forecasts including chance (expected number of randomly correct forecasts above a threshold) as a parameter. ETS should vary between 0 to 1. Hit rate (HR) also known as success rate is the ratio of number of correctly forecasted points above a threshold to the number of forecasted points above that threshold. HR values are between 0 to 1. Bias score (BS) is the ratio of number of forecasted points above a threshold to the number of observation points above that threshold. If the BS is closer to 1, then it shows that the model rainfall forecast has less bias. Higher values (> 1) means positive (wet) bias, and lower values (< 1) indicated negative (dry) biases.

Figure 3 shows the threshold based skill scores for the central India region (73-90 E; 22-28 N). This region is representative of the region where the monsoon trough is generally seen.

Most of the models have difficulty in representing this monsoon trough related features realistically. In ETS all scores are below 0.2, and only 1 cm threshold shows the highest score. Forecasts for thresholds of 3 cm and above have a poor score of 0.05 or less. The HR for all threshold and all days are below 0.4, showing the below average performance. For threshold of 2 cm and above the scores become 0.2 or lesser. In BS except day-1, for all thresholds and days positive (wet) biases are seen for the central India region.

Figure 4 shows the threshold based skill scores for the peninsular India region (74-85 E; 7-21 N). The ETS falls rapidly with increasing thresholds. For threshold of 2 cm and above the ETS scores are seen to be 0.15 and lesser. For higher rainfall amounts (> 4cm) the scores become very low. The scores for HR also falls rapidly with increasing thresholds. The BS shows that the model has really higher positive (wet) biases for threshold of 4 cm and above for the peninsular India region.

Figure 5 shows the threshold based skill scores for the west coast region of India (70-78 E; 10-20 N). ETS are always lower than 0.15, for all thresholds and days. Beyond the thresholds of 3 cm and above, the ETS are as low as 0.1 and less. The HR also falls rapidly with increasing thresholds. For 3 cm and above thresholds the HR becomes 0.3 or lesser. For west coast also the BS shows a positive (wet) bias for heavier rainfalls (> 4 cm).

Figure 6 shows the performance for the All India region (67 - 100 E; 7 - 37 N) . For each threshold the ETS decreases from day-1 to day-5 gradually. Only for 1 cm threshold and day-1 to day-3 we see the skill scores are above 0.2, and for rest of the thresholds and all, days the scores are all below 0.2 indicating below average performance. For threshold 4 cm and above the scores become very low (leas than 0.1), and by day-5 they all reach a low score of 0.05. The HR also falls rapidly with thresholds for different days. Only forecasts for 1 cm threshold looks good, and for heavier rainfall (> 2 cm) the scores are below 0.4 indicating poor performances by model. The BS indicates that for thresholds of 5 cm and 6 cm the model has positive biases.

The all India rainfall (AIR) variability from model (compared to observations) in time scales like daily, weekly, monthly and also in a season are useful model diagnostics, which depicts important aspects of the model skill to capture the monsoon over the Indian region in a broad sense. Several forecasters at IMD also seek (monitor) this AIR figures from the model to infer about the monsoon strength in medium range time-scale. In figures 7 and 8 the variability of AIR from observations and model are shown. It is seen that, there is a good correspondence between the observed and model in day-1 prediction and as the forecast lead time increases to day-3 and day-5, the resemblance reduces (Fig. 7). Panel (a) in figure 8 shows the comparison of model AIR for the whole season. The values are seen to be quite reasonable and close to the observations. However, through day-1 to day-5, it is seen to gradually increase (overestimate). This is also seen (consistent) in all the monthly comparisons in panel (b) of figure 8. Just for reference, in these two panels (a) and (b), CLIM shows the observed long period averaged values (climatology) of AIR. Panel (c) in figure 8 shows the comparison of the weekly (7 days accumulated predicted rainfall) AIR from model and observations during monsoon 2008. These weekly forecasts are made from a single initial condition once a week. Consistent with monthly and seasonal, the model in general overestimates the weekly accumulated rainfall in the forecasts. All these AIR comparison also agrees broadly with the positive biases shown in figure 2 in the form of geographical plots.

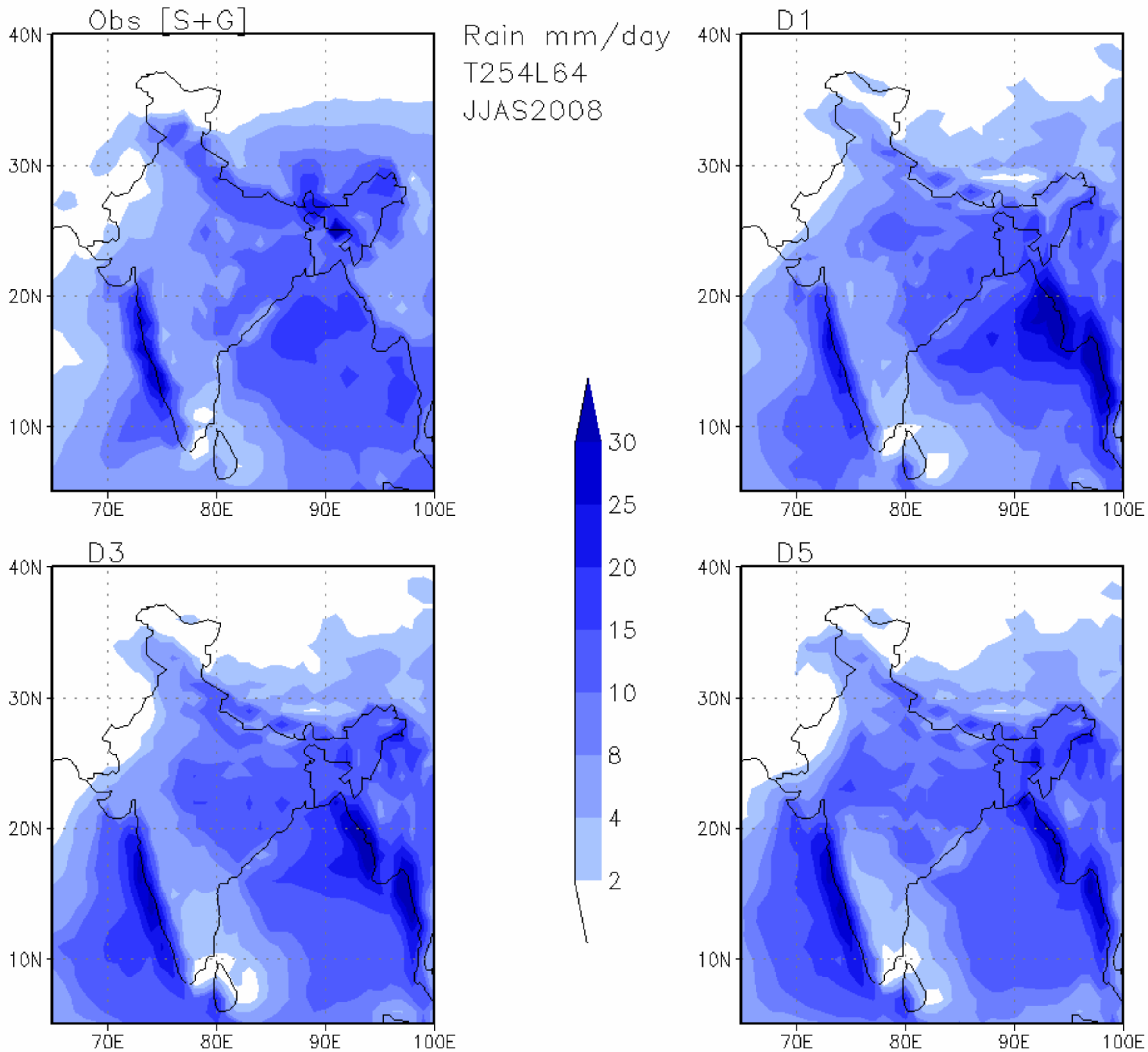


Fig. 1: Observed and day-1, day-3 and day-5 rainfall forecasts from the model for the season

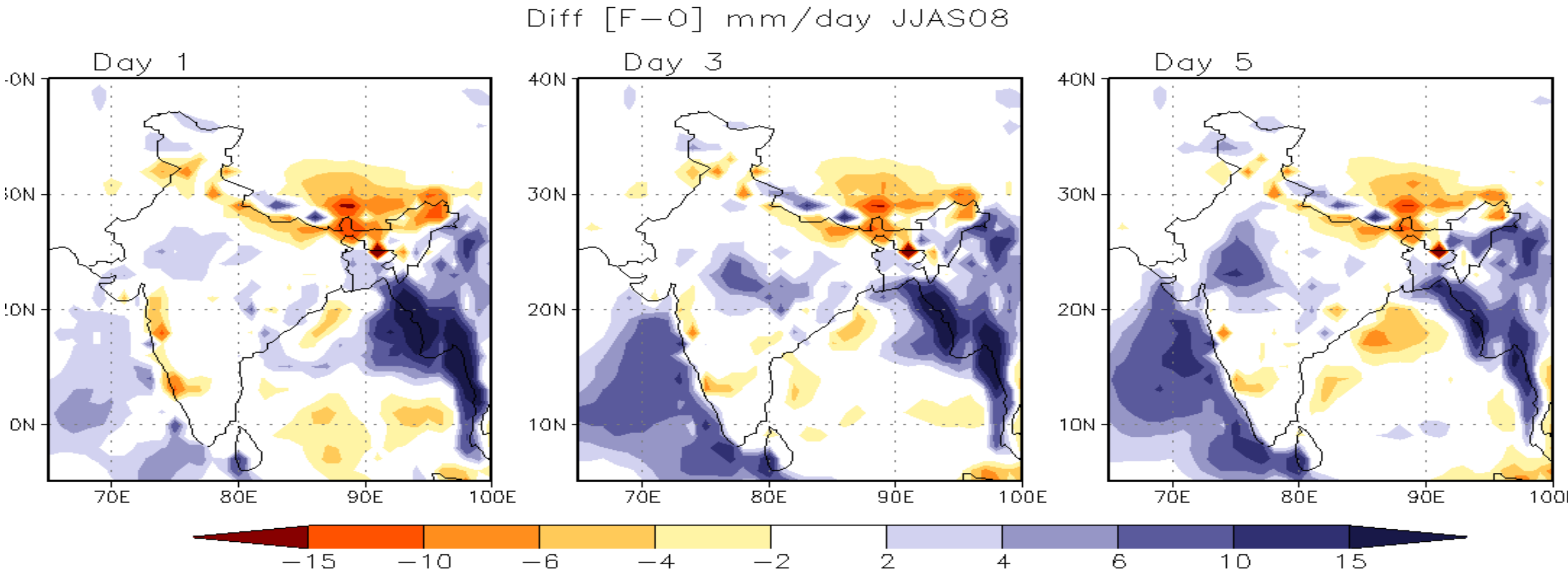
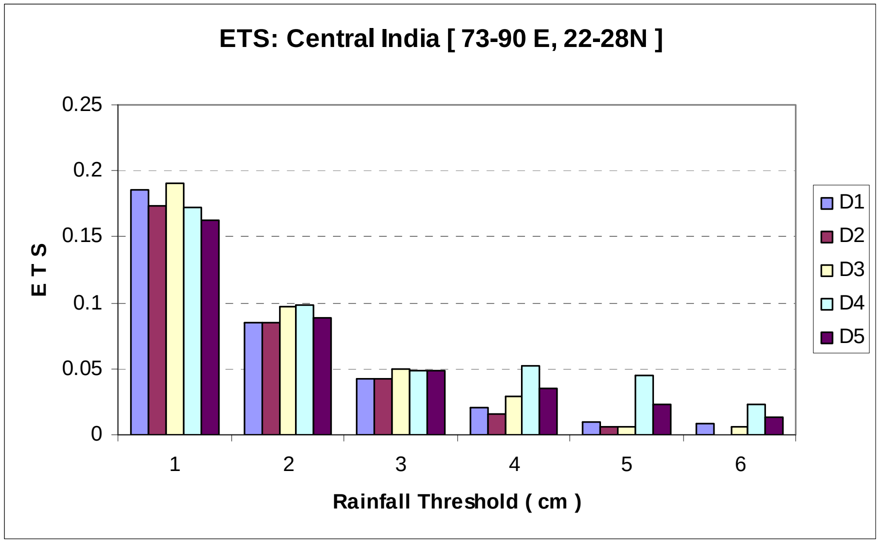
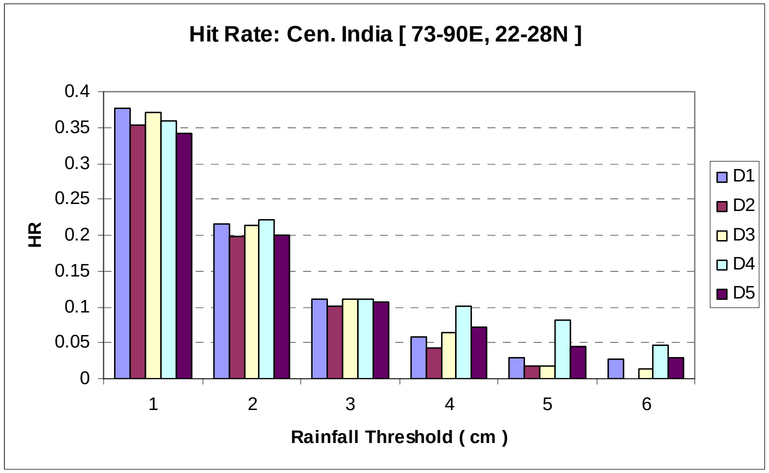


Fig. 2: Difference (Forecast - Observation) rainfall for day-1, day-3 and day-5 for the season





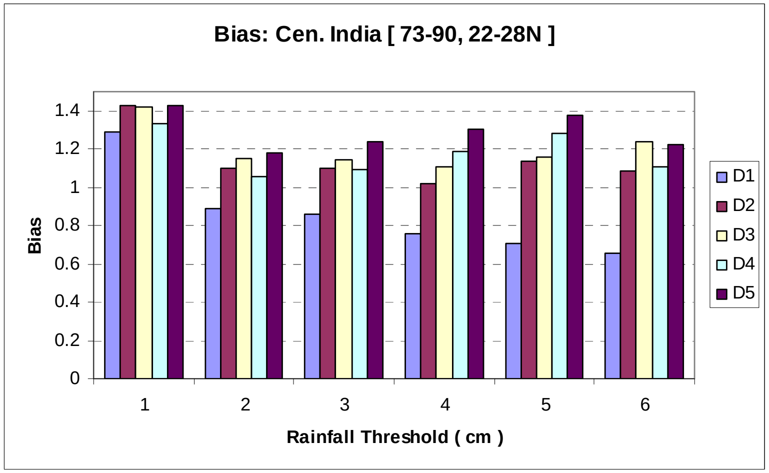


Fig. 3: Rainfall threshold based skill scores for Central India Region for the season

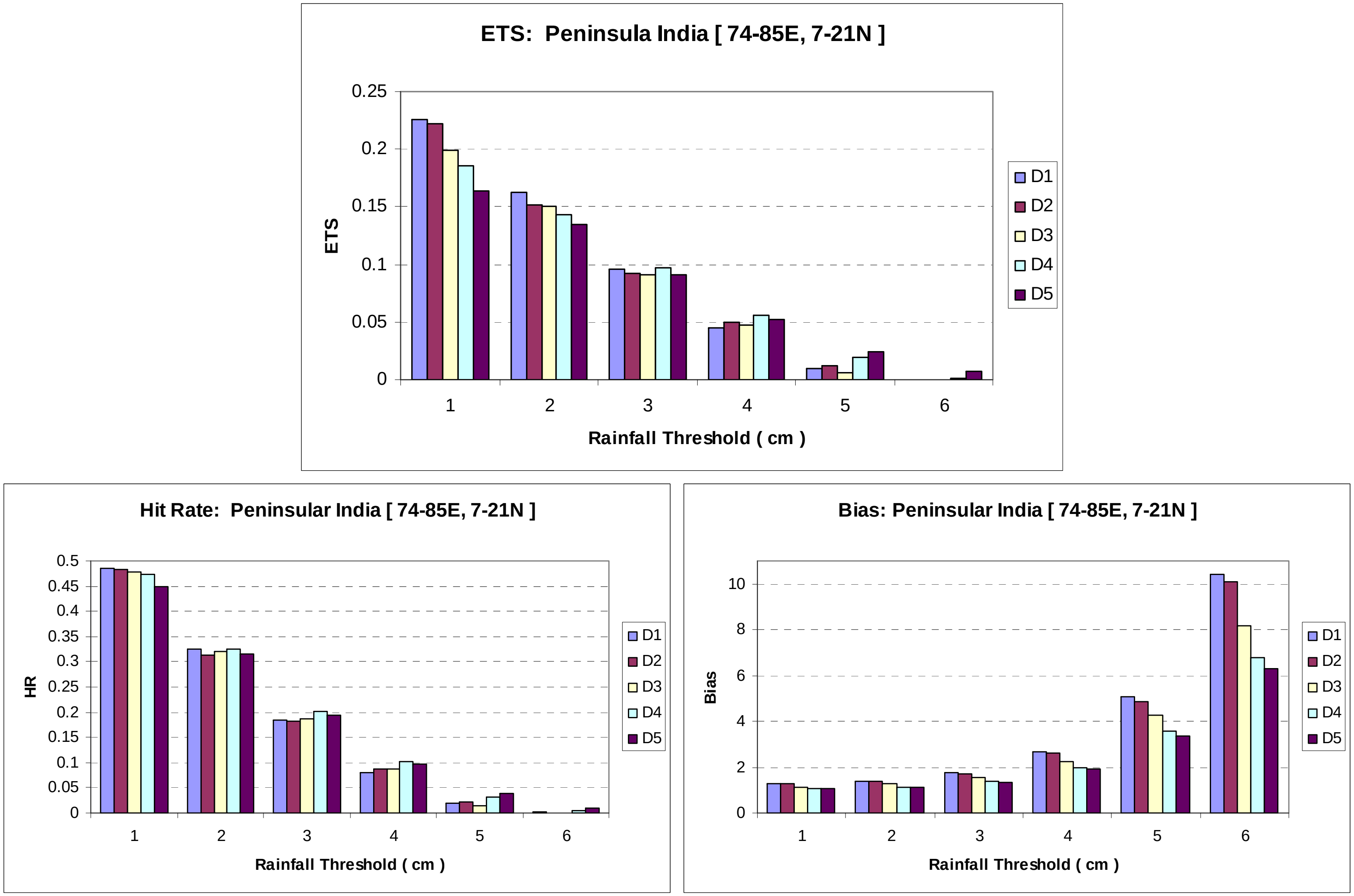


Fig. 4: Rainfall threshold based skill scores for Peninsular India Region for the season

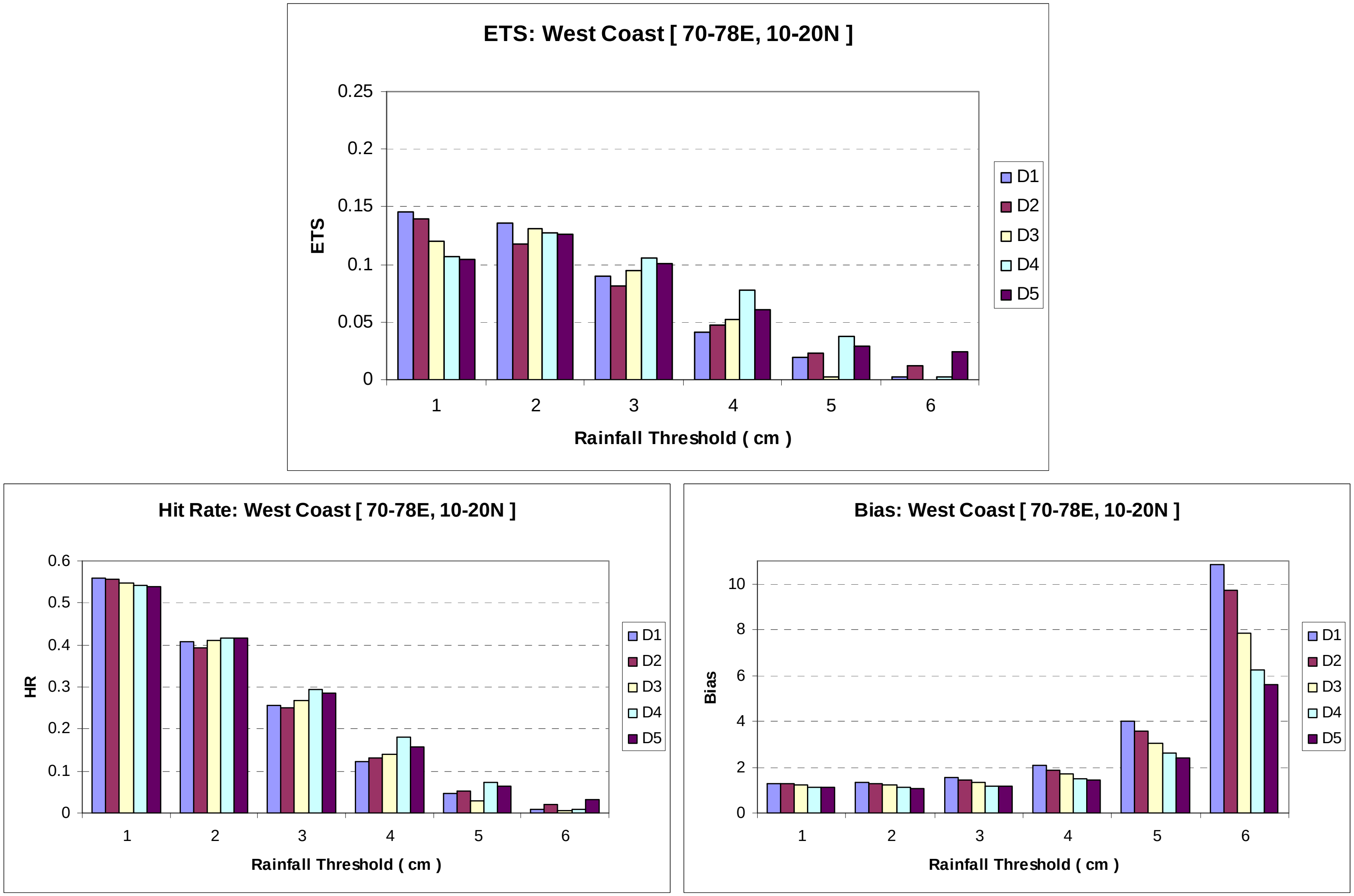


Fig. 5: Rainfall threshold based skill scores for West Coast Region for the season

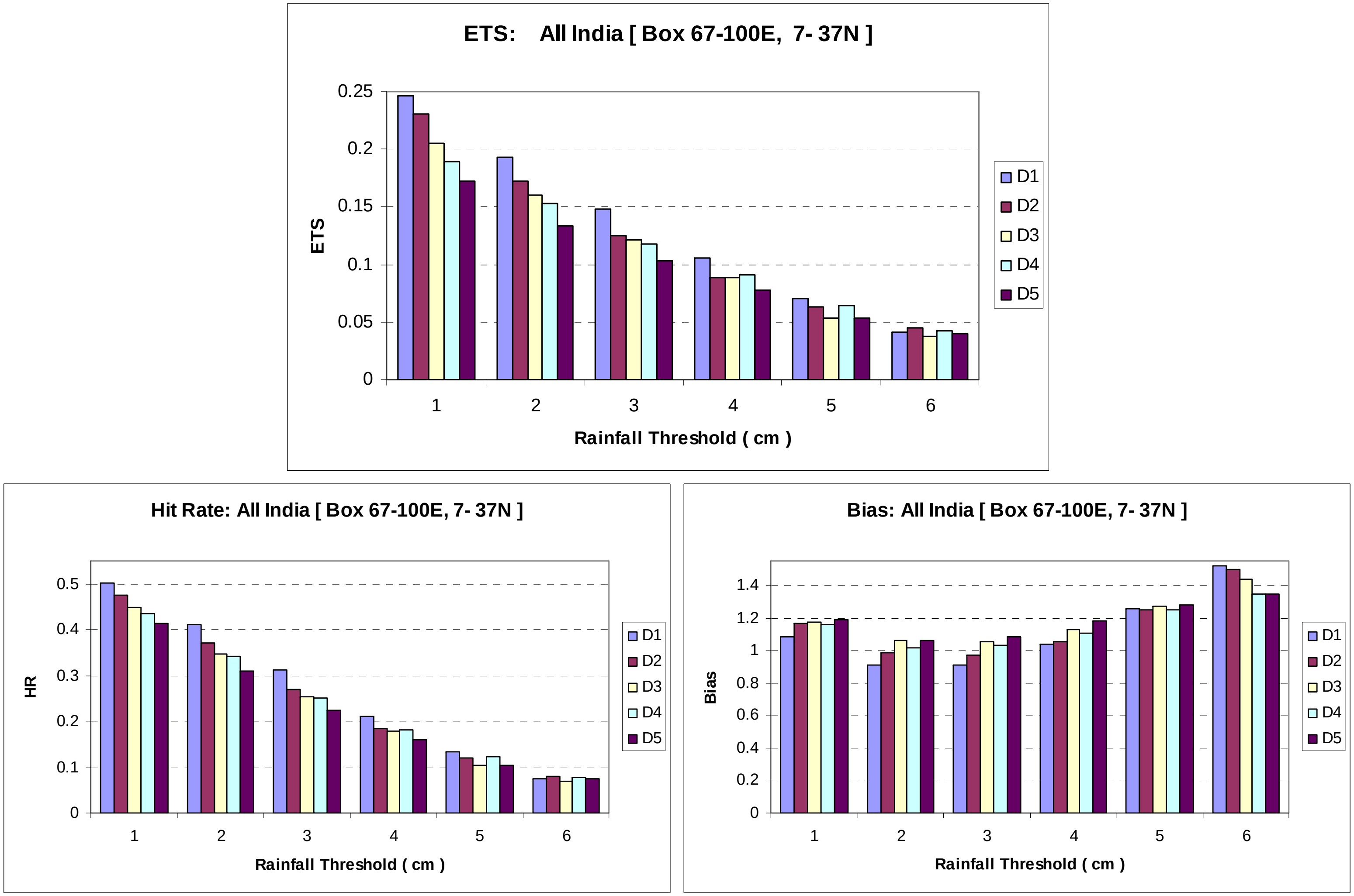


Fig. 6: Rainfall threshold based skill scores for All India Region for the season

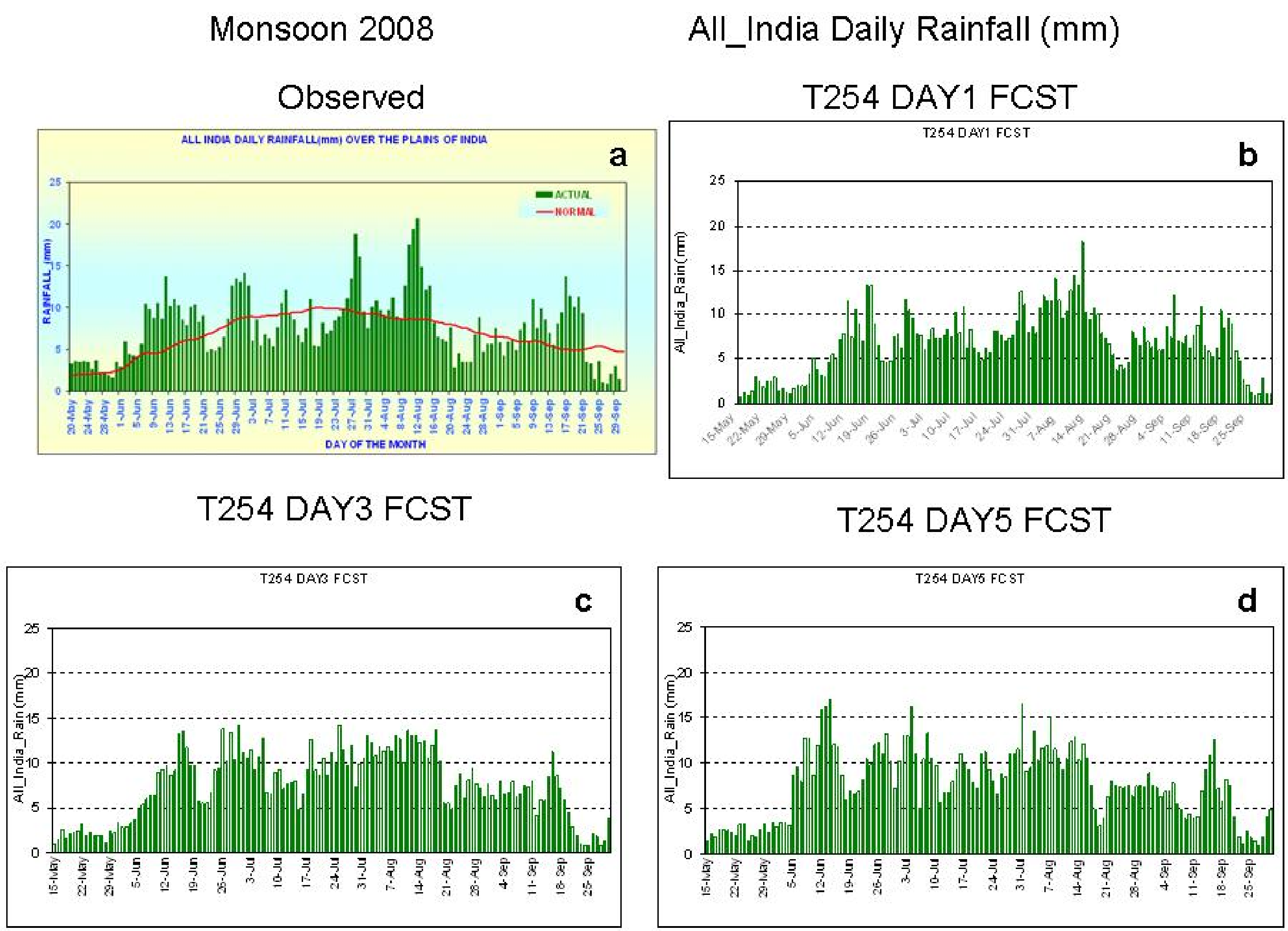


Fig.7: All India daily rainfall (mm) predicted by T254L64 for day-1, day-3 and day-5, against observed rainfall during Monsoon 2008

Monsoon-2008 All India Rainfall (mm) Observed vs. T254L64

Fig. 8: All India rainfall (mm) from T254L64 against observed; (a) Seasonal, from day-1, day-3 and day-5 forecasts (b) Monthly, from day-1, day-3 and day-5 forecasts (c) Weekly forecasts from single initial condition, once a week [CLIM shows the observed long period averaged values (climatology)]

Onset and Advancement of Monsoon

M. Das Gupta and A. K. Mitra

1. Introduction:

The onset of southwest monsoon over India has been associated with the heralding of monsoonal rains over the Kerala coast of the Indian mainland. The onset dates over Kerala varied from 11 May in 1918 to 18 June in 1972. Normal onset date of southwest monsoon over Kerala is 1 June, with a standard deviation of eight days. Monsoon affects not only rainfall but also tropospheric wind, humidity and temperature fields.

An objective method for predicting monsoon onset, advancement and withdrawal date using dynamic and thermodynamic precursors form NCMRWF T80L18 analysis-forecast system was developed (Ramesh et al. 1996, Swati et al. 1999.) and used since 1995 at NCMRWF. The same has been extended for NCMRWF T254L64 analysis-forecast system this year. Results based on these objective criteria during monsoon 2008 for T254L64 analysis-forecast system are discussed in this chapter.

2. Onset over Bay of Bengal :

The advancement summer monsoon over southwest Bay of Bengal (BOB) normally takes place prior to that over Arabian Sea(ARB) around 2nd-3rd week of May. The evolution of monsoon onset was monitored routinely from the first week of May by taking into consideration the daily variations of the analysed and predicted value of 850 hPa kinetic energy (KE), net tropospheric(1000-300 hPa)moisture (NTM) and mean tropospheric(1000-100hPa) temperature (MTT) computed over BOB(0°N -19.5°N,78°E-96°E) . Figure 1 depicts the daily variations of KE, NTT and MTT over BOB form 1st May to 1^{sT} October 2008 for 0000UTC analysis (black line) and subsequent day-1 to day-7 predictions. As seen from the plot there were several episodes of active monsoon condition over BOB, corresponding with the peaks in KE analysis plot (Fig 1a). In general all these active and weak phases of monsoon over BOB are captured well in predictions also.

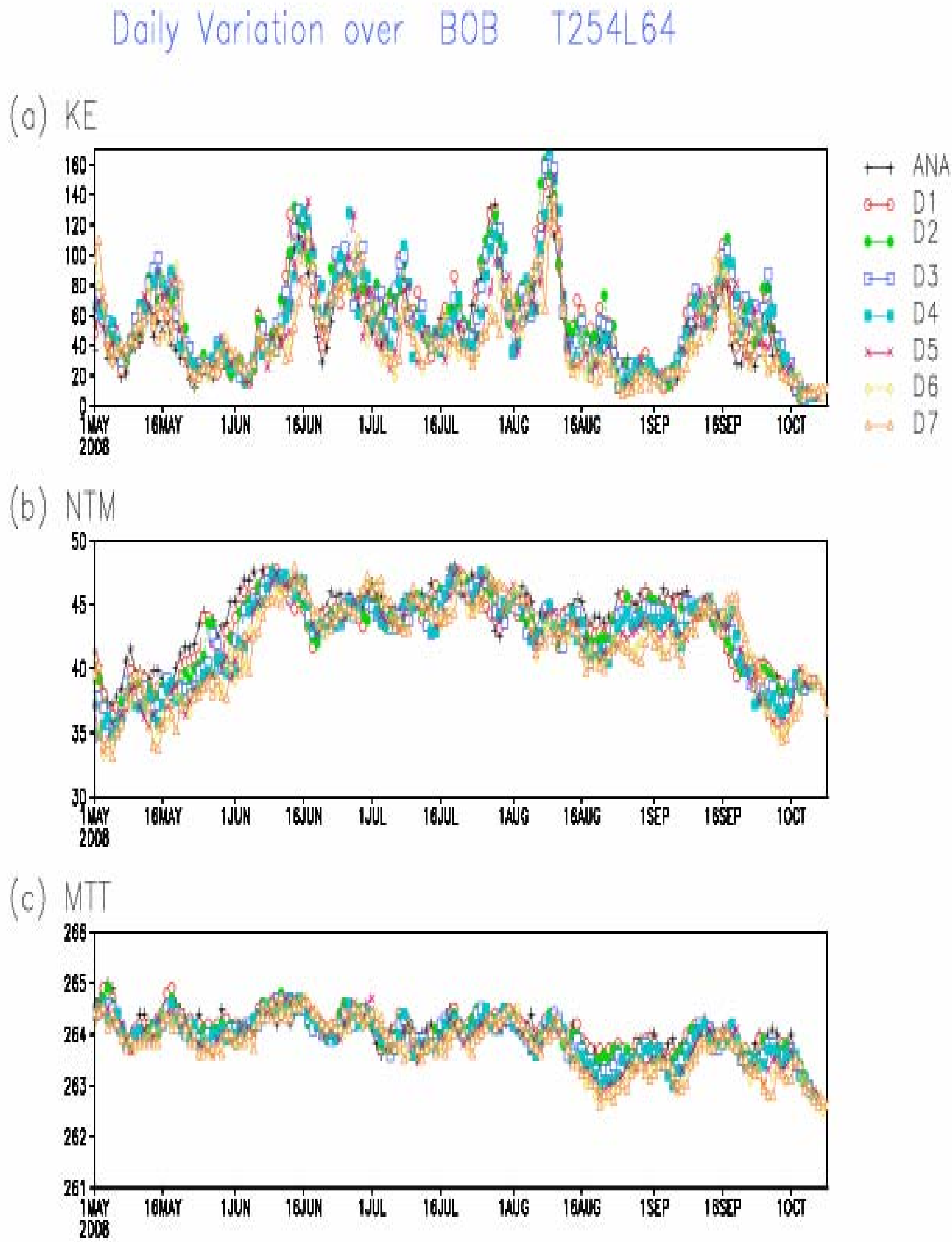


Fig.1 Daily variation of (a) Kinetic energy, (b) Net Tropospheric Moisture and (c) Mean Tropospheric Temperature over Bay of Bengal

Rise of KE above $60m^2s^{-2}$ at 850 hPa over BOB was noticed first on predictions valid for 12th May and also in the analysis of 12th May. There was a rise in NTM above 40 mm on 8th May, followed by a sudden fall at 11th & 12th May and then further increase there after till 10th June. Fall in the MTT was also noticed almost around the same time. The changes in prevailing wind regimes over certain selected points monitored over BOB also indicated the conducive changes around 12th May. So, following the objective criteria based on data from NCMRWF T254L64 analysis-forecast system, the date of onset over BOB was determined as 12th May. However, based on conventional procedure, India Meteorological Department (IMD) declared the onset over southwest Bay and adjoining most parts of Andaman Sea and Bay Islands on 10 May, 2008 about 5 days ahead of its normal date.

3. Onset over Kerala (Arabian Sea Branch):

The Arabian Sea branch of monsoon generally first hits the Western Ghats of the coastal state of Kerala around 1st June with standard deviation of 8 days. This year IMD declared the monsoon onset over Kerala on 31st May, one day prior to the normal date. However, rapid advance of monsoon over Arabian sea (ARB) and adjoining west coast of India took place mainly due to a depression (5th–6th June) over the east central Arabian Sea and a well marked low pressure area (9th–11thJune) over Saurashtra & Kutch.

Figure 2 depicts the daily variations of analysed and predicted KE at 850 hPa, NTM and MTT computed over ARB (0-19.5° N; 55.5°E-75°E) form 1st May onwards. KE at 850 hPa over ARB reached above the threshold value $60m^2s^{-2}$ on 4th June in the analysis/predictions and subsequently increased to 120 m^2s^{-2} on 6th June. Prior to that from 28th May onwards NTM also reached about 40mm and from 4th June onwards the steady decrease in NTM is noticed up to 16th June. This decrease was basically due to occurrence of rainfall associated with monsoon onset over the region. Hence, based on T254L64 analysis-forecast system the onset date of monsoon over Kerala was determined as 4th June.

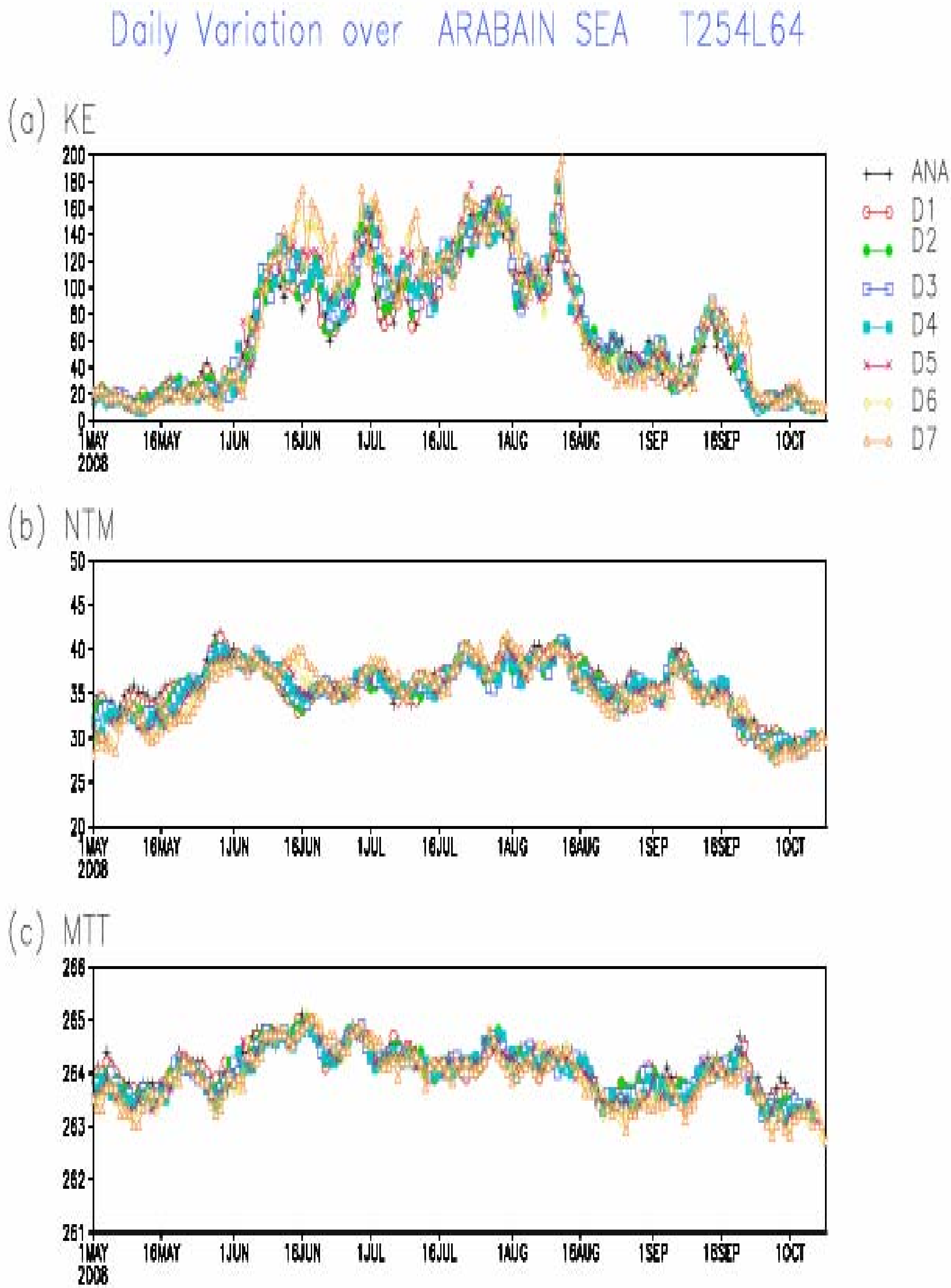


Fig.2 Daily variation of (a) Kinetic energy, (b) Net Tropospheric Moisture and (c) Mean Tropospheric Temperature over Arabian Sea

4. Advancement of Monsoon:

Advancement of monsoon over main land of India has been determined by examining changes in NTM together with the flow characteristics at 850hPa in analyses and subsequent predictions. The criteria adopted for determining the progress of monsoon over a particular location are as follows:

(i) Steady increase of NTM under the influence of expected wind regime at 850 hPa

(ii) Sharp fall in the net moisture content and subsequent rise there after under the influence of same wind regime

(iii) Date for advancing the northern limit of monsoon over a location is fixed on the day of fall in the net moisture content, which is believed to be utilized for producing the rainfall associated with the advancement of monsoon over that region

For determining the advancement of monsoon over different locations over Indian main land, NTM MTT and wind direction and speed at 850hPa in analysis and predictions are examined over 43 locations over India.

Figure 3 depicts the same at Mumbai for 1st May to 16th June 2008. As seen from the plot, NTM at Mumbai reached above 40mm value on 3rd June (after last week of May i.e. after monsoon onset over Kerala). On 5th June there was a slight fall in NTM and then further raise. Significant change of wind regime (i.e. form north-westerly to southerly & south-westerly) was also noticed from 5th June. Based on these objective criteria, the date of advancement of monsoon over Mumbai was determined as 5th June, however IMD's northern limit of monsoon line covered Mumbai on 7th June.

Table 1. shows the dates of advancement of monsoon at few important locations over India using NCMRWF objective criteria along with that declared by IMD (as northern limit of monsoon) . This year rapid advancement of monsoon over west coast and monsoon trough region was seen mainly due to formation of two depressions , first over the Arabian Sea during 5th to 6th June, 2nd depression over the Bay of Bengal during 16th to 18th June.

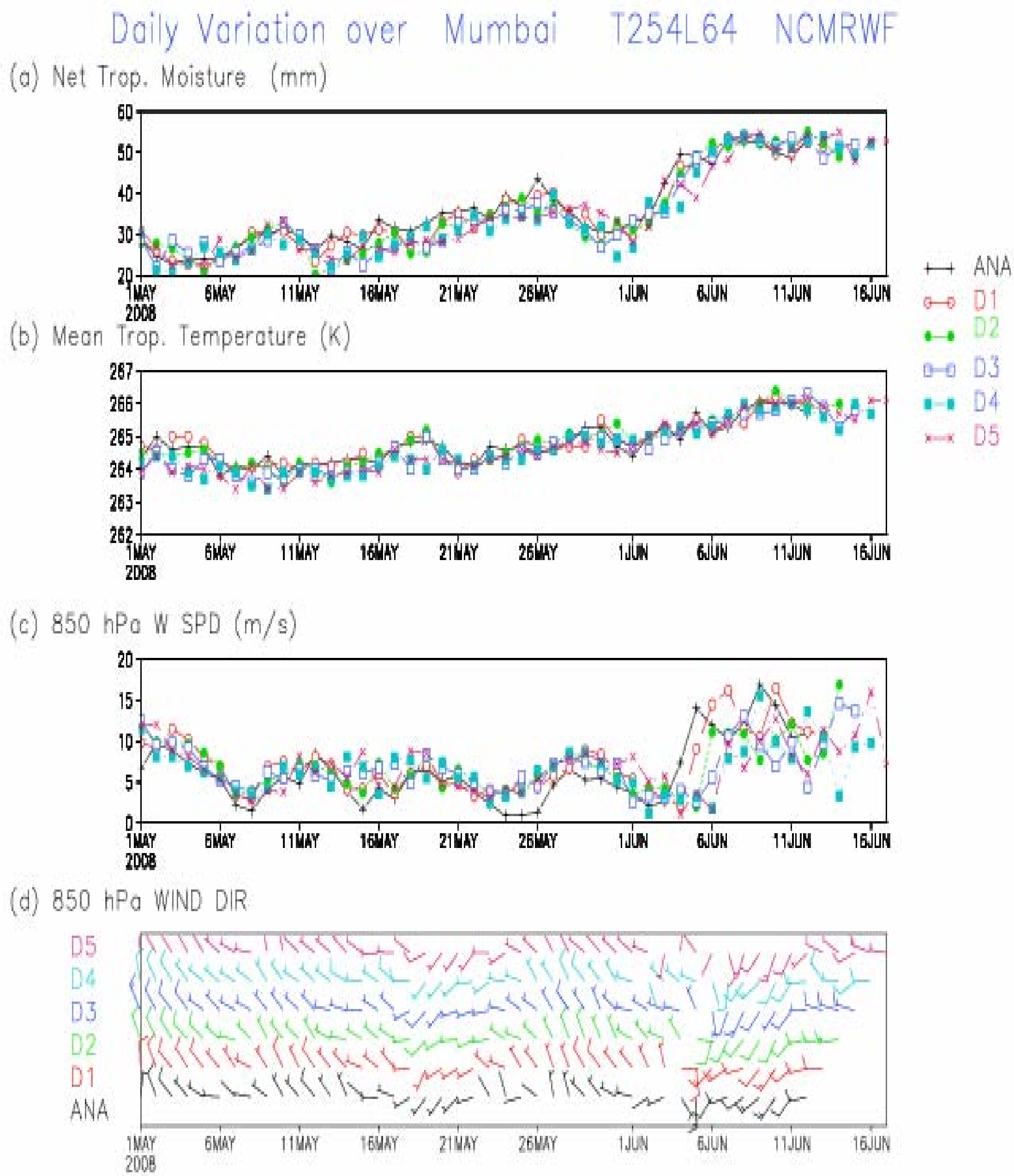


Fig.3 Daily variation of (a) NTM, (b) Net MTT (c) Wind Speed at 850 hPa and (d) Wind direction at Mumbai (IC: 1st May- 12th June 2008)

According to NCMRWF objective criteria also the advancement of monsoon was quite rapid and most of the places the date of advancement of monsoon by objective method and date declared by IMD differ by 1-3 days. However there are two significant disagreements between these two sets of date also. Northern limit of monsoon (IMD) covered Jodhpur & Jaisalmer on 10th July, but according to NCMRWF criteria, monsoon advanced over Jodhpur on 20th June, though that over Jaisalmer was on 16th July.

Table 1. Date of advancement of monsoon

Locations	Date determined by NCMRWF objective criteria	Date declared by IMD
Cochin	3rd June	1st June
Mumbai	5th June	7th June
Gopalpur	8th June	9th June
Kolkata	8th June	9th June
Patna	8th June	10th June
Varanasi	9th June	12th June
Allahabad	9th June	12th June
Agra	12th June	15th June
Delhi	18th June	15th June
Jodhpur	20th June	10th July
Jaisalmer	16th July	10th July

This year withdrawal of monsoon was also late due to presence of systems in westerlies over northwest India interacting with the monsoon circulation and IMD declared withdrawal of monsoon form north and north-west India on 29th September. The objective criteria for withdrawal of monsoon are as follows:

(i) value of NTM below 30-35mm for three consecutive days after the progression of Tibetan anti-cyclone at 200 hPa and formation of anti-cyclonic circulation over NW India

Reduction of NTM below 30mm over Jaisalmer and Jodhpur (west Rajasthan) was noticed from 8th September for six consecutive days in the analysis, though the subsequent forecast indicated the increase of NTM again above 35 mm. NCMWRF analysis-forecast system suggested the withdrawal of monsoon from of north and northwest India on 23rd September.

5. Summary :

Objective criteria for onset/progress of monsoon developed based on analysis and forecast data from a coarser resolution global model (T80L/18) has now been tested during monsoon 2008 with data from a higher resolution global model (T254L64). The analysis and the medium range forecasts of parameters related to the objective criteria of onset and progress of monsoon over India are also represented well by the higher resolution model. Onset over bay of Bengal and Arabian Sea and west coast of India were predicted well. Progress (advancement) of monsoon over Indian landmass as seen over stations using model output are seen to be captured, though there are few disagreements with date of advancement declared by IMD. In the medium range, T254L64 global model forecasts were useful for monitoring the onset and progress of monsoon during 2008 monsoon season.

References:

Ramesh, K.J, Swati Basu ,and Z.N. Begum, 1996: Objective determination of onset, Advancement and Withdrawal of the summer monsoon using large scale forecast fields of a global spectral model over India, Meteor. and atmospheric Physics,61, 137-151.

Swati Basu, K.J. Ramesh and Z.N. Begum,1999: Medium Range Prediction of summer monsoon activities over India vis-avis their correspondence with observational features, Adv. in Atmos. Sci.,16,1,133-146.

Monsoon Indices: Onset, Strength and Withdrawal

D. Rajan, G. R. Iyengar and A. K. Mitra

1.Introduction

Asian monsoon is one of the major components of the earth climate system. Because of the need of referring to monsoon variability with reference to specific features and the time of their occurrence, many monsoon indices have been developed and used in research. The annual reversal of wind and rainfall regimes in monsoon is spectacular. The onset and withdrawal of the broad scale Asian monsoon occur in many stages and represent significant transitions in the large-scale atmospheric and ocean circulations (Fasullo and Webster 2003), which can be studied by analyzing various monsoon indices. Useful indices provide a simple characterization of the state of the monsoon during different epochs and also the inter annual variability. While there exist no widely accepted definitions of these monsoon transitions at the surface, the onset is recognized as a rapid, substantial increase in rainfall with in a large scale. The arrival of the summer monsoon over the Kerala coast is found to be reasonably regular either towards the end of May or beginning of June (Ramesh et al. 1996; Prasad and Hayashi 2005; Taniguchi and Koike 2006). The monitoring and forecasting of the summer monsoon onset over the Indian subcontinent is very important for the economy of the country as well as the guidelines/monograms for the forecaster reference. This migration and location of the heat source has important implications for the withdrawal of monsoon over South Asia. However, to date there has been no systematic investigation of the retreat of the monsoon system despite its key contribution to total rainfall variability. But it is known that, in terms of rainfall, the onset is better defined than the withdrawal. In this section of the report, data from T254L64 analysis forecasts system have been used to compute various monsoon indices to monitor onset, strength and the withdrawal of the monsoon during 2008.

2.Monsoon circulation indices for onset, strength and withdrawal

Based on Kerala rainfall, the mean onset date occurs around 1 June and varies with a standard deviation of 8-9 days from year to year. Given the relatively small scale of Kerala that is less than 200 km in breath, sensitivity of the declaration of onset based solely on the district’s rainfall to spatial area in the monsoon transitions is also likely to be large. The onset date is normally declared based on rainfall, wind, temperature, moisture, cloud pattern, and the state of the sea, etc. For a forecaster it is difficult job to declare the date of onset because all the above parameters are highly variable in space and time. The India Meteorological Department (IMD) has been using the qualitative method over a long period using rainfall to declare the onset date. As per IMD (2008) daily weather bulletins; Southwest monsoon advanced over parts of southeast Bay, most parts of Andaman Sea and Bay Islands on 10 May 2008, about 5 days ahead of its normal date. The observed onset date of the southwest monsoon 2008 over the Kerala was declared as 31 May by IMD, which is a day before the normal.

Ramesh (1996) et al. suggested the following characteristics for the evolution of the onset over the Arabian Sea covering the area of 0° – 19.5° N and 55.5°E – 75°E: (a) the net tropospheric (1000 – 300 hPa) moisture build-up, (b) the mean tropospheric (1000 – 100 hPa) temperature increase, (c) sharp rise of the kinetic energy at 850 hPa. The author read that the above objective study most of the time computed the onset date delayed by few (2–6) days than the actual date given by IMD. In the pervious section of this report, onset and progress have been described with the above said criteria. This year it is noted that the onset date is seen to be around 4 June.

Here the following four dynamical indices are undertaken with data from the present NCMRWF high resolution T254/L64 analysis and forecast system. Some of the frequently used monsoon dynamical indices of the South Asian summer monsoon are shown in the table I with the their corresponding brief definition. These monsoon indices are based on circulation features associated with convection centers related with rainfall during the summer for the Indian region.

In 1999 Goswami et al ., defined the index based on the meridional wind (*V*) shear between 850 hPa and 200 hPa over the south Asian region 10°N – 30°N, 70°E- 110°E which is related to the Hardley cell features. These index can be used to study the onset and advancement phases of the monsoon.

In 2001 Wang et al., introduced a dynamical index based on horizontal wind (*U*) shear at 850 hPa called the circulation index. They recommend that the circulation index computed with the mean difference of the zonal winds (*U*) between the two boxes; one for southern region and the other for the northern region, i.e. 5°N – 15°N, 40°E– 80°E and 20°N–30°N, 70°–90°E can be used as the criteria for identifying the onset date. The southern region box is taken over South Arabian Sea an the northern region box is taken over South China sea. This circulation index describes the variability of the low-level vorticity over the Indian monsoon trough, thus realistically reflecting the large scale circulation.

In the year 2006 Taniguchi and Koike emphasized the relationship between the Indian monsoon onset and abrupt strengthening of low-level wind over the Arabian sea (7.5°N – 20°N, 62.5°E – 75°E). This is a measure of the strength of the Low-Level Jet over South Arabian Sea and indicates the strength of the monsoon over India.

In 2009 Wang et al., found that the onset date can be objectively determined by the beginning of the sustained 850 hPa zonal wind (*U*) averaged over the southern Arabian Sea (5°N–15°N, 40°E–80°E). The rapid establishment of steady westerly is in excellent parameters to correlate with the abrupt commencement of the rainy season over the southern tip of the Indian peninsula. In this index, the onset date is defined as a sustained zonal westerly exceeding 6.2 m/s and persists for more than six days. The definition is objective and depends on large scale circulation feature.

In 2002, Syroka and Toumi also defined a similar type of circulation index by taking the box slightly towards east of Wang's (2001) case. A daily circulation index is defined as the difference in average 850 hPa zonal winds between a southern region 5°N – 15°N, 50°E–80°E and a northern region 20°N – 30°N, 60°E–90°E. This daily circulation index is a physically sensible and practical tool to study the withdrawal of the monsoon also. According to them the date of withdrawal of the monsoon is defined as the first of seven consecutive days for which the index becomes negative. The daily circulation index can be used to define both the dates of onset and withdrawal of the Indian summer monsoon from these regions. The index changes sign, reflecting both the changing intensity of the low-level westerly monsoon flow and the vorticity associated with the monsoon trough and synoptic activity. In this section we have computed the above described circulation indices based upon the various definitions that are tabulated in table I .

3. Results and discussions

We use the daily NCMRWF high resolution version of T254L64 analysis and forecast data sets for the period May to September 2008. Details of the NCMRWF assimilation and forecast systems are described in chapter 1 of this report. The IMD Climate Diagnostics Bulletin of India (2008) daily/seasonal reports have been referred for the observation of rainfall, flow patterns, the dates for the declaration of onsets monsoon strength and withdrawal etc during the entire period of this study.

Figure 1 (a) shows the circulation indices calculated by Wang and Ding (2009) for the analysis and forecast for the length of 24 hr, 72 hr and 120 hr. From this figure it is seen that the onset date is calculated as 31 May, by the sustained westerly (*U*) exceeding 6.2 m/sec and persisting for more than six days i.e. up to 6 June. This high value of *U* persists beyond 6 June also. In the forecasts also broadly these features are captured well, However 72 hr and 120 hr forecast have difficulty in capturing the transition of the onset.

Figure 1 (b) shows the circulation indices calculated by Syroka and Toumi (2002, 2004) for the onset phase. From the figure (1b) we infer that the onset date around 30 May 2008, because on that day onwards the daily index is changing it's sign from negative to positive and maintained there after. The analysis and the 24 hr forecast, 72hr forecast, 120hr forecast also shows the change of sign, but with lag of three days.

Figure 1 (c) shows the circulation indices/vertical shear calculated by Goswami et al., (1999) for the onset phase. This is known as Hadley cell circulation index. From this figure we infer that the onset date is seen after 31 May and around 3 June 2008, because on that day onwards the daily index is changing it's sign from negative to positive and maintained the sign there after. The analysis and the 24 hr forecast, 72 hr forecast, 120 hr forecast also having the same trend and are able to change the sign from negative to positive with a lag of 2-3 days.

Figure (2 a) shows the Wang (2001) circulation index for the 122 days of the monsoon 2008. From the IMD source by 16 June southwest monsoon has covered most parts of the country except for some parts of Rajasthan. The wind strength more than 10 m/sec in the circulation index scale is seen around the period 8-11 June in the analysis of T254/L64; which has been reflected in the monsoon rainfall reported by IMD. As shown in the figure there are more than 8 peaks having the strength of more than 10 m/sec wind speed, those can be correlated wit the peaks rainfall observed Fig (2 b) during this season with some lag. The break monsoon conditions also prevailed over the country during the second half of July. It has affected the rainfall (-17 %) over the central and South peninsular India during July. The less amount of rainfall distribution was mainly due to the break monsoon condition that developed during 14–22 July, which can be easily correlated with the circulation index shown in figure (2 a).

The figure (3) shows the wind circulation index as per Syroka & Toumi (2002) for the period of August to September 2008. It is seen that the circulation index changes its sign from positive to negative on 5 September, but it does not persists even for a day. Hence 5 September can not be taken as withdrawal date of the southwest monsoon 2008. This date can be commented as the bogus withdrawal date. In the second occasion circulation index changes its sign from positive to negative on 26 September; subsequently it persists for more than 5 days. Thus the day 26 September can be regarded as the withdrawal date of southwest monsoon for the year 2008. When we consider the IMD official information it is closer to our dates. It is reported that the withdrawal started on 29 September over the Rajasthan.

4. Summary

Several popular monsoon indices have been used to study the onset, strength and withdrawal of monsoon during 2008 season. In general, the indices are able to represent the onset, variability in strength of monsoon and the withdrawal in a reasonable way. The indices when used with forecast data from the global model indicates that the same could be used to forecast the changes in phases of the monsoon system within a season. These indices have to be refined with more years of data from such a higher resolution system. In future use of thermodynamic parameters from the model will add value to the monitoring of monsoon by such indices.

Acknowledgement: Thanks are due to the observed rain data of IMD made available at IITM web site.

References

Climate Diagnostic Bulletin of India (2008) Issue No. 148-151. Issued by National Climate Center office of the Additional Director General of Meteorology (Research) India Meteorological Department, Pune.

Fasullo. J., and P. J. Webster, 2003: A hydrological definition of Indian monsoon onset and withdrawal. *J. climate*, **16**(14), 3200-3211.

Goswami. B.N., V. Krishnamurthy and H. Annamalai 1999: A broad scale circulation index for interannual variability of the Indian summer monsoon .*Quart. J. Roy. Meteor. Soc.,* **125**, 611-633.

Prasad. V S and Hayashi.T. 2005: Onset and withdrawal of Indian summer monsoon. *Geophy. Res. Lett.,* **32** L20715**.**

Ramesh. K J., Swati Basu and Z N Begam 1996: Objective determination of onset, advancement and withdrawal of the summer monsoon using large-scale forecast fields of a global spectral model over India. *J of Meteo. and Atmospheric physics,* **61**, 137-151.

Syroka, J., and R. Toumi 2002: Recent lengthening of the south Asian summer monsoon season. *Geophy. Res. Lett.,* **29**, (DOI: 10.1029/2002/ GL015053).

Syroka, J., and R. Toumi 2004: On the withdrawal of the Indian summer monsoon. *Quart. J. Roy. Meteor. Soc.,* **130**, 989-1008.

Taniguchi. K., and T. Koike 2006: Comparison of definitions of Indian summer monsoon onset: better representation of rapid transitions of atmospheric conditions. *Geo. Res. Lett.,* **33**, L02709, 5 pages.

Wang, B., Q. Ding, and V. Joseph 2009: Objective definition of the Indian summer monsoon onset using large-scale winds. *J. Climate* (In Press).

Wang. B., R.Wu and K.M. Lau 2001: Interannual variability of the Asian summer monsoon: Contrasts between the Indian and Western North Pacific-East Asian monsoons. *J. Climate,* **14**, 4073-4090

Webster, P.J., S. Yang 1992: Monsoon and ENSO: Selectively interactive systems. *Quart. J. Roy. Meteor. Soc.,* **118**, 877-926.

Table I

Name of the Index	Type of Index	Domain of application	Definition in terms of regions	Reference
Wang and Ding	Circulation zonal wind	Tropical South Asia	*U*850 averaged over (5°N– 15°N, 40°E–80°E)	Wang et al .,2009
Wang and Wu	Circulation index	Tropical Asia	*U*850 (5°N – 15°N, 40°E–80°E) – *U*850 (20° N – 30°N, 70°E–90°E)	Wang et al ., 2001
Goswami	Meridianal wind	South Asia	*V*850 – *V*200 over (10°N – 30°N, 70°E – 110°E)	Goswami et al., (1999)
Syroka and Toumi	Circulation zonal wind	Tropical Asia	*U*850 (5°N – 15°N, 50°E–80°E) – *U*850 (20°N – 30°N, 60°E –90°E)	Syroka and Toumi (2002)

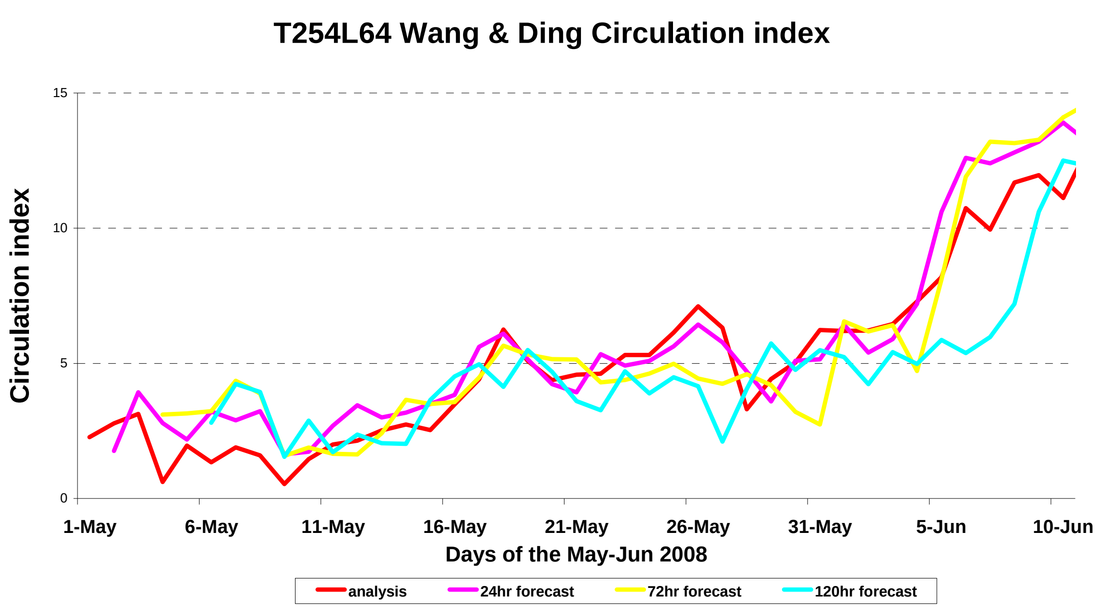


Figure 1(a)

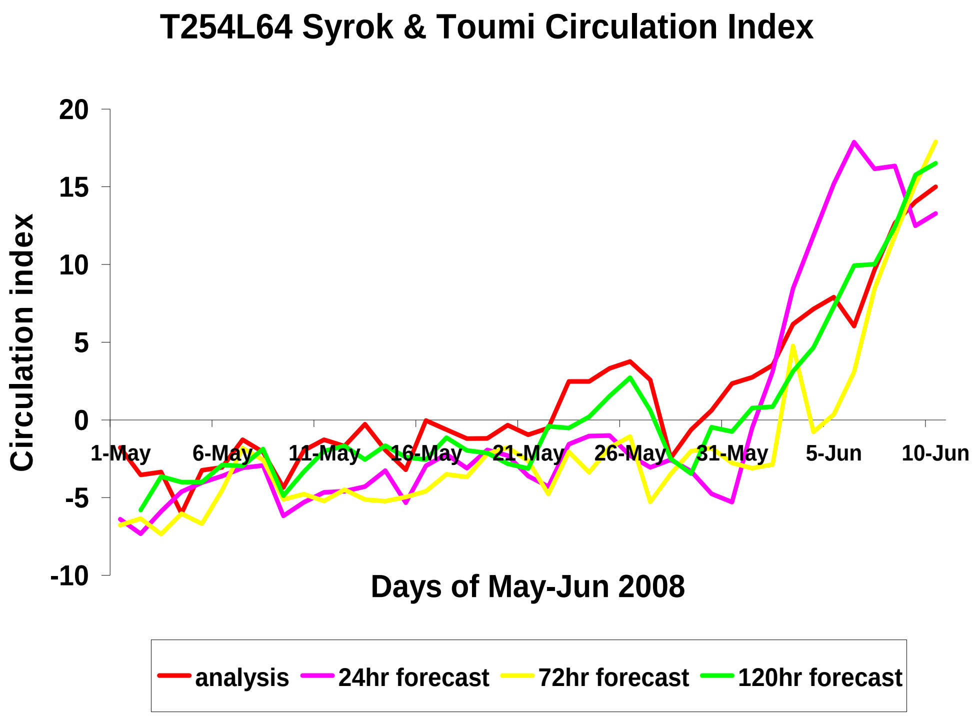


Figure 1(b)

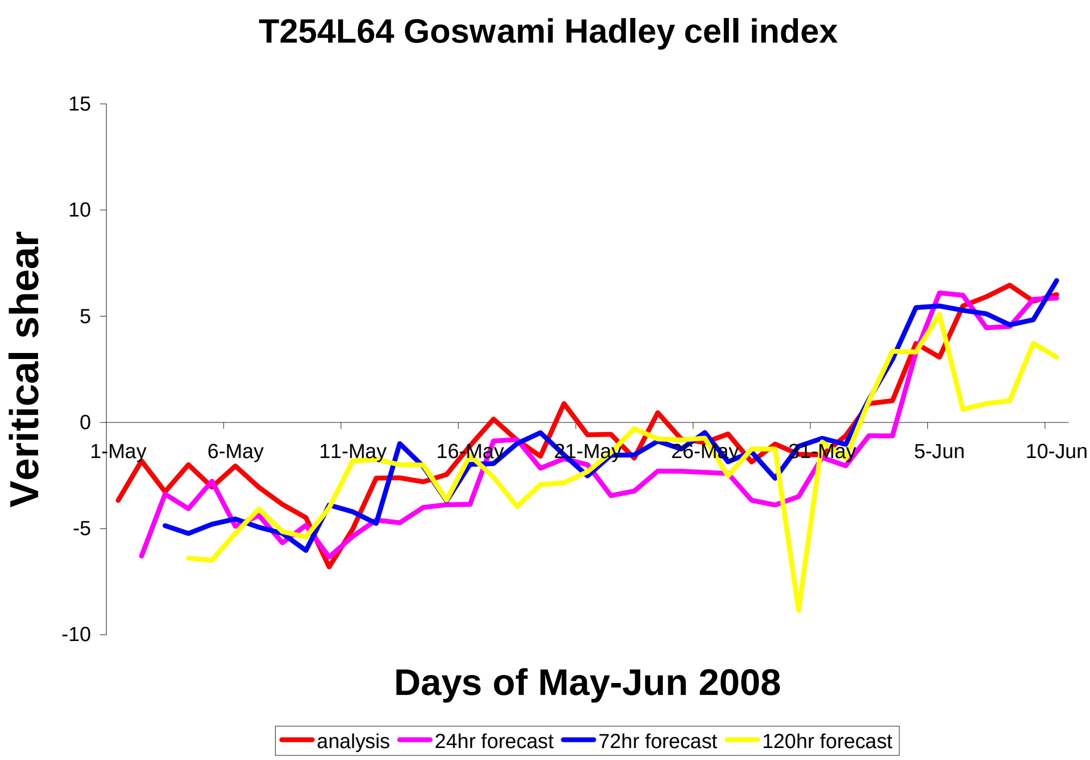


Figure 1(c)

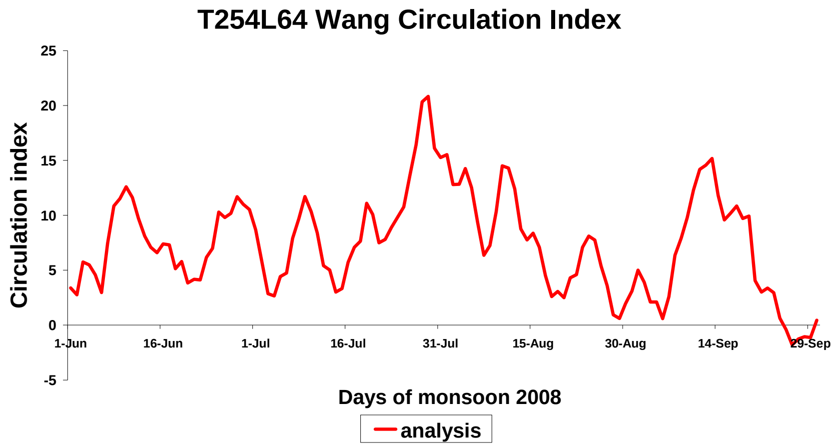


Fig. 2(a)

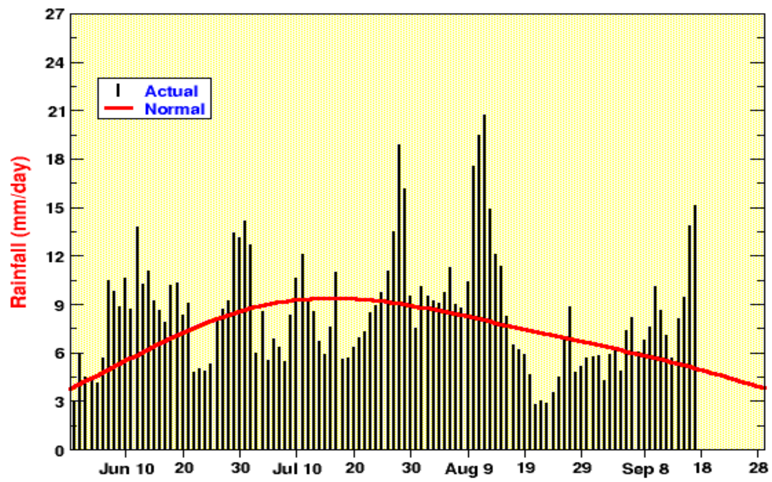


Fig. 2(b)

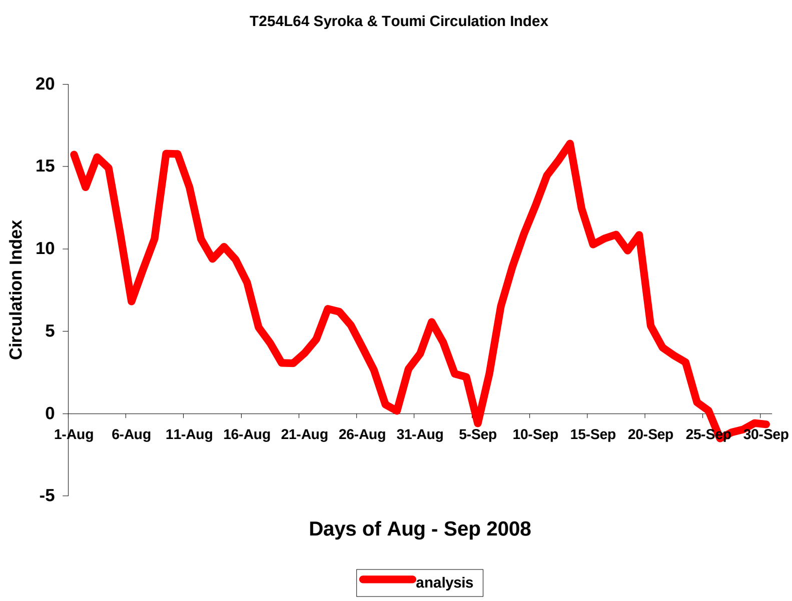


Fig. 3

Heat Low, Monsoon Trough, Lows and Depressions

R.G. Ashrit and John P. George

1. Introduction

Heat low over Saudi Arabia and Pakistan and monsoon trough over the Gangetic plains are the two most important quasi-permanent near surface features of monsoon circulation and are closely related to the large scale monsoon activity over the Indian sub-continent. Due to the intense heating in summer months a low pressure belt develops over the Afro-Asian continent running from North Africa to North-West (NW) India through Arabia and Pakistan. The deepest low pressure area over Pakistan and adjoining NW India is known as the heat low. The intensity of heat low is a good indicator of the continental heating and land-sea contrast which drives the monsoon. Deeper (shallower) heat low will usually be associated with stronger (weaker) North-South pressure gradient and enhanced (subdued) monsoon activity. The large scale monsoon activity is closely associated with the position of the monsoon trough. During the established phase of the monsoon, the monsoon trough normally runs at surface from Sriganganagar in NW India to the Head Bay of Bengal. A northward shift (towards the foothills of Himalayas in the extreme cases) of trough is usually associated with weaker monsoon activity over major parts of the country except over the Sub-Himalayan regions and South-East peninsula. A southward location of monsoon trough is favorable for good monsoon activity over large parts of the country. Monitoring and prediction of the position and the intensity of the monsoon trough is thus very important for assessment of monsoon activity. The characteristics of these two semi-permanent features, viz. Heat low and Monsoon trough in the global model analysis and day-1 forecasts, day-3 forecasts and day-5 forecasts during monsoon-2008 are examined in this chapter.

2. Heat Low

The intensity of the heat low is represented in this study by the magnitude of the innermost closed isobaric contour on a mean sea level pressure chart. By this terminology, a higher value of innermost closed isobar will mean shallower or less intense heat low.

The average heat low centre pressure of NCMRWF T254 model analyses and forecasts for different months during the monsoon season (Fig. 1) were examined to understand the behavior of the heat low during monsoon-2008. In all months, the mean heat low position is close to 70ºE, 28ºN in both in the analysis and forecast up to Day-5. In September, the mean MSLP values over this location is well above 1000 hPa. The Day-1, Day-3 and Day-5 forecast position of the heat low for all months, except September, are close to its analysis position. In June, the lowest MSLP contour in the analysis is 997 hPa and in the Day-1 forecast it is reduced to 995 hPa. In Day-2 forecast also, over the heat low region, MSLP values are around 995 hPa which is increased in Day-5 forecast. In July, MSLP at heat low region is around 997 hPa. As in June, the Day-1 and Day-3 values over heat low region is reduced to 994 hPa and in Day-5 monthly mean MSLP over heat low region increased to 995 hPa compared to the mean Day-3 forecast. In August, heat low becomes weak in both analysis and forecast. The MSLP values in the analysis is around 999 hPa and in the Day-1 and Day-3 forecast the heat low was intensified. In the Day-5 forecast, as in the previous months, heat low intensity is reduced (MSLP values are around 998 hPa). In September no heat low is seen in both analysis and forecast. It is seen that the heat low is generally more intense in model forecast as compared to the analysis. Also the Day-1 and Day-3 forecast intensity is more than that of Day-5 forecast. In general, the model forecast tends to intensify the heat lows, compared to analysis.

3. Monsoon Trough

Monsoon trough is the most prominent semi-permanent feature of the Indian summer monsoon. Intensity and location of the monsoon trough is indicative of general monsoon condition over India and neighborhood. To identify the strength and position of the monsoon trough at surface level in the T254 analysis and forecast, the MSLP field is used (Fig. 1).

In June, compared to the mean analysis, Day-1, Day-3 and Day-5 forecasts show low MSLP values over the monsoon trough region. The mean June position of the monsoon trough is the same in both analysis and forecast, up to day-5 forecast and is over the Indo-Gangetic plains close to foot hills. In the July mean analysis, in the eastern part of the monsoon trough extends up to the head Bay, which was not the case in June where it extended only up to 86.0^0 E. As in the case of June, the intensity of the monsoon trough is more in the forecast. It is also noted that the intensity of monsoon trough in Day-1 and Day-3 forecast is more compared to day-5 forecast. The east ward and southward extension of the trough is also more up to the Day-3 forecast. In August, the eastward extension of monsoon trough is nearly similar to that of July. However the MSLP values are much higher over the trough region in August. As in the previous months in August also the MSLP values over the trough region are smaller in the forecast compared to the analysis. In September the monsoon trough is very weak both in analysis and in the corresponding forecasts.

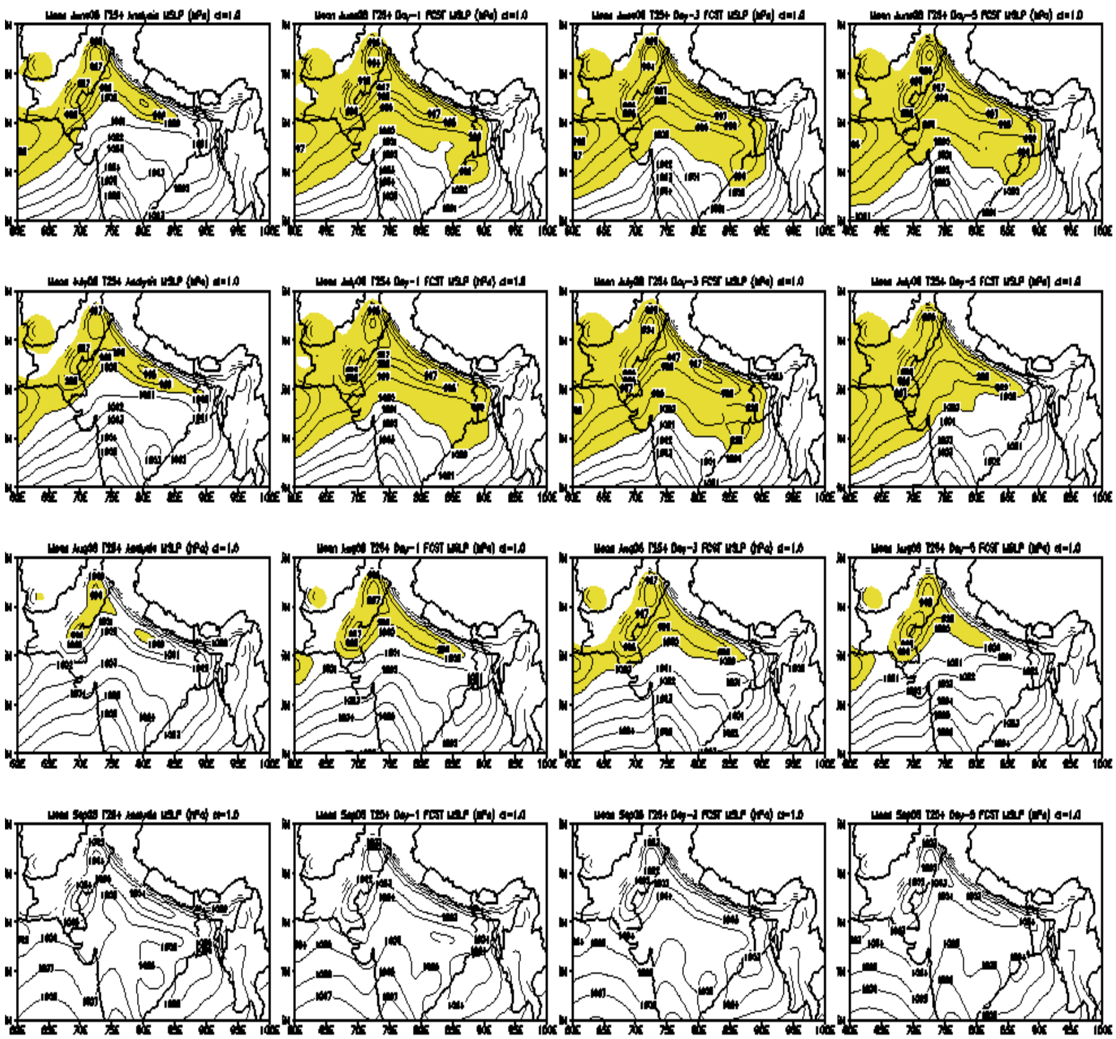


Fig. 1 NCMRWF T254 model monthly mean of MSLP analysis and Day-1 (24 hrs), Day-3 (72 hrs) and Day-5 (120 hrs) forecast over the Indian region for June, July, August and September, 2008.

4. Monsoon Depressions

During June-September 2008, only four depressions formed ((i) one depression over the Arabian Sea and (ii) another over Bay of Bengal during June, (iii) one land depression over coastal Orissa during August and (iv) one deep depression over the Bay of Bengal during September. The tracks of all four systems are shown in Figure. 1. The month of July was devoid of any monsoon depression like the previous July of 1995, 1998, 2000, 2001, 2002 and 2004.

Global model forecast verification is carried out with the aim of studying the impact of higher resolution and radiance assimilation available with the new global model. The study is carried out for the three systems of Bay of Bengal and one depression of Arabian Sea.

(1) Depression during 5th and 6th June 2008 over Arabian Sea that moved westward and weakened over the Arabian Sea as shown in Figure 2.

(2) Depression during 15th to 18th June 2008 over Bay of Bengal that crossed Bangladesh coast and moved into Gangetic WestBengal and Jharkhand (Figure 2).

(3) Depression during 9th and 10th August 2008 over coastal Orissa (Figure 2).

(4) Deep Depression during 15th to 19th September 2008 over northwest Bay of Bengal and crossed Orissa coast (Figure 2).

(1) 5th - 6th June - Arabian sea

On 4th June a low pressure area formed over east-central Arabian Sea and persisted all through the day. It was predicted to become more marked and move northwestwards. On 5th June the depression over east-central Arabian Sea moved northwestwards and lay centered at 1430 hours IST over east-central and west-central Arabian Sea near Lat. 17.0°N Long. 65.0°E about 850 km west-southwest of Mumbai. It was predicted to intensify further and move in a northwesterly direction. It indeed moved westward and weakened over the Arabian Sea. Figure 2 shows the 850 hPa circulation in the T254L64 analysis (Day-0) and the Day-1, day-3 and Day-5 forecasts of T254L64 valid for 6th of June 2008. The Arabian Sea typically features weak monsoon current which is still picking up. The weak diffused cyclonic circulation can be seen at around 20 N in the analysis (Figure 3). In the forecasts the circulation is much to the south.

(2) 16th - 18th June - Bay of Bengal

On 16th June 2008 the depression over north Bay of Bengal off Bangladesh coast moved in a westerly direction and lay centered at 1430 hrs. IST of 16th June 2008 near Lat 21.5°N & Long. 89.5°E, close to Bangladesh coast and about 170 km southeast of Kolkata. It was predicted to move in a northwesterly direction and cross Bangladesh coast between Long 89.0°E & 89.5°E by 16 evening. However on 17 Jun 2008 the depression over Gangetic West Bengal and adjoining Bangladesh moved west-northwestwards and lay centered at 1430 hours IST of 17th June 2008 over Gangetic West Bengal close to Burdwan about 100 km north-northwest of Kolkata. It was predicted to move in a northwesterly direction causing wide spread rainfall with heavy to very heavy falls at a few places and isolated extremely heavy falls (>25 cm) is likely over Gangetic West Bengal during next 24 hours and over north Orissa and Jharkhand for following next 48 hours. On 18th the depression over Jharkhand weakened and lay as a well marked low pressure area over Jharkhand and neighborhood and on 19th the low pressure area moved over northeast Madhya Pradesh and adjoining East Uttar Pradesh. On 20th June the low pressure area over northeast Madhya Pradesh and adjoining East Uttar Pradesh persists. The system caused heavy to extremely heavy rainfall over Gangetic West Bengal, north Orissa and Jharkhand leading to flood over these regions. Figure 4 shows the 850 hPa circulation in the T254L64 analysis and the forecasts. The movement of the system over land is predicted in the Day-5 forecast also and is consistently seen in the Day-1 and Day-3 forecasts.

(3) 9th-10th August over Coastal Orissa

On 6th of August 2008 it was predicted that a fresh low pressure area is likely to form over northwest and adjoining west-central Bay of Bengal around 9th August and also that it was likely to increase rainfall activity over central & adjoining peninsular India from 9th onwards. The rainfall activity is also likely to increase along the west coast and Gujarat state with possibility of heavy to very heavy falls from 9th onwards. On 8th morning a low pressure area over northwest and adjoining westcentral Bay of Bengal off Orissa and West Bengal coast formed and persists. It was predicted to become more marked. On 10th August 2008 the depression over north interior Orissa remained practically stationery and lay centered at 1430 hours IST of 10th August 2008, near Keonjhargarh. The system was predicted to move in a northwesterly direction and weaken gradually. Figure 5 shows the

850 hPa circulation in the analysis and forecasts valid for 10th August 2008. The formation of an intense system off Orissa coast is clearly seen in the Day-5 forecast.

(4) 15th to 19th September 2008

On the morning of 14th September the Numerical Weather Prediction models indicated the formation of a fresh low pressure area over west central and adjoining northwest Bay of Bengal around 15^{th}. Under its influence, rainfall activity is likely to increase initially over Andhra Pradesh and Orissa. Further at 14:30 of same day the forecasts indicated that it is likely to develop into a low pressure area during next 24 hours. On 16th it intensified into a depression and lay centered at 19.5^{0} N and 88.0^{0} E. The system was predicted to further intensify and move initially in a west-northwesterly direction. On 17th evening the deep depression lay centered at 1730 hrs IST near Jharsuguda. On 18th morning the deep depression over north Orissa remained practically stationary. Same afternoon it moved northwestwards and weakened into a depression and lay centered close to Pendra in Chhattisgarh. Later on 20th the depression weakened into a well marked low pressure area and lay over northwest Uttar Pradesh. Figure 6 shows the 850 hPa circulation in the analysis and forecasts valid for 18th August 2008 close to the landfall position over Orissa. Day-1, Day-3 and Day-5 forecasts indicate slightly varying landfall positions. Day-5 forecast indicates rather very intense system not seen in the analysis.

Tracks of the Arabian sea depression in each of the models is shown in the Figure 7a. A comparison with Figure 1 clearly suggests that none of the models could correctly predict the northwestward prediction of the system. Eta, T254 and UKMO predicted the movement in the north-ward direction while WRF and MM5 predicted movement in the north-north-east-ward direction taking the system closer to the Indian coast. For the Bay of Bengal depression of the June 2008, the models indicate a larger spread as seen in the Figure 7b. The north-west-ward movement is captured only in the UKMO model. Although T254 also takes the depression north-west-ward, the track is much to the south of the observations. The mesoscale models completely miss the track and they keep the depression towards north. For the August 2008 depression off the Orissa coast, the models show a greater consensus and are closely packed as shown in Figure 7c. However for the September 2008 depression the models show no consensus. T254 and UKMO show north-west ward movement while the mesoscale models show north-ward movement.

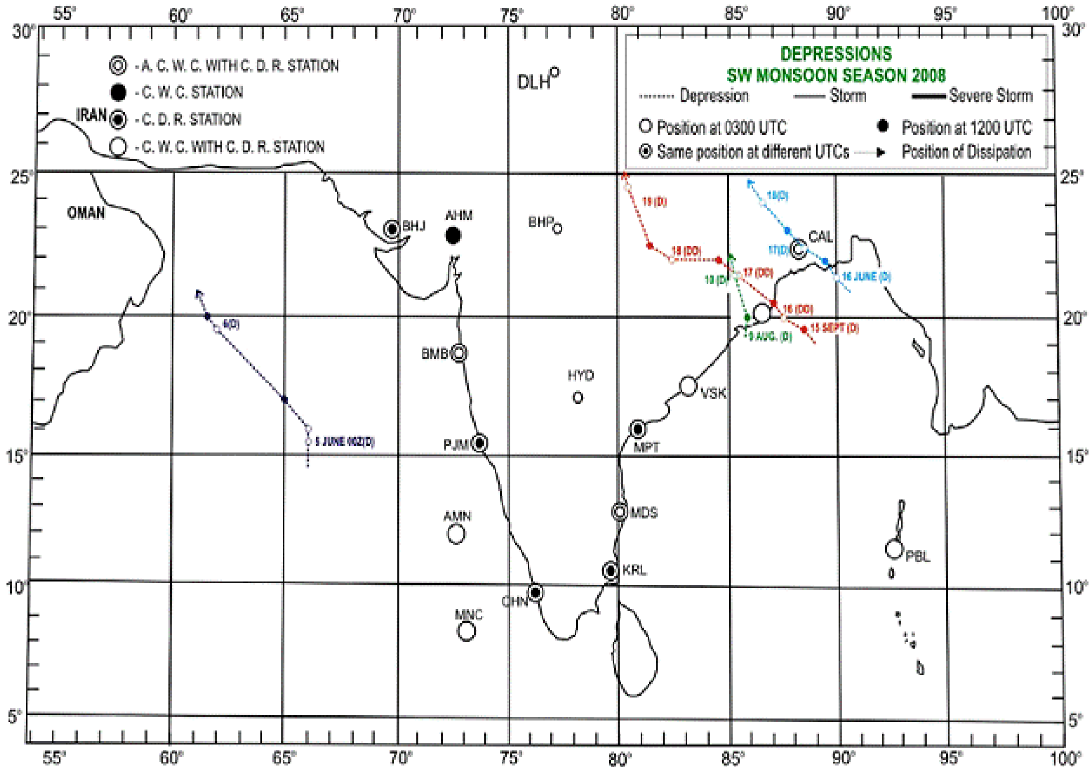


Figure 2. Observed tracks of the Arabian Sea and Bay of Bengal Monsoon depressions during JJAS 2008

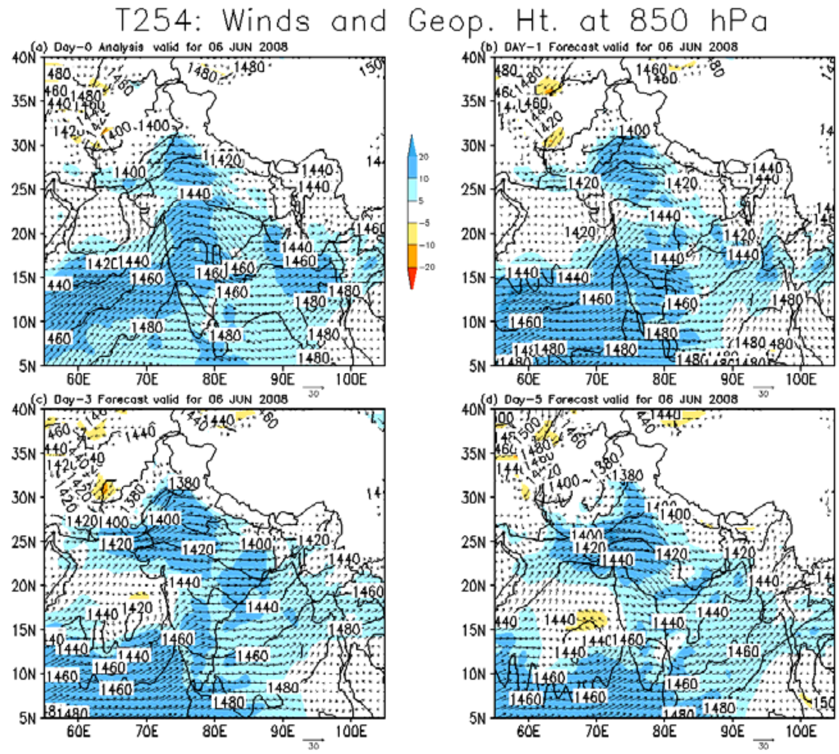


Figure 3. Winds and Geopotential height at 850 hPa in the T254L64 analysis and forecasts valid for 6th June 2008.

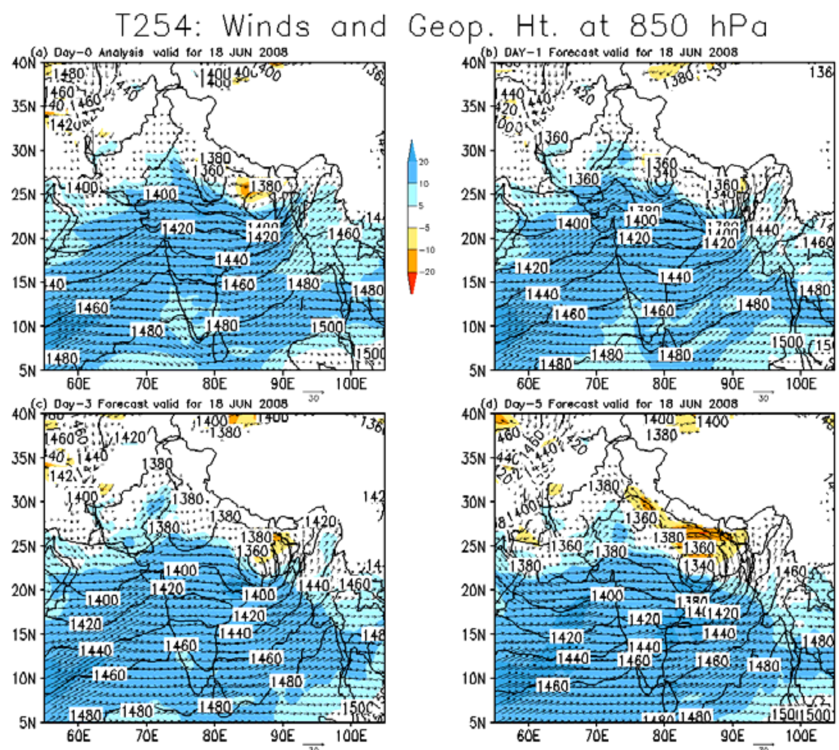


Figure 4. Winds and Geopotential height at 850 hPa in the T254L64 analysis and forecasts valid for 18th June 2008.

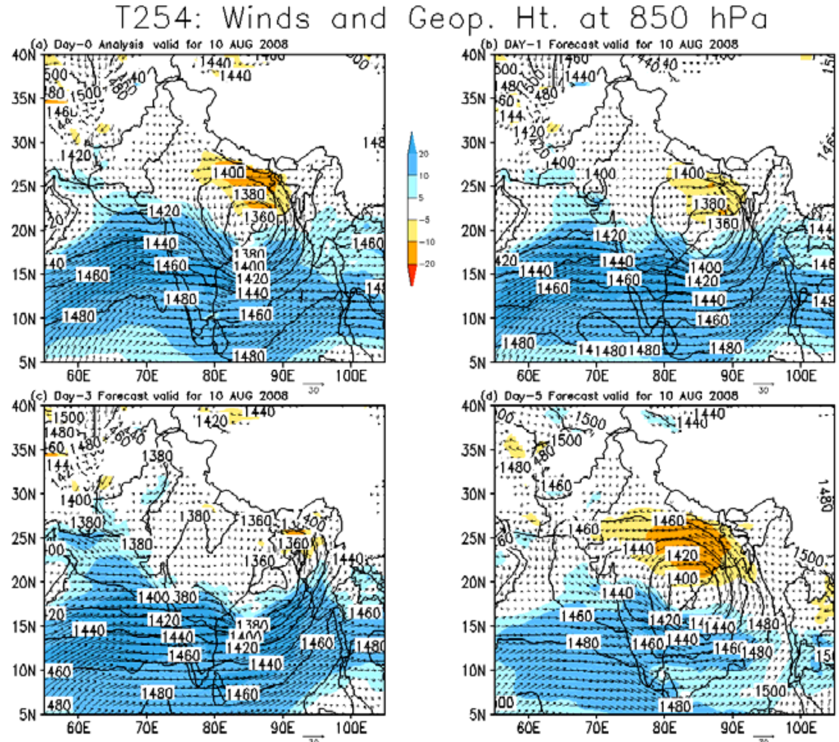


Figure 5. Winds and Geopotential height at 850 hPa in the T254L64 analysis and forecasts valid for 10th Aug 2008.

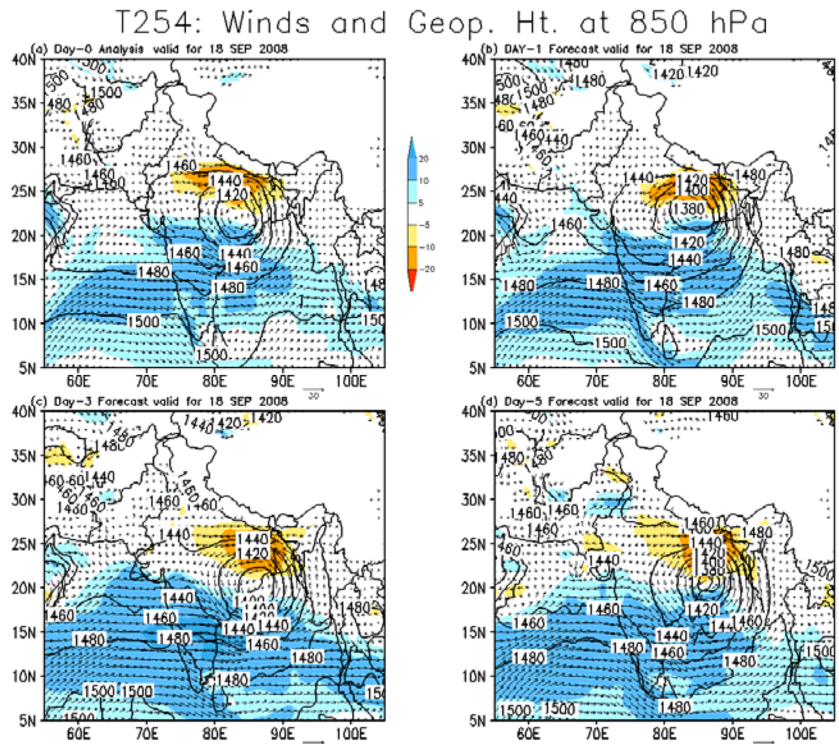


Figure 6. Winds and Geopotential height at 850 hPa in the T254L64 analysis and forecasts valid for 18th Sept 2008.

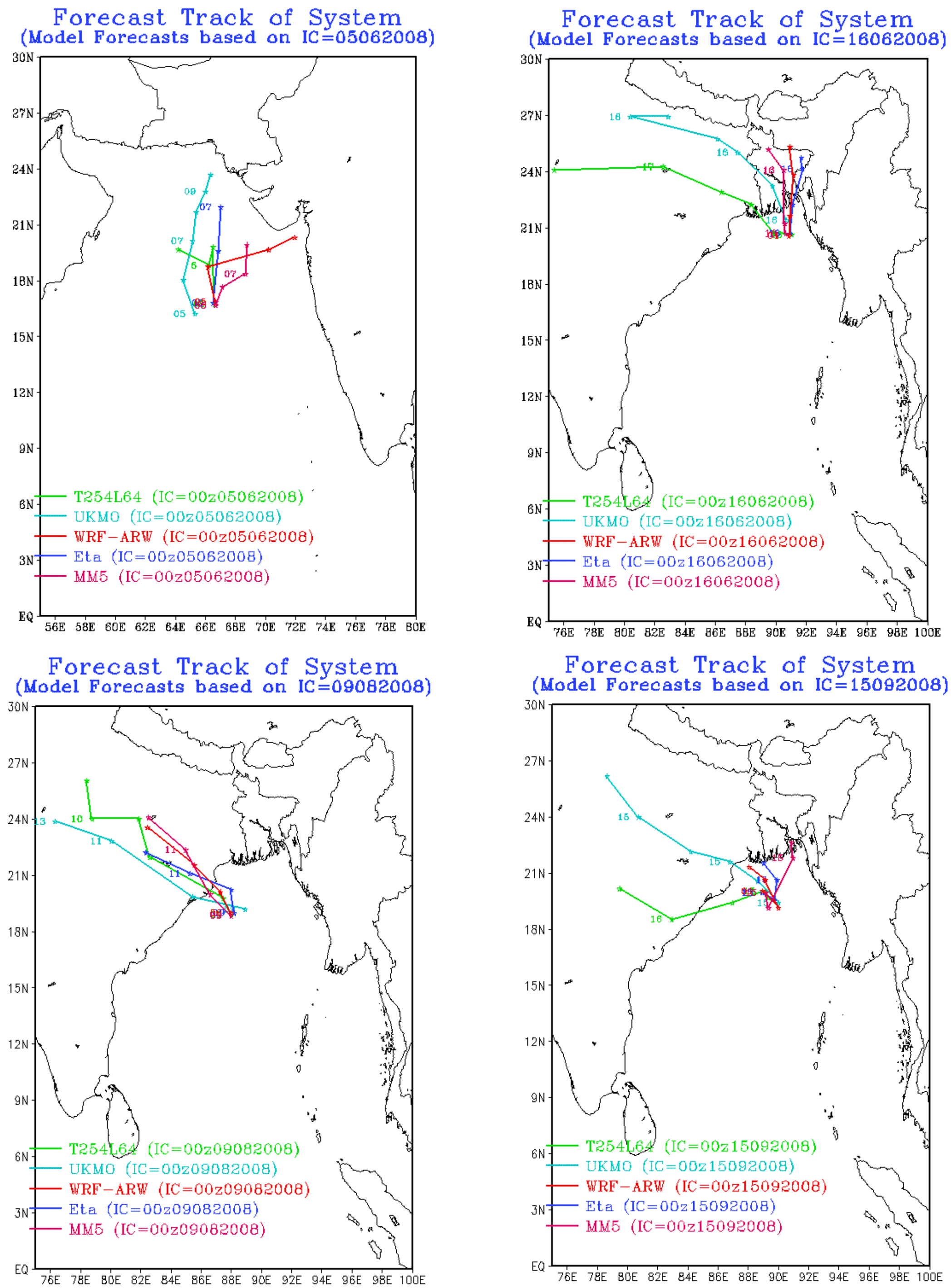


Figure 7. Model predicted tracks of the Monsoon depressions during JJAS 2008.

Mascarene High, Cross-Equatorial Flow, Low-Level Westerly Jet and North-South Pressure Gradient

A. K. Mitra, M. Das Gupta and G.R.Iyengar

1. Introduction

Low-level westerly jet is one of the most important feature of the south Asian summer monsoon system. Through the cross-equatorial flow, southern hemisphere's Mascarene High influences the low level jet in the Arabian Sea. The influence of the southern hemispheric weather systems on the activity of monsoon over India is also very important (Rodwell, 1997). The final strength of the monsoon flow is manifested in the north-south pressure gradient along the west coast of India. Arabian Sea and the Bay of Bengal are among the few regions of earth, where the low-level jets (LLJ) are seen with some regularity in the annual cycle. These jets are related to the synoptic-scale forcing and have narrow zones of high-speed flow that extend for hundreds of kilometers. These LLJs have appreciable horizontal and vertical shear. These are also important for the fluxes of temperature and moisture (both horizontal and vertical) and are generally associated with the development and evolution of deep convection over the Indian sub-continent and the neighboring regions in the south Asia. Under a wide variety of synoptic conditions, the proper representation of the development and the evolution of these LLJs in a global numerical model (with particular resolution) the physical mechanisms like the shallow baroclinicity (in PBL) interacting with many factors like the strong geostrophic forcing, the horizontal SST gradients, terrain effects are to be taken care of adequately (Stensrud, 1996; Krishnamurti et al., 1976). Oscillations in the strength of the Mascarene high have been linked to variability of monsoon rainfall (Krishnamurti and Bhalme, 1976). The model vertical and horizontal resolution should also be fine enough to represent adequately the forces responsible for maintenance and day-to-day variations in the strength of the low level westerly jet over the Arabian Sea. A higher resolution model is highly desirable for capturing the meso-scale convective structures in the monsoon system adequately (Krishnamurti et al.,1995; Sperber et al., 1994) .

The performance of the high resolution global model's (T254L64) assimilation-forecast system running in real-time during the monsoon 2008 in respect of the Mascarene High (MH), Cross-equatorial flow (CEF), the low level westerly jet (LLWJ) and the north-south pressure gradient along west coast is described briefly in this chapter. Description of the global modeling system with its assimilation aspects are described in section one of this report.

2. Performance of Model

2.1 Mascarene High (MH)

During monsoon 2008, the analyzed mean intensity of the Mascarene High was 1032.9 hPa (more intense) and it's position was approximately at 70^0 E and 35^0 S, as seen from the data of T254L64 global modelling system. The observed analysed positions from the modeling system (during 2008) are to further south in latitudinal position of the long-term (80 years mean data) observed mean location of 69^0 E, 27^0 S with intensity of 1024 hPa (Gorshkov, 1977). Three panels in Fig. 1 show the day-to-day variations of the intensity of the Mascarene High produced by the T254L64 analyses (lines with square marks) during monsoon (June-September 2008). The corresponding intensities from the T254L64 model forecasts for Day-1, Day-3 and Day-5 are shown in lines with diamond marks. The intensities produced in Day-1 forecasts agree very well with the analysis. For the Day-3 forecasts, a very good agreement is seen in general, except few episodes. In Day-5 forecasts the disagreement is more compared to Day-1 and Day-3 forecasts. The root mean square errors (RMSE) of the predicted intensity of the Mascarene High for Day-1, Day-3 and Day-5 forecasts are 2.7 hPa, 4.5 hPa and 5.6 hPa respectively. These errors are higher compared to the errors seen during monsoon 2007 season.

The longitudinal positions of the Mascarene High (MH) produced from T254L64 system's analysis (lines with square marks) and forecast (lines with diamond marks) are shown in different panels of Fig.2 for the full monsoon 2008 period. From the analyzed positions it is seen that the major Indian Ocean Anticyclone (MH) moves from west to east in association with the passage of southern hemisphere's westerly waves with variations in the amount of eastward movement in time. The Day-1 forecasts are able to reproduce these variations very well. The agreement between the analysis and the Day-3 forecasts are also generally very good, with just few noticeable mismatches. The Day-5 forecasts indicate that the variability in longitudinal positions are captured well, but have more errors compared to the Day-1 and Day-3 forecasts. The RMSE of the predicted longitudinal positions of the Mascarene High for Day-1, Day-3 and Day-5 forecasts are 16.9^0, 24.5^0 and 22.8^0 respectively. These errors are almost double in magnitude compared to those during monsoon 2007 period.

Latitudinal positions of the Mascarene High during monsoon 2008 are shown in different panels of figures 3. Lines with square marks show the analysed (observed) positions, and the line with diamond marks show the predicted positions. From the analyzed positions it is clear that the MH also oscillates in north-south direction around its mean position during monsoon season. In the T254L64 model, the Day-1 and Day-3 forecasts are agreeing well with the analyzed latitudinal positions, except few episodes. In Day-5 forecasts the positional errors are more compared to Day-1 and Day-3 errors. The RMSE of the predicted latitudinal positions of the Mascarene High for Day-1, Day-3 and Day-5 forecasts are 3.6^0, 4.6^0 and 4.5^0 respectively. These errors are higher to those compared for the monsoon 2007 period.

2.2 Cross-Equatorial Flow (CEF)

The time mean analyzed, Day-1, Day-3 and Day-5 forecasts of the meridional wind at equator over the sector 30^0 E-100^0 E with mean taken over the entire monsoon period (June to September 2008) are shown in figure 4 in the form of longitude-height cross-sections. In T254L64 model, the analyzed field shows prominent maxima of 14 mps around 40^0 E at 875 hPa representing the core of the Arabian Sea branch of the cross-equatorial flow and a secondary maxima of 3 mps between 80^0 E - 90^0 E, representing the Bay of Bengal branch. The dual core of cross-equatorial flow in the Arabian Sea is not seen in this year's analysis, which was observed during monsoon season of 1995 and 1998. This dual core was also absent in recent monsoons of 2005, 2006 and 2007(NCMRWF Report 2006a, NCMRWF Report 2006b and NCMRWF Report 2008). During monsoon 2008, all the forecasts (day-1 through day-5 predictions) of the cross-equatorial flow (Arabian Sea branch) indicate a slight intensification of the strength of cross equatorial flow to 15 mps (very similar to monsoon 2007). The core of the Arabian Sea branch of CEF is well maintained at 15 mps in a very consistent way. The Bay of Bengal branch of the cross-equatorial flow is also maintained well in the T254L64 model. Overall, the skill of the new T254L64 model is very good during monsoon 2008, in terms of capturing and maintaining the low-level cross equatorial flow both in the Arabian Sea and the Bay of Bengal.

The mean (June to September 2008) vertical profiles of meridional wind averaged over the domain 2.5^0 S - 2.5^0 N; 39^0 E - 51^0 E from the analysed, Day-1, Day-3, and Day-5 prediction fields from T254L64 are shown in figure 5. It is seen that the maxima of the cross-equatorial flow occurs at around 875 hPa in the mean analysis. The intensity and location forecasts of CEF from the T254L64 model agrees very well with the observations (analysis), indicating that the CEF is well maintained in the T254L64 model.

2.3 Low-Level Westerly Jet (LLWJ)

The mean analyzed and predicted positions and strength of the low-level westerly jet (LLWJ) in the Arabian Sea at 850 hPa from T254L64 are shown in different panels of figure 6 for the whole monsoon season. This diagram brings out clearly the well maintenance of the strength and location of LLWJ in the Arabian Sea throughout the forecast length (day-1 through day-5) in this new high-resolution model. The contour of 15 mps adjacent to Somalia coast in the Arabian Sea is very consistent in analysis and the forecasts. The winds in the Bay of Bengal and peninsular India are also very well maintained in the forecasts compared to the analysis. As a result the monsoon trough over the central India is also well maintained in the forecasts in the T254L64 model.

The north-south cross-sections of seasonal mean analyzed and predicted (Day-1, Day-3 and Day-5) zonal component of wind along 54^0 E, a longitude which falls within the climatological location of LLWJ, from T254L64 model are given in figure 7. The observed core of the jet matches with the climatological location. The jet core is observed to be at 16 mps in T254L64 model. Here the second core (dual core) of 10 mps at around 15^0 N is also seen during 2008 monsoon. The model forecasts (Day –1 through Day –5) are matching very well with the observed jet strength and position. Even the dual core system is very well maintained in the model. Throughout the forecast length the LLWJ is seen to be very consistent in structure among each other and also with the observed analysis. The strength is seen to be slightly intensifying from day-1 through day-5 forecasts. In general, the representation and maintenance of LLWJ is very good in the high resolution T254L64 model.

The latitude-height cross-sections of seasonal mean analyzed and predicted zonal wind along 75^0 E (a longitude where the low-level westerlies interact with the west coast orography leading to heavy rainfall) from T254L64 system is given in figure 8. The maximum zonal wind in analysis is seen to be between 7 to 8 mps. The second core at 16^0 N represents the monsoon trough region (a very important feature of monsoon system) is seen to be quite strong at 10 mps. During the forecast in general the strength is well maintained, with slight intensification. The position and intensity of the monsoon trough is also well maintained. The strength of the core at 10^ON is well maintained, but its position is seen to shift southward (from 10^0 N in analysis to 6^0 N in day-5 forecast). This southward shift was also noticed during monsoon 2007 season in data from T254L64 system. This will have impact on the location of the rainfall distribution along the west coast of India in respect to LLWJ. Figure 9 shows the daily verification of day-1, day-3 and day-5 forecasts of the zonal winds (u) at a station (Mumbai) against RS/RW observed values at 850 hPa during monsoon 2008. It is seen that daily variability of wind at a station is also captured well in the model forecasts. The RMS errors of the day-1, day-3 and day-5 forecasts are 3.42, 3.76 and 3.71 mps respectively. The error of the analysis itself (from the data assimilation system) is seen to be 2.0 mps during the season. This shows that the high resolution model forecasts do a fairly good job in capturing the zonal wind variability even at a station like Mumbai.

2.4 North-South Pressure Gradient

The daily variations of analyzed (line with square marks) and predicted (line with diamond marks) values of north-south pressure gradient along the west coast of India from T254L64 model are shown in different panels of figure 10, for the monsoon 2008 season. In T254L64 model, the day-1 forecasts match very well with the corresponding analyzed values. Even in day-3 forecasts the feature of north-south pressure gradient along west coast of India is captured reasonably well. However, day-5 forecasts have higher errors (in amplitude and phases) compared to day-1 and day-3 forecasts. In T254L64 model the RMSE of the predicted north-south pressure gradient along the west coast of India for Day-1, Day-3 and Day-5 forecasts are 1.2, 2.3 and 3.2 hPa respectively. These errors are similar in magnitude as compared to monsoon 2007 season from the same model. Overall, in high resolution T254L64 model the day-to-day variability in the north-south pressure gradient (a measure of strength of monsoon) in terms of amplitude and phases are captured well.

3. Summary

The high resolution T254L64 global model running in real time at NCMRWF with it assimilation system is able to represent the low level features of monsoon circulation system adequately. During monsoon 2008, in general the medium range forecasts from the model are able to bring out the order of variability in the intensity and positions of Mascarene High. The cross-equatorial flow near its core is captured well in the model having less error. The low level westerly jet's strength and positions near Somalia coast (Arabian Sea) are represented well in the T254L64 model. The T254L64 model has a tendency to slightly shift the LLWJ (zonal wind around 75^{O} E, near west coast) southward over the Arabian Sea. All these features are manifested in the T254L64 model representation of low-level wind flow, north-south pressure gradient and the monsoon trough over India sub-continent. The high resolution T254L64 modelling system captures the low-level circulation features well.

Legends for Figures

Fig. 1. Intensity of the Mascarene high in the analysis against Day-1, Day-3 and Day-5 forecasts during monsoon 2008.

Fig. 2. Longitudinal position of Mascarene high in the analysis against Day-1, Day-3 and Day-5 forecasts during monsoon 2008.

Fig. 3. Latitudinal position of Mascarene high in the analysis against Day-1, Day-3 and Day-5 forecasts during monsoon 2008.

Fig. 4. Time mean analyzed, Day-1, Day-3 and Day-5 forecasts of meridional wind at equator over the sector 30^0 E-100^0 E, during monsoon 2008.

Fig. 5. Time mean vertical profiles of meridional wind averaged over the domain 2.5^0 S-2.5^0 N & 39^0 E-51^0 E, during monsoon 2008.

Fig. 6. Mean analyzed, Day-1, Day-3 and Day-5 forecasts of 850 hPa flow pattern and wind speeds, during monsoon 2008.

Fig. 7. North-south cross-section of seasonal mean analyzed, Day-1, Day-3 and Day-5 forecasts for Zonal component of wind along 54^0 E, during monsoon 2008.

Fig. 8. North-south cross-section of seasonal mean analyzed, Day-1, Day-3 and Day-5 forecasts for Zonal component of wind along 75^0 E, during monsoon 2008.

Fig. 9. Daily verification of day-1, day-3 and day-5, forecast zonal winds (u) at a station (Mumbai) against RS/RW observed values during monsoon 2008, at 850 hPa

Fig. 10. Analyzed, Day-1, Day-3 and Day-5 forecasts of North-South Pressure Gradient along west coast during monsoon 2008

Reference

Gorshkov, S.G., (Ed.), 1977: World Ocean Atlas - Atlantic and Indian Oceans, Chief Directorate of Navigation and Oceanography, Former USSR.

Sperber,K.R., S.Hameed, G.L.Potter and J.S.Boyle 1994: "Simulation of the norther summer monsoon in the ECMWF Model: Sensitivity to horizontal resolution",MWR,122(11),2461-2441.

Krishnamurti T.N., S.K. Roy Bhowmik, D. Oosterhof, G. Rohaly, and N. Surgi, 1995, Mesoscale Signatures within the Tropics Generated by Physical Initialization , MWR, 123 (9), 2771–2790

NCMRWF, DST(GOI), January 2006a: ‘Monsoon 2005: Performance of the NCMRWF Global Assimilation Forecast System’, Report no. NMRF/MR/01/2006, 139 pages, Published by NCMRWF(DST), A-50, Institute Area, Sector – 62, UP, India 201307, chapter 5, pages 71–88

NCMRWF, MoES(GOI), December 2006b: ‘Monsoon 2006: Performance of the NCMRWF Global Assimilation-Forecast System’, Report no. NMRF/MR/02/2006, 114 pages, Published by NCMRWF(MoES), A-50, Institute Area, Sector – 62, UP, India 201307, Chapter 4, pages 51–66.

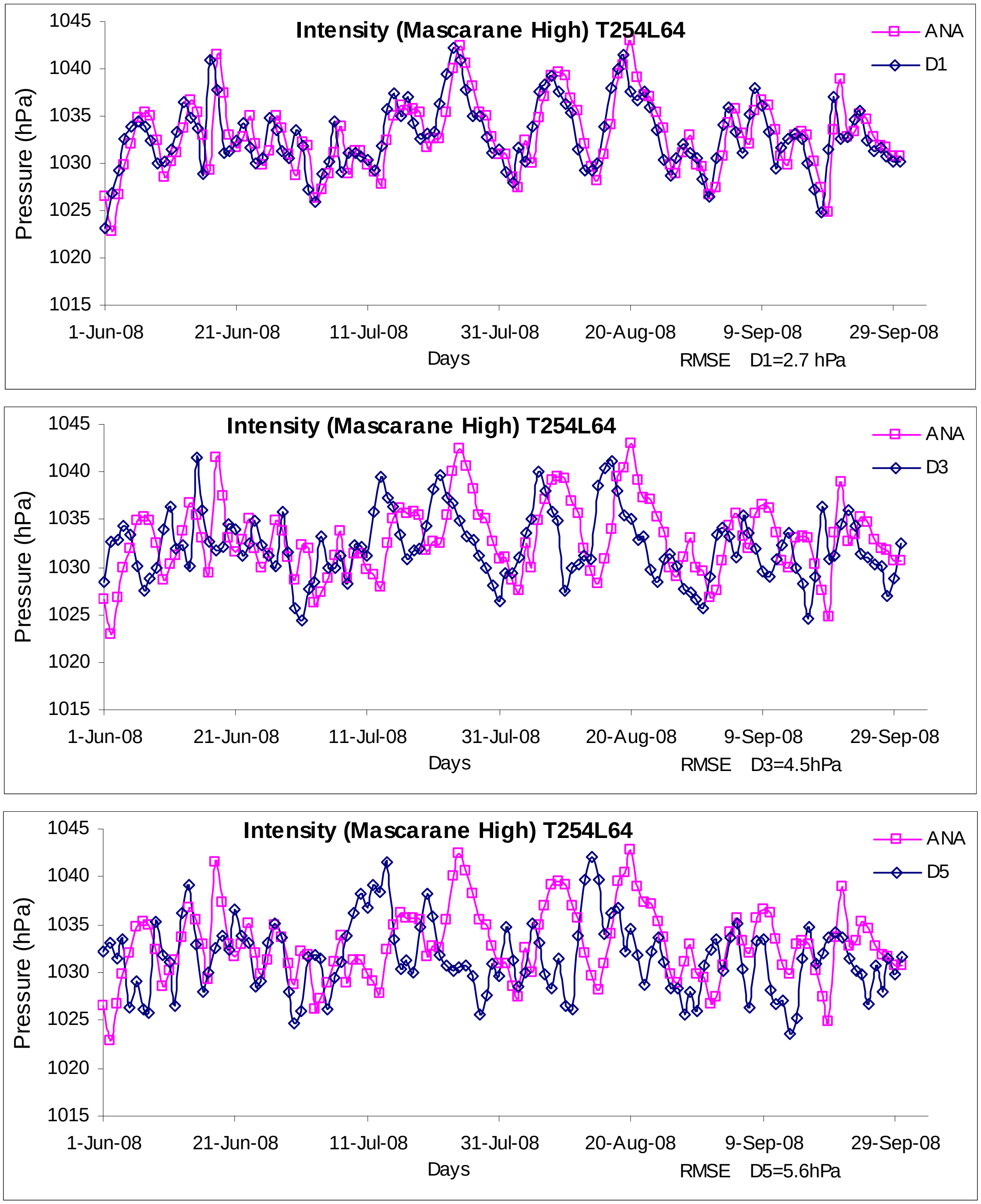
NCMRWF, MoES(GOI), January 2008: ‘Monsoon 2007: Performance of T254L64 Global Assimilation-Forecast System’, Report no. NMRF/MR/01/2008, 143 pages, Published by NCMRWF(MoES), A-50, Institute Area, Sector – 62, UP, India 201307, Chapter 5, pages 67–93.

Krishnamurti,T.N., and Bhalme,H.N., 1976 : Oscillations of a monsoon system . Part I: Observational aspects, JAS, 33, 1937-1954.

Krishnamurti,T.N.K., J.Molinari and H.L.Pan 1976: Numerical Simulation of the Somali Jet, JAS, 33, 2350-2362.

Rodwell,M.J., 1997: Breaks in the Asian Monsoon: The influence of southern hemisphere weather system, JAS, 54(22), 2597-2611.

Stensrud, D.J., 1996: Importance of Low-Level Jets to Climate: A Review, J. of Climate,8(9), 1698-1711.



Intensity (Mascarane High) T254L64
ANA
D1
Pressure (hPa)
1045
1040
1035
1030
1025
1020
1015
1-Jun-08
21-Jun-08
11-Jul-08
31-Jul-08
20-Aug-08
9-Sep-08
29-Sep-08
Days
RMSE D1=2.7 hPa
Intensity (Mascarane High) T254L64
ANA
D3
RMSE D3=4.5hPa
Intensity (Mascarane High) T254L64
ANA
D5
RMSE D5=5.6hPa

Fig. 1

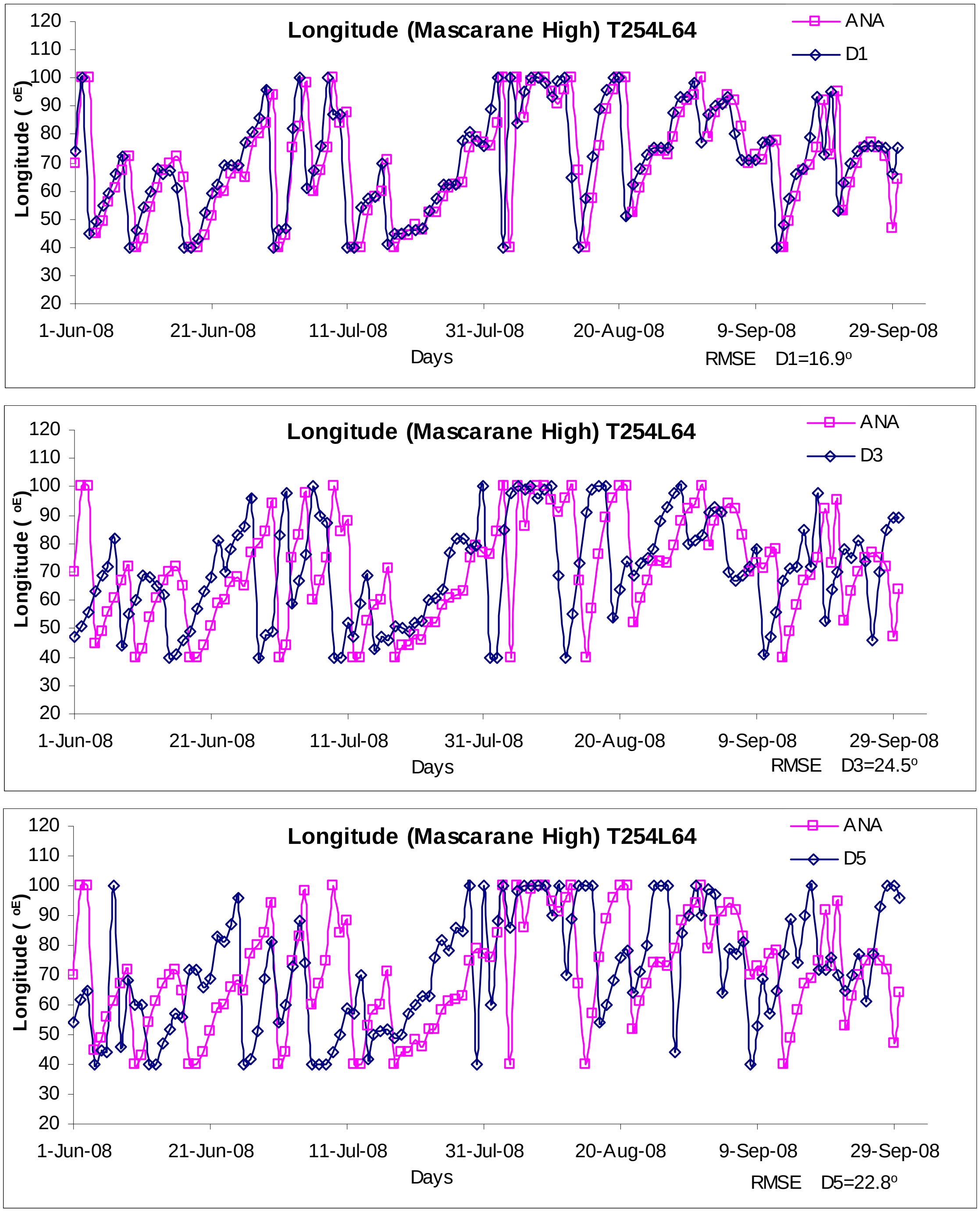
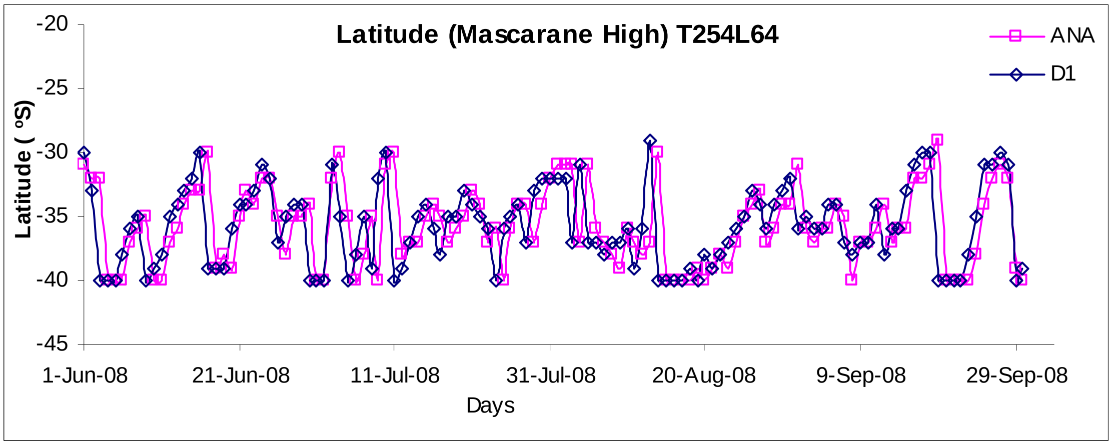
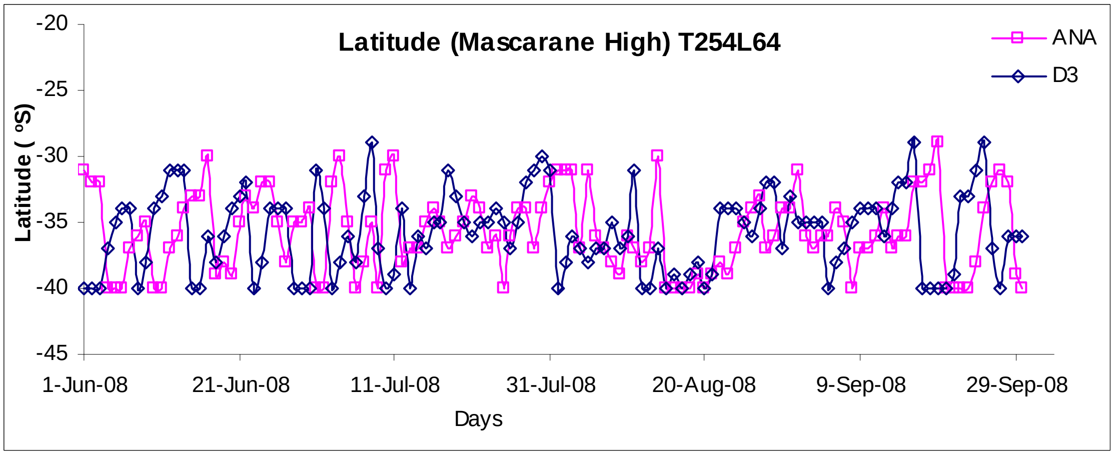

Longitude (Mascarane High) T254L64
ANA
D1
Longitude (oE)
Days
RMSE D1=16.9o
1-Jun-08
21-Jun-08
11-Jul-08
31-Jul-08
20-Aug-08
9-Sep-08
29-Sep-08
Longitude (Mascarane High) T254L64
ANA
D3
RMSE D3=24.5o
Longitude (Mascarane High) T254L64
ANA
D5
RMSE D5=22.8o

Fig. 2

RMSE D1 = 3.6^0



RMSE D3 = 4.6^0



RMSE D5 = 4.5^0

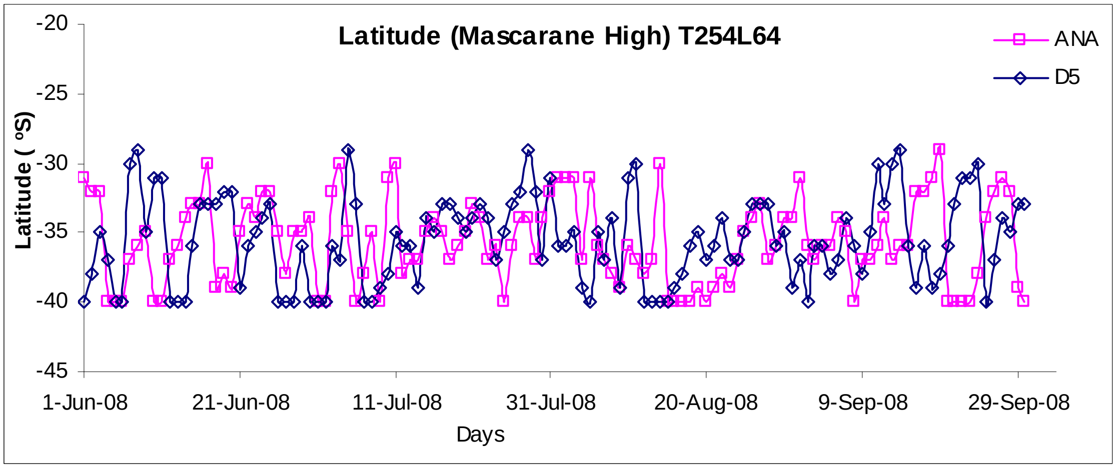


Fig. 3

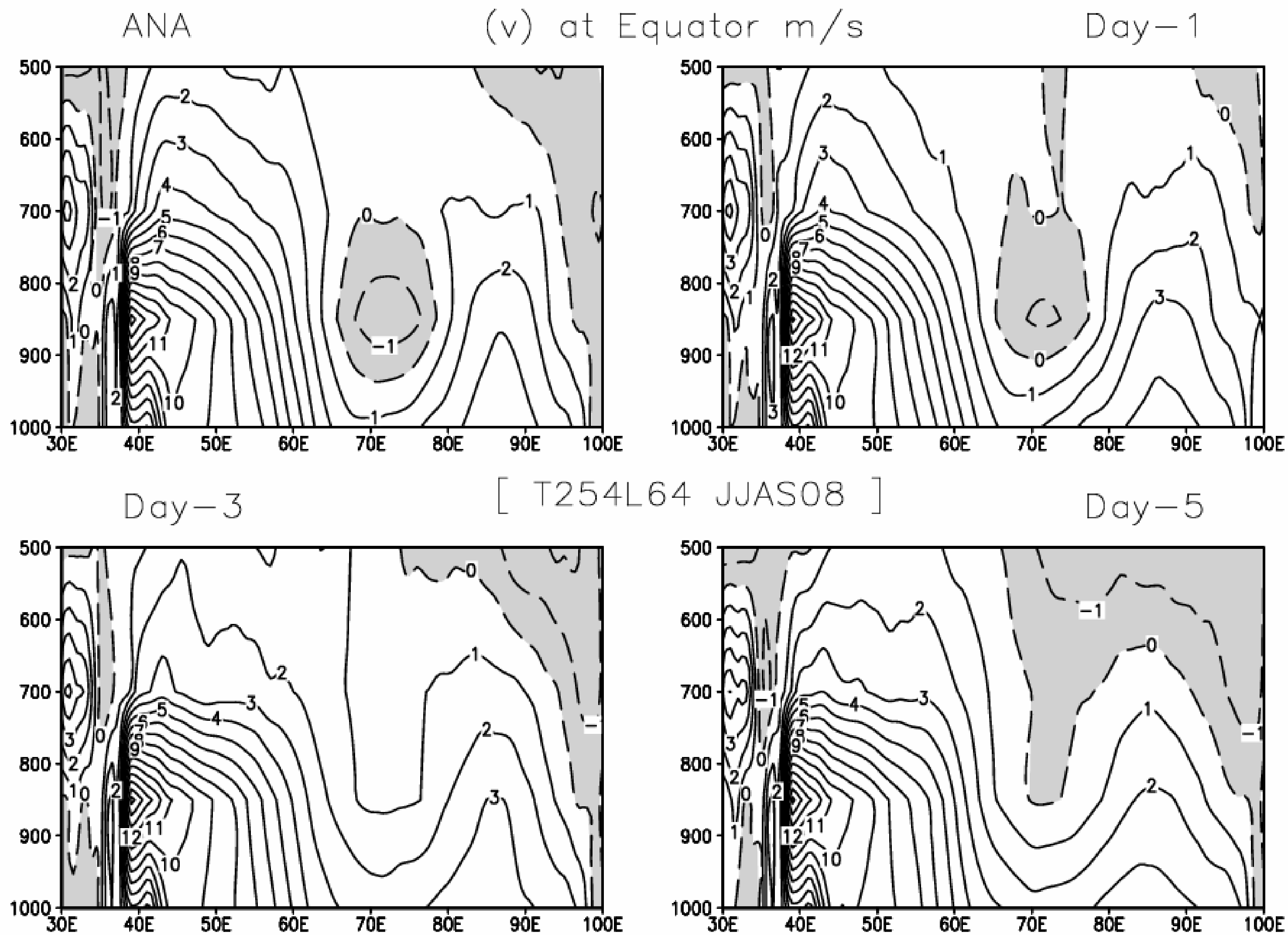

(v) at Equator m/s
ANA
Day−1
Day−3
Day−5
[T254L64 JJAS08]
500
600
700
800
900
1000
30E
40E
50E
60E
70E
80E
90E
100E

Fig. 4

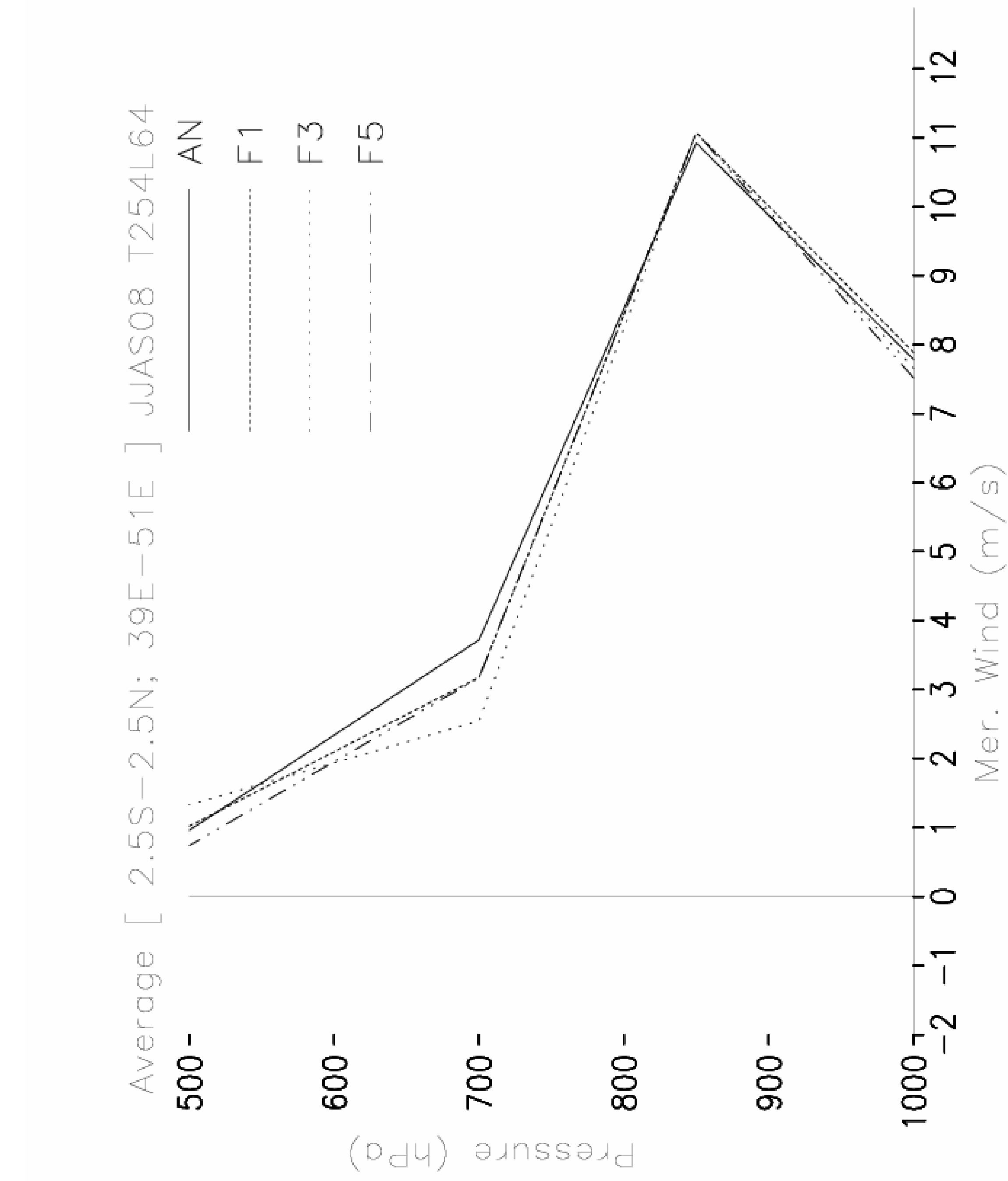

Average [2.5S–2.5N; 39E–51E] JJAS08 T254L64
AN
F1
F3
F5
Pressure (hPa)
500
600
700
800
900
1000
–2
–1
0
1
2
3
4
5
6
7
8
9
10
11
12
Mer. Wind (m/s)

Fig. 5

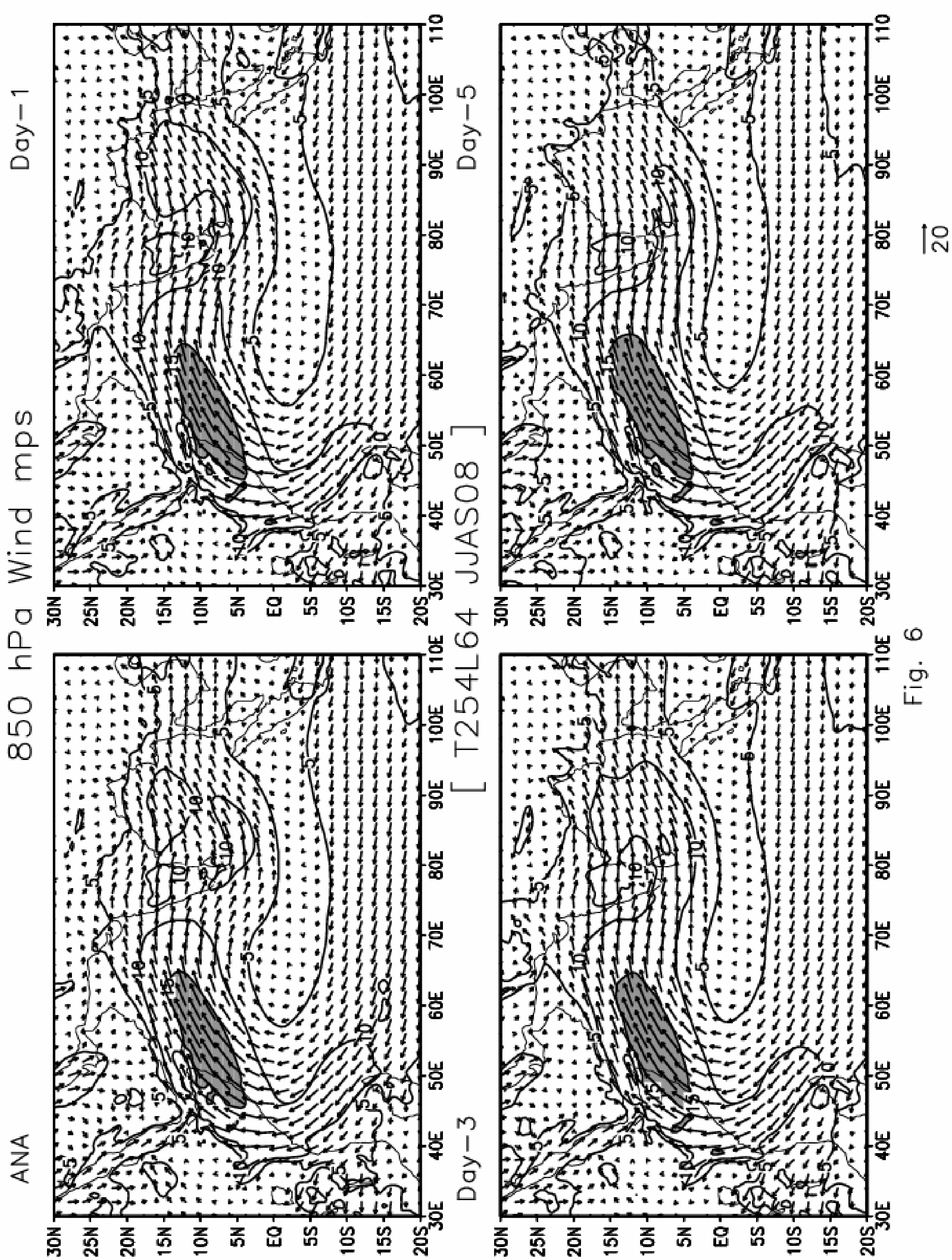


Fig. 6

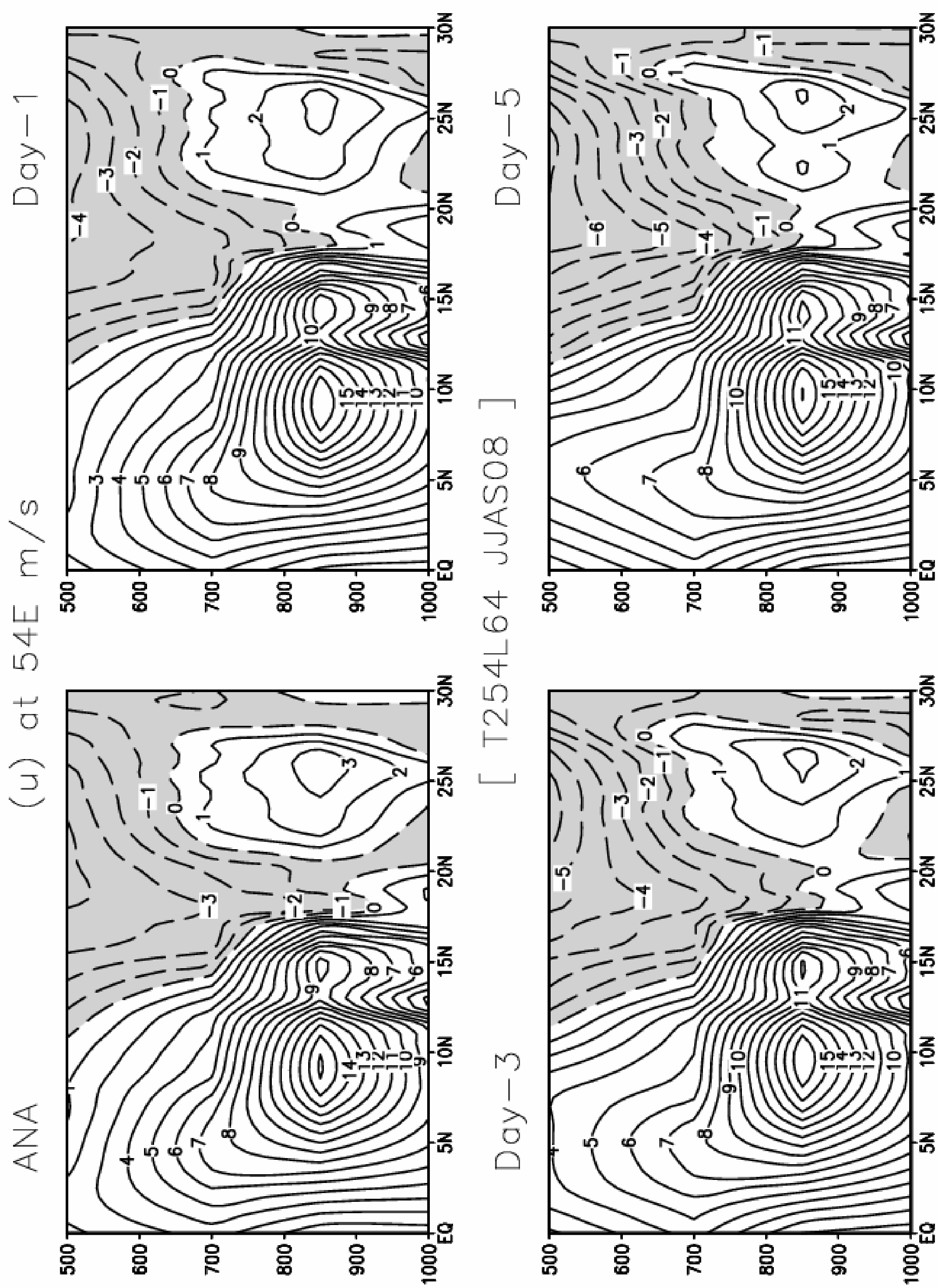


Fig. 7

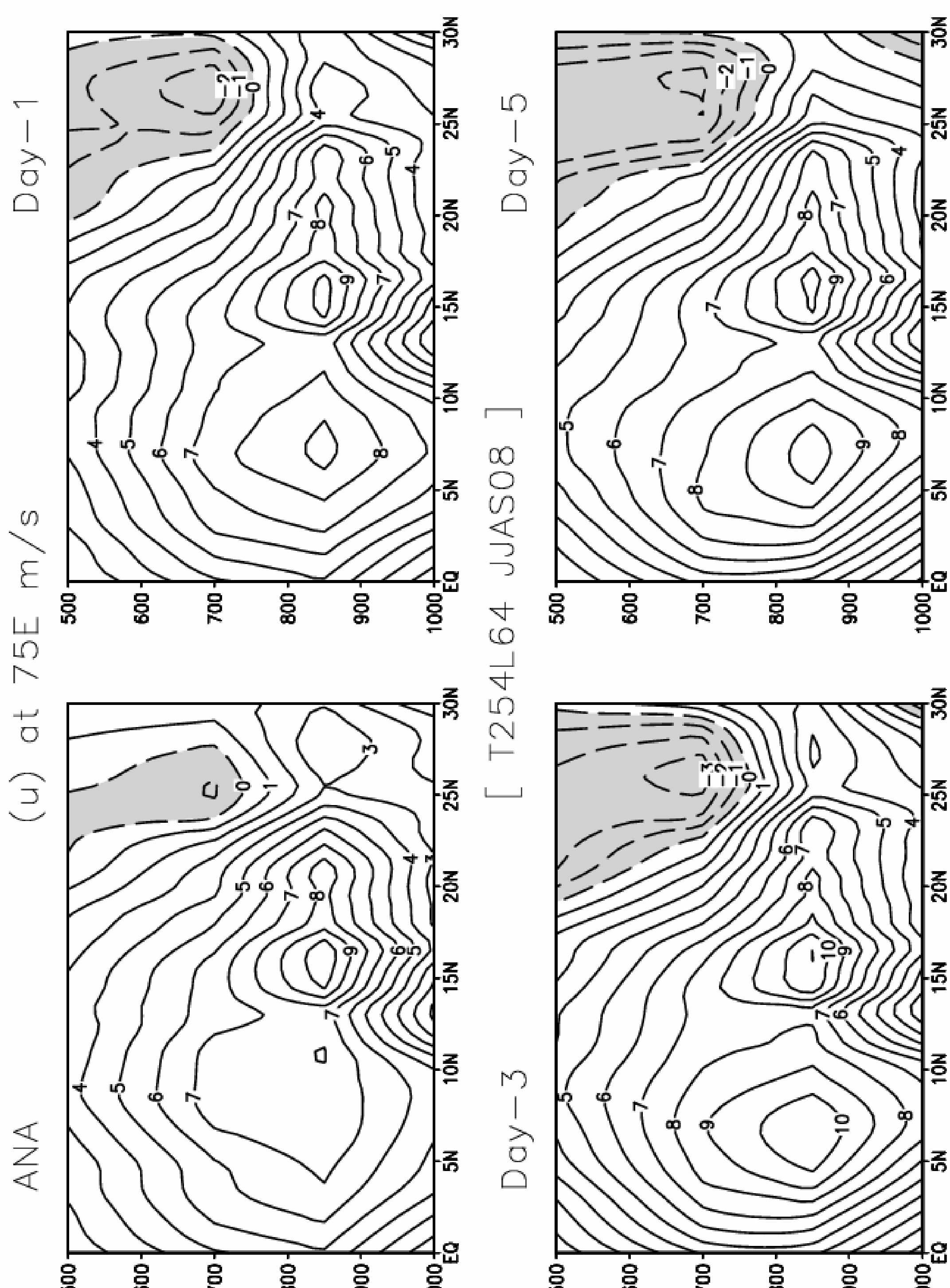
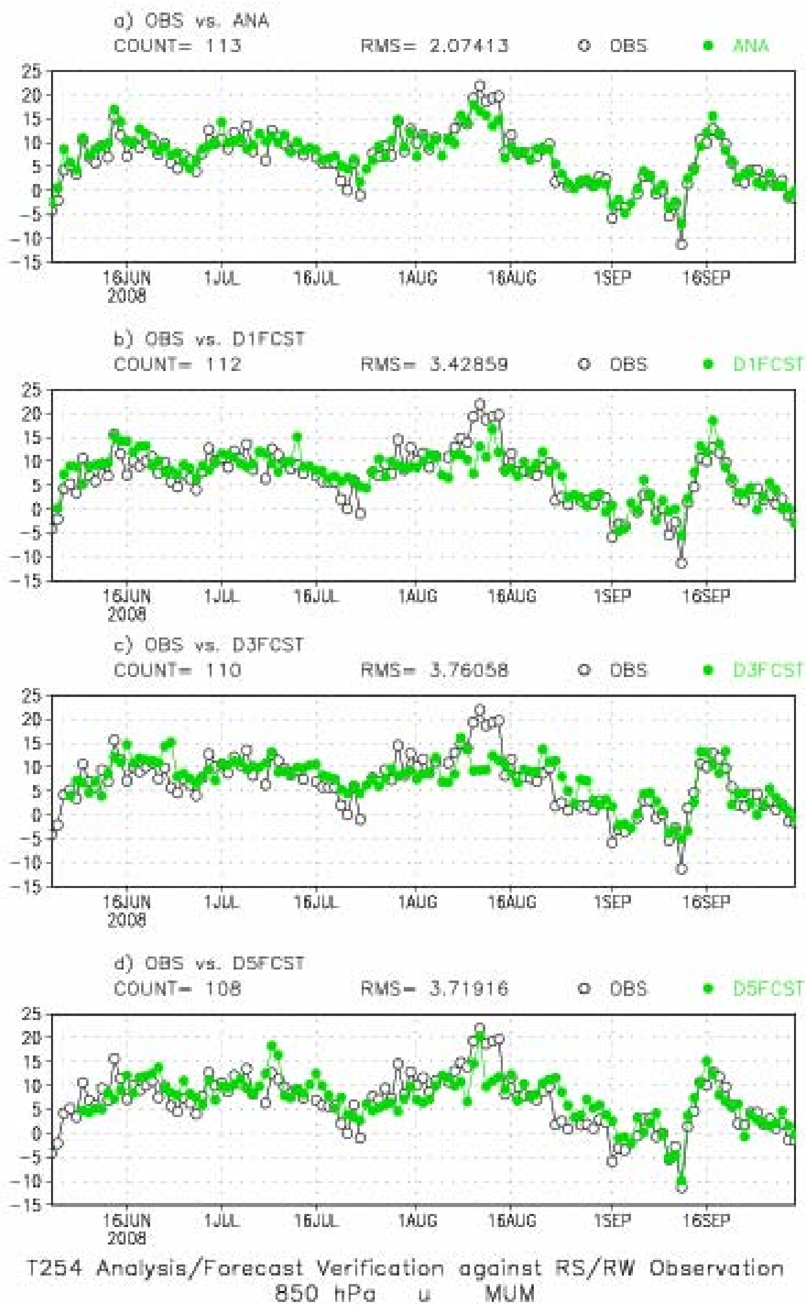

(u) at 75E m/s
ANA
Day-1
Day-3
Day-5
[T254L64 JJAS08]
500
600
700
800
900
1000
EQ
5N
10N
15N
20N
25N
30N

Fig. 8



a) OBS vs. ANA
COUNT= 113
RMS= 2.07413
OBS
ANA
b) OBS vs. D1FCST
COUNT= 112
RMS= 3.42859
OBS
D1FCST
c) OBS vs. D3FCST
COUNT= 110
RMS= 3.76058
OBS
D3FCST
d) OBS vs. D5FCST
COUNT= 108
RMS= 3.71916
OBS
D5FCST
16JUN
2008
1JUL
16JUL
1AUG
16AUG
1SEP
16SEP
T254 Analysis/Forecast Verification against RS/RW Observation
850 hPa u MUM

Fig. 9

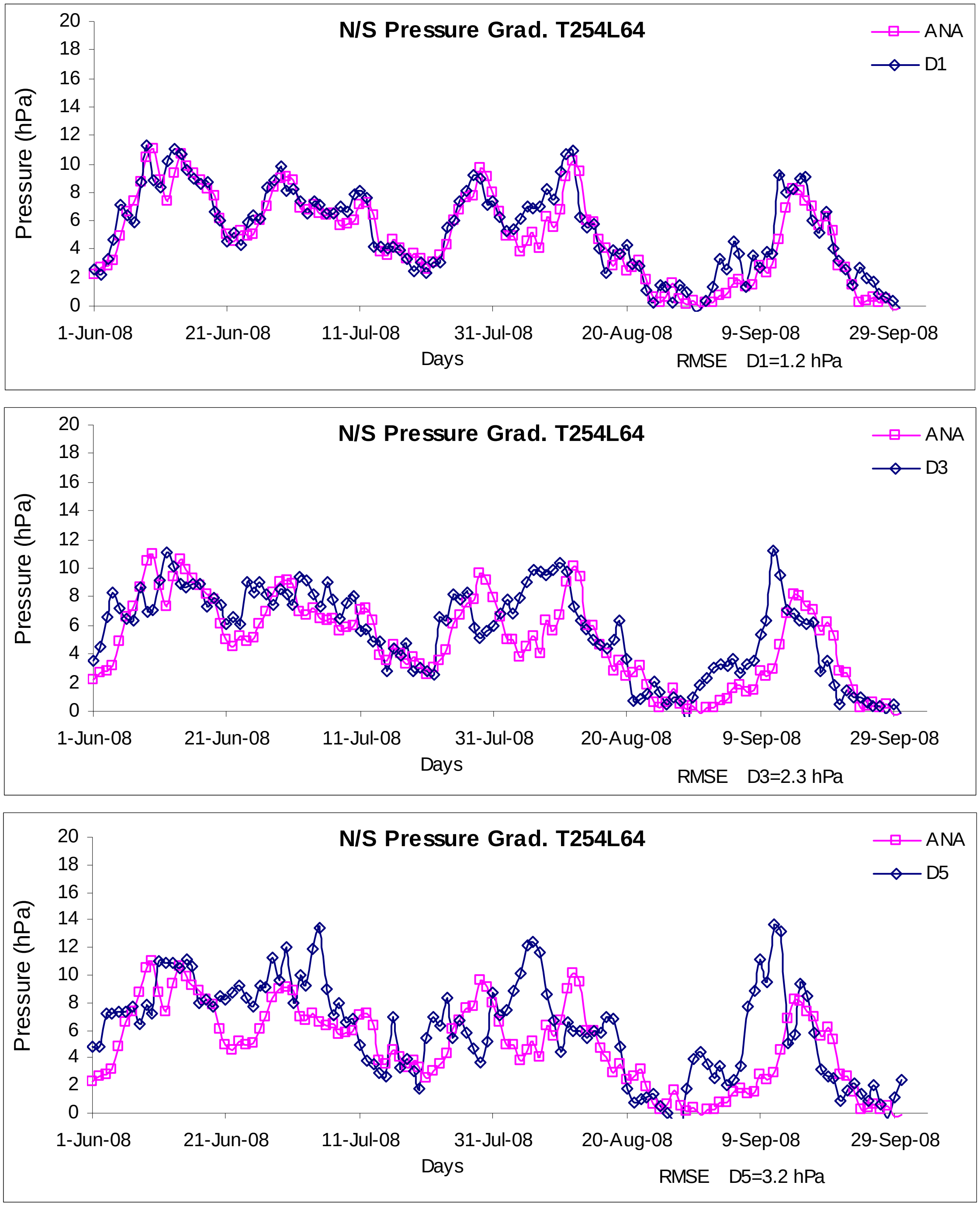

N/S Pressure Grad. T254L64
ANA
D1
Pressure (hPa)
20
18
16
14
12
10
8
6
4
2
0
1-Jun-08
21-Jun-08
11-Jul-08
31-Jul-08
20-Aug-08
9-Sep-08
29-Sep-08
Days
RMSE D1=1.2 hPa
N/S Pressure Grad. T254L64
ANA
D3
Pressure (hPa)
Days
RMSE D3=2.3 hPa
N/S Pressure Grad. T254L64
ANA
D5
Pressure (hPa)
Days
RMSE D5=3.2 hPa

Fig. 10

Tropical Easterly Jet, Tibetan High and Mid-Latitude Interaction

Saji Mohandas and L. Harenduprakash

1. Introduction

Tropical Easterly Jet (TEJ) and Tibetan High are two prominent semi-permanent flow structures that exist during the Indian summer monsoon season (Koteswaram, 1958, Rao, 1976). The easterly jet is found to the south of subtropical ridge over Asia, which runs from the east coast of Vietnam to the west coast of Africa. Normally, the jet is at an accelerating stage from South China Sea to South India and decelerates thereafter, with latitudinal positions and speed fluctuating from day to day.

Tibetan High is a warm anticyclone, which gets established much later, after the onset of monsoon. Tibetan high prominently appears with its center being most marked at 300hPa level, approximately at 30 °N, 90 °E. It usually extends from 70 °E to 110 °E. There is also a ridge normally found at 700hPa level, with its axis along 40 °N, between 75 °E and 95 °E, just north of the Tibetan massif (Rao, 1976). In July another ridge also is normally observed to lie at about 700hPa and aloft, over Pakistan and northwest India to the west of 75 °E, with its axis along 30 °N. The high over Tibet from 500hPa upward, centred near Tibet at 500hPa and over Tibet at 300hPa and 200hPa levels is normally termed as Tibetan High. In June the axis of anticyclonic belt is at about 25 °N at 300hPa and 200hPa levels. In August, the anticyclone is more or less similar to July, but is shifted to more north and is slightly more intense. In September, the anticyclonic belt is nearabout 26 °N upto 200hPa level. Ramaswamy (1965) associates well-distributed rainfall over India with well-pronounced and east-to-west oriented anticyclone over Tibet at 500hPa and 300hPa levels.

During the onset period, the position of sub-tropical high is to the south and even middle latitude westerlies may be prevailing in northern India in the upper troposphere. When the southwest monsoon is fully established over India, middle latitude westerlies prevail mostly to the north of 30 °N. However, these westerlies appear to affect the monsoon weather over north India to a considerable extend (Rao et al., 1970, Chakravorty and Basu, 1957, Mooley, 1957). Weather produced by monsoon depressions could be accentuated by extra-tropical eastward moving disturbances at a higher latitude (Malurkar, 1958). The weather on the southern side of the high latitude disturbance may be further increased by orography near Himalayas.

In this section, the significant features of the monsoon circulation over the Indian region at 200hPa level and its interactions with mid-latitude disturbances as seen from the model analysis and forecast during southwest monsoon season of 2008 are documented. The circulation at this level is characterized largely by anticyclone (Tibetan High) extending over the domain from 20°E to 140°E, with its axis along 28°N and the tropical easterly jet (TEJ) formed to the south of this anticyclone, covering most parts of the North Indian Ocean and the southern part of India. The Tibetan anticyclone may break into two distinct cells, one close to 65°E and the other close to 85°E and oscillates about its axis. This breaking up and oscillation of the anticyclone at 200hPa may be due to the intrusion of transient mid-latitude westerly troughs over to the Indian region. Some of these large amplitude troughs between 65°E and 100°E affect the weather over the Indian region. In this report, the time series of the fluctuations in the location of Tibetan Anticyclone along 65°E and 85°E, the location of strong easterlies (at 200hpa and along 75°E) and passage of westerly troughs between 65°E and 95°E are documented for the monsoon season of 2008.

The charts give a concise record of the variations of the features mentioned above and form the result of this work. The discussion therefore is brief.

2. Axis of the 200hPa Anticyclone

During the onset phase of Monsoon, seasonal anticyclone cell generally moves northwards accompanied by the northward shift of upper level westerly flow over to its northward fringes. Latitudinal positions of this 200hPa anticyclone along 65°E and 85°E have been extracted from the daily analyses, and Day-1, Day-3 and Day-5 predictions by NCMRWF operational T254L64 analysis and forecast systems. These are shown in the panels a & b in the respective figures for Day-1 (Fig. 1), Day-2 (Fig. 2) and Day-3 (Fig. 3) predictions. It is seen that the general features of all the three forecast leading times are similar.

The meridional movement of ridge axis in T254L64 analysis at 65°E and 85°E during the period JJAS 2008 is marked with lesser latitudinal fluctuations with the average latitudinal position being around 28°N. Only during September month it gradually shifted southward at 65°E. The maximum northern position is attained during the end of July and the first week of August at both longitudes, which is reflected in all three forecast panels of day-1, day-2 and day-3 (Figs. 1(b), 2(b) and 3(b)). However, the agreement between analysis and forecasts are fairly good for day-1 and day-3 at 65°E, whereas for day-5, forecast curves show more latitudinal fluctuations and do deviate from the analysis curves throughout the season. At 85°E, ridge line shows generally very little latitudinal fluctuations. Compared to day-1 or day-5 forecasts, day-3 forecast curve shows the best match and almost coincides with the analysis curve at 85°E. In general it can be seen that T254L64 forecasts up to day-3 are in good agreement with the corresponding analyses.

3. Tropical Easterly Jet

Strength of tropical easterlies at 200hPa along 75°E was monitored throughout the season as the strongest wind with speed exceeding 20 m/s (meter per second). Panels c & d of the respective figures show the latitudinal positions and strength of easterlies in the analyses and Day-1, Day-3 and Day-5 forecasts. In the figures, latitudinal positions (where the strength of easterly is maximum along 75°E) have been marked by crosses and vertical lines show the strength of easterly in m/s for the day at that position. For simplifying the plot, 20 mps has been subtracted from the strength of easterly and in the figures, 1 m/s represents one-degree latitude of the vertical axis.

T254L64 analysis clearly displayed an intraseasonal variability in the northward movement of the position of the strongest easterly wind. During June the pattern is not very clear, with a sudden development of strong TEJ by the second week around 8°N and again during the third week with a northward shift from near equator to 8°N. Another major episode starts from the beginning of July, which sustains and appears to propagate northwards from near equator to around 23°N by the third week of July. Thereafter there is a period of lull and the southward movement reappears during the first week of August, which continues till the middle of August. Again northward propagation-like pattern can be observed till the end of

August, which attains a maximum northward position of 21°N. Another southward shift is activity is observed during the first part of September with the TEJ continuing to be active between equator and 10 °N during the rest of the month.

The forecasts (panel d) agree fairly well with the analysis in presence of this type of intra-seasonal variability at day-1, while for day-3 and day-5 forecasts, the strength of TEJ is much less compared to the analyses though they vaguely capture the variability in the latitudinal positions during July-September.

4. Troughs in Upper Level Westerlies

Panels e & f show the north south extension of the westerly troughs that passed through Indian region between 65°E and 85°E in the analyses and day-1, day-3 and day-5 forecasts. It may be noted that these figures do not show any other characteristics of the trough such as its orientation and strength. Also in these figures almost all long and smaller wave activities seen even up to 50°N are presented whereas the major activities affecting the Indian region may be related to those extending southward of 40°N. Still these may give some indication of the variations in zonal index.

Westerly trough activity is found to be much less at 200 hPa level in T254 analysis during most part of June and though a weak trough is observed in the beginning of June much to the south between 20-30°N for a couple of days. Otherwise much of the westerly trough activity is confined to north of 28°N during the monsoon season, except during the September, when it showed southward extensions on one or two occasions. The same is fairly well captured in day-1 and day-3. The activity is predicted as comparatively less frequent and less intense in 5 day forecasts.

Figure Legends

Fig. 1: Latitudinal positions of ridge axis at 200hPa level along 65 °E (a) and 85 °E (b) for both T254L64 analysis (dotted curve) and corresponding T254L64 forecasts (solid curve) for day-1. Latitudinal positions of maximum easterly wind along 75 °E at 200hPa level (marked by crosses) and the wind speed in knots above 20 knots denoted by the length of the vertical lines in terms of degrees of latitude, for analysis (c) and day-1 forecasts (d). Meridional extend in terms of degrees of latitude of the prominent trough(s) in westerlies at 200 hPa level over north India and the neighbouring parts to the north of India denoted as vertical lines for analysis (e) and day-1 forecasts (f). The x-axis is the number of days starting from 1 June, 2008 through 30 September and y-axis is latitude in degrees.

Fig. 2 Same as Fig. 1, except for day-3 forecasts.

Fig. 3 Same as Fig. 1, except for day-5 forecasts.

References

Chakravorty , KC and SC Basu, 1957, The influence of western disturbances on the weather over north-east India in monsoon months, Indian J. Met. Geophys., 8, 261 – 272.

Koteswaram, P, 1958, The Easterly Jet Stream in the Tropics, Tellus, 10, 43 – 57.

Malurkar, SL, 1958, Monsoons of the world–India Monsoon, Monsoons of the World,92-100.

Mooley, DA, 1957, The role of western disturbances in the production of weather over India during different seasons, Indian J. Met. Geophys., 8, 253 – 260.

Ramaswamy, C, 1965, “On synoptic methods of forecasting the vagaries of southwest monsoon over India and neighbouring countries”, Proc. Symp., IIOE, 317 – 326.

Rao, YP, 1976, Southwest Monsoon, Meteorological Monograph, Synoptic Meteorology No. 1/1976, India Meteorological Department, June 1976, 367pp.

Rao, YP, V Srinivasan and S Raman, 1970, Effect of middle latitude westerly systems on Indian monsoon, Symp. Trop. Met., Hawaii, N IV 1 – 4.

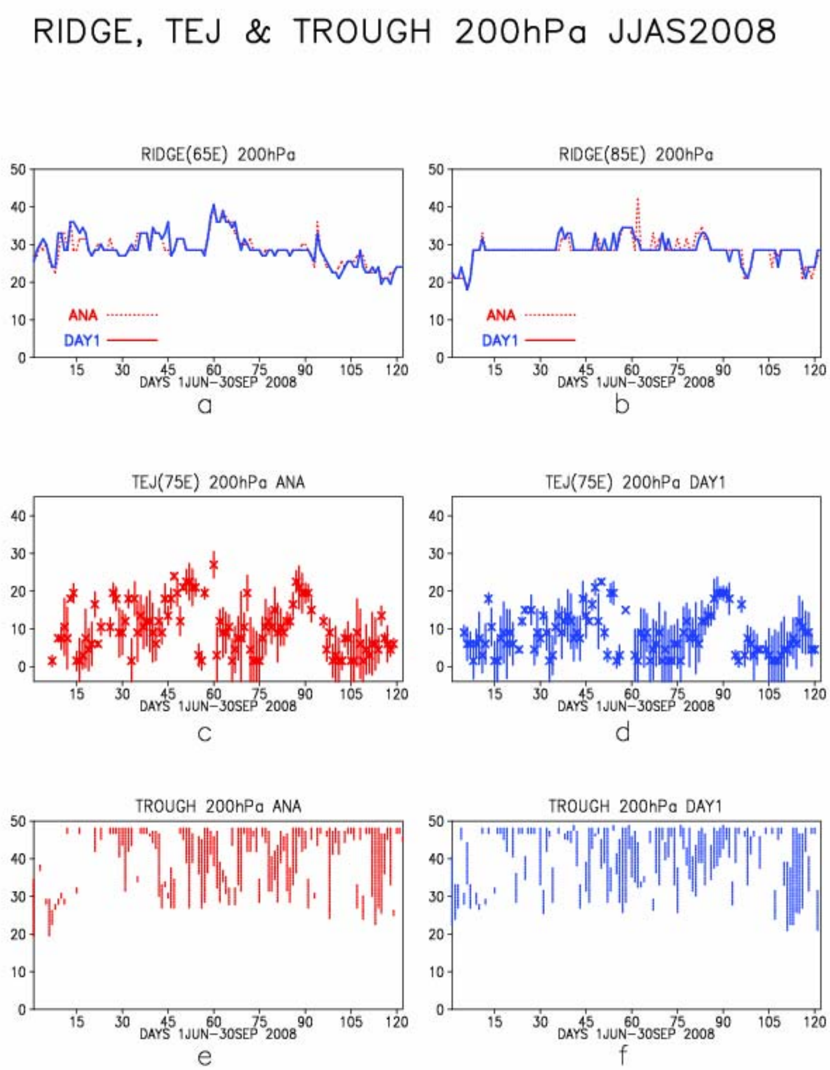

RIDGE, TEJ & TROUGH 200hPa JJAS2008
RIDGE(65E) 200hPa
RIDGE(85E) 200hPa
ANA
DAY1
DAYS 1JUN–30SEP 2008
a
b
TEJ(75E) 200hPa ANA
TEJ(75E) 200hPa DAY1
c
d
TROUGH 200hPa ANA
TROUGH 200hPa DAY1
e
f

Fig. 1

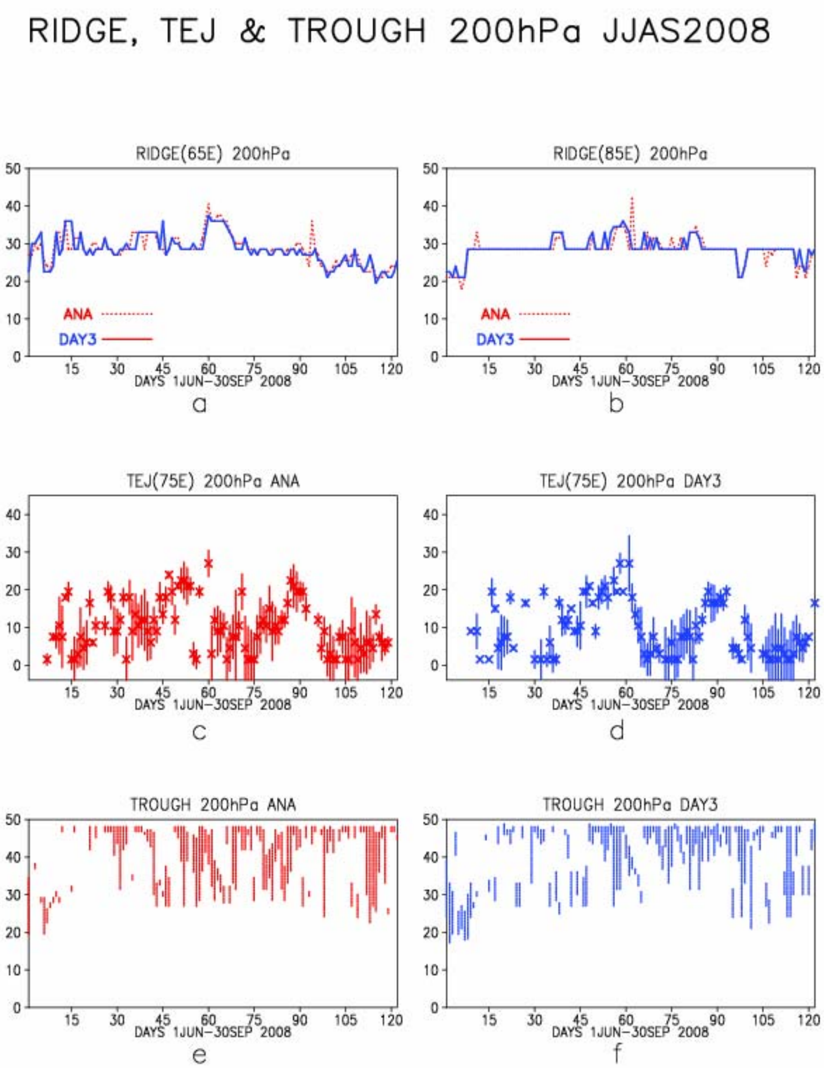

RIDGE, TEJ & TROUGH 200hPa JJAS2008
RIDGE(65E) 200hPa
RIDGE(85E) 200hPa
ANA
DAY3
DAYS 1JUN–30SEP 2008
a
b
TEJ(75E) 200hPa ANA
TEJ(75E) 200hPa DAY3
c
d
TROUGH 200hPa ANA
TROUGH 200hPa DAY3
e
f

Fig. 2

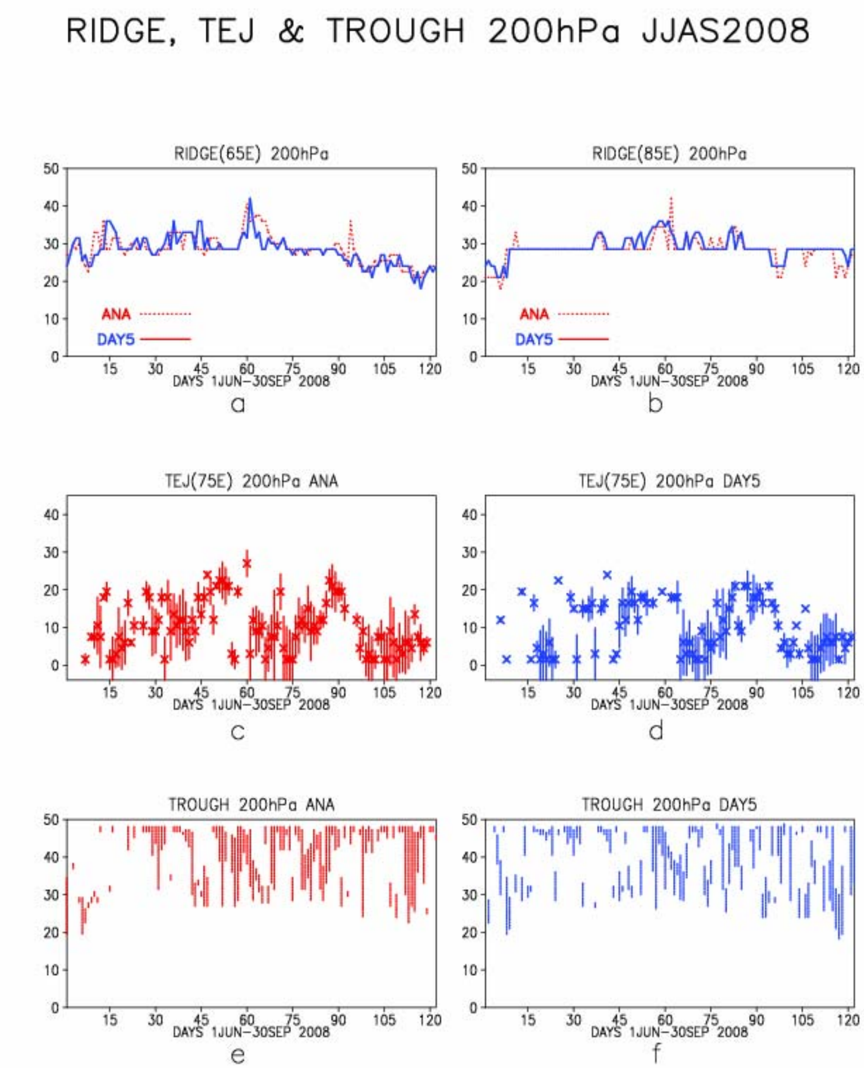

RIDGE, TEJ & TROUGH 200hPa JJAS2008
RIDGE(65E) 200hPa
ANA
DAY5
DAYS 1JUN–30SEP 2008
a
RIDGE(85E) 200hPa
ANA
DAY5
DAYS 1JUN–30SEP 2008
b
TEJ(75E) 200hPa ANA
DAYS 1JUN–30SEP 2008
c
TEJ(75E) 200hPa DAY5
DAYS 1JUN–30SEP 2008
d
TROUGH 200hPa ANA
DAYS 1JUN–30SEP 2008
e
TROUGH 200hPa DAY5
DAYS 1JUN–30SEP 2008
f

Fig. 3

Location Specific Weather Forecast Including Statistical Interpretation Forecast and Its Evaluation

Ashok Kumar and Parvinder Maini

1. INTRODUCRTION:

The mandate of NCMRWF was to issue location specific forecast in medium range to the agromet field units for preparation of agromet advisory bulletins for disseminating to the farmers.
Although mandate of issuing the forecast and preparation of agromet advisory bulletin had been shifted to IMD. The local weather forecasting system operational at NCMRWF is essentially a Man-machine mix approach. At present this system is based upon T-80 general circulation model operational at NCMRWF and T-254 general circulation model installed in May 2007. Local weather forecast is prepared for the four days for 130 AAS units once a week on every Tuesday and for 73 units twice a week i.e. on every Tuesday and Friday. Forecast issued is verified against the observations at the end of each season. The forecast performance in monsoon 2008 is presented below and is found up to the mark almost every time.

2. LOCAL WEATHER FORECAST:

Two essential components of the local weather forecast are Direct Model Output(DMO) and Statistical Interpretation(SI) forecasts. A forecaster's Panel consisting of the scientists from NCMRWF. Observed flow patterns in detail and on the basis of the prevailing synoptic situation around a station prepares the final forecast, (Fig. 1.). A forecast table(Table-I) is obtained for each station that contain the input from all the components of the forecasting system , and is used preparation of final forecast. Forecast is prepared for the following weather parameters, each forecasted for next 24 hours starting from 8.30 am.:

- Rainfall (mm)
- Cloud Cover(Okta)
- Wind Speed (m/sec)
- Predominant Wind Direction(deg)
- Maximum temperature trend
- -Minimum temperature trend

This forecast is prepared for four days i.e. 24,48,72 and 96 hour projection times twice a week on every Tuesday and Friday.

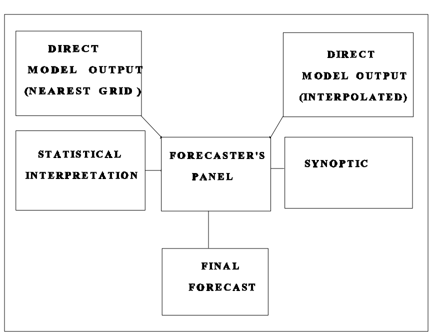


Fig. 1. An integrated scheme for preparation of local weather forecast (Man-Machine-Mix Approach)

Table-I

NATIONAL CENTRE FOR MEDIUM RANGE WEATHER FORECASTING

STATION:DELHI
DATE:05-08-2008 TIME: 03 GMT

COORDINATES: 28.58 N 77.20 E | **To**
ALTITUDE: 229 meters | **NODAL OFFICER,AGRO ADVISORY SERVICE UNIT**
BASED UPON 00GMT ANALYSIS FOR:04-08-2008 | **DELHI ,DELHI**

SR NO.	WEATHER PARAMETERS	DIRECT MODEL OUTPUT T-80 MODEL				DIRECT MODEL OUTPUT T-254 MODEL				STATISTICAL INTERPRETATION				FINAL			
		5-8 48hr	6-8 72hr	7-8 92hr	8-8 120hr	5-8 48hr	6-8 72hr	7-8 96hr	8-8 120hr	4-8 24hr	5-8 48hr	6-8 72hr	7-8 96hr	5-8 24hr	6-8 48hr	7-8 72hr	8-8 96hr
1	MSL PRESSURE hp	1001.	998 .	998.	997 .	999.	996.	995.	996.								
2	CL COVER okta E M	0 8	4 0	0 0	0 0	7 8	8 8	8 8	8 6					6	6	6	6
3	PROB. OF PRECIP. PRECIPITATIONmm PPM eqn PRECIP.	15.5	4.4	2.3	2.3	16.2	24.7	19.1	11.3	0.72 4.4 4.4	0.79 4.9 4.9	0.95 3.6 3.6	0.86 4.3 4.3	15	15	10	10
4	WIND SPEED kmph	5	6	4	4	6	4	7	9					6	4	6	7
5	WIND DIRECT.deg	251	244	214	285	114	129	110	96					110	110	110	90
6	MAX. TEMP. deg cel	32.2 0.4	31.2 -1.0	31.3 0.1	31.9 0.6	33.6 0.7	31.1 -2.5	30.3 -0.8	30.3 0.0	31.0	31.3 0.3	30.8 -0.5	31.7 0.9	1	-1	-1	0
7	MIN. TEMP. deg cel	26.6 0.2	25.0 -1.6	25.7 0.7	25.6 0.1	26.3 0.0	25.9 0.4	25.9 0.0	25.8 -0.1	25.6	25.5 -0.1	24.9 -0.6	25.0 0.1	0	0	0	0
8	R.H.MAXIMUM(%)	100	100	100	100	94	95	96	95								
9	R.H. MINIMUM(%)	71	72	70	65	68	77	81	80								
10	WIND DIR. FREQ. 0---45 45---90 90---135 135---180 180---225 225---270 270---315 315---360	 0.0 0.0 4.2 9.4 8.3 57.3 20.8 0.0	 0.0 0.0 0.0 0.0 27.1 56.2 16.7 0.0	 0.0 0.0 0.0 6.3 43.8 31.2 18.7 0.0	 0.0 0.0 0.0 0.0 0.0 33.3 66.7 0.0	 0.0 16.7 62.5 20.8 0.0 0.0 0.0 0.0	 0.0 4.2 33.3 29.2 20.8 12.5 0.0 0.0	 0.0 16.7 83.3 29.2 0.0 0.0 0.0 0.0	 0.0 45.8 54.2 0.0 0.0 0.0 0.0 0.0	WEEKLY CUMULATIVE RAINFALL FORECAST FOR NEXT WEEK:- MODEL:T80: 33.4 T254: 94.9 mm , FINAL : 70 mm							

*** MORE WEIGHT TO BE GIVEN AS COMPARED TO OTHER TYPE OF DIRECT MODEL OUTPUT**

2.1 DMO FORECAST:

DMO forecast is obtained directly from the T-80/T254 model forecast for the surface weather elements. The forecast values for each 24 hours are derived from the T-80 model output values at each time step of 15 minutes for the required weather parameters. The forecast values for each 24 hours are also derived from the T2-54 model output every hour for these parameters. As the T-80/T-254 model output values are at Gaussian grid points. Hence two different values of the DMO forecast are considered, one as the forecast value at the nearest grid to the station and other as the interpolated value of the forecast from the four grid points surrounding the station. If the station is located very near to a grid ,then nearest grid is considered else interpolated vale is considered.

As T-80/T-254 models are run only for 7days based on 00GMT analysis, hence only the 24,48,72 ,96 and 120 hours forecasts are obtained valid for next 24 hours starting from 8.30 am, for the following parameters.

- Average Mean Sea Level Pressure
- Cloud Amount (Morning and Evening)
- Rainfall (24 hours accumulated)
- Maximum Temperature
- Minimum Temperature
- Average Wind Speed
- Predominant Wind Direction
- Maximum Relative Humidity
- Minimum Relative Humidity

For wind direction, eight different classes of wind are considered and frequency is obtained. The class with maximum frequency is taken as predominant wind direction. .

2.2 SI Forecast:

Statistical Interpretation(SI) forecast is obtained for maximum/minimum temperature and rainfall based upon PPM models developed by using ECMWF model analysis and linking these with the T-80 model forecast operation at NCMRWF.SI forecast is obtained on operational basis for 45 stations during monsoon –2008. SI forecast models are also developed and forecast obtained on operational basis, based upon T-80 model analysis for 30 stations(included in the 45 stations). For rainfall quantitative precipitation(QP) forecast and Probability of Precipitation(PoP) forecast are obtained.

2.2.1 SI forecast approach.

Most of the surface weather elements like rainfall, maximum temperature and minimum temperature etc. are highly dependent on local orography.In NWP models and particularly in GCM its is very difficult to include each and every aspect of the local orographic conditions of all the locations. But upper air circulation at a particular location is not so dependent on local orographic conditions and can be obtained from the analysis or forecast from GCM easily. A statistical relation developed between upper air circulation around the location of interest and observed values of the surface weather elements at the location, will definitely account for the effect of these local orographic conditions. This forms the basis of Statistical Interpretation of the NWP products.

2.2.2 SI forecast methods.

Basically two methods are used for SI forecast. One is the Model Output Statistics(MOS), and the other is the Perfect Prog Method(PPM) (Glahn and Lowry,1972).In MOS equations are developed based on the observed data and the T-80 model forecasts over the last five to six years whereas in PPM equations are developed between the observed and the analysis using past five to six years of data. Hence in MOS an equation is obtained specific for a day wheras in PPM only one equation is valid for all the days

2.2.3 SI forecast models.

At NCMRWF, SI forecast model equations are based upon PPM models. Initially PPM equations are developed for monsoon season using six years(1985-90) of ECMWF(TOGA) analysis(2.5 x 2.5) data for 45 stations in India. Later the PPM equations are developed for monsoon season using six years(1994-99) of T-80 model analysis(1.5x1.5) data for 30 stations out of these 45 stations. SI forecast is obtained for 45 locations in India during monsoon 2008. Monsoon season is taken as June-September.

The predictands are quantitative precipitation(QP), Probability of Precipitation(PoP) and Maximum/Minimum (MAX/MIN) temperatures.The analysis fields at 1000,850,700 and 500 mb levels for forty seven parameters are chosen for inclusion in the set of predictors(Table-II).The predictors values are considered at 00 GMT of forecast day and at 12 GMT of the previous day. For getting predictors values at the station canonical variate values are obtained for each predictors by using the values at the nine grid points surrounding the station .Then using step-wise selection procedure, only those predictors which explain most of the variance are selected as the final predictors. PPM equations are obtained based upon these selected predictors only.

For getting 24,48,72 and 96 hrs forecast for MAX/MIN temperatures and for PoP and QP, values of the predictors from the T-80 model output are put in the corresponding PPM equations. These forecasts are biased. For removing the bias in MAX/MIN temperatures, the correction factors are obtained as difference of the mean between the observed and forecasted values based upon last one or two seasons. In case of Qp and PoP correction factors for threshold value and adjustment of probability value respectively, are generated by trial and error method so that the skill of the forecast gets maximised. The same correction factors are used while obtaining the bias free SI forecast along with the operational run of T-80 model. The bias free SI forecast is while preparing the final forecast.

Table II. Meteorological parameters considered as possible predictors

Parameters	Level
Relative humidity	1000,850,700,500
Temperature	1000,850,700,500
Zonal wind component	1000,850,700,500
Meridional wind component	1000,850,700,500
Vertical velocity	1000,850,700,500
Geopotential	1000,850,700,500
Saturation deficit	1000-500
Precipitable water	1000-500
Mean sea level pressure	--------
Temperature gradient	850-700, 700-500
Advection of temperature gradient	850-700, 700-500
Advection of temperature	1000,850,700,500
Vorticity	1000,850,700,500
Advection of vorticity	1000,850,700,500
Thickness	850-500
Horizontal water vapour flux divergence	1000-500
Mean relative humidity	1000-500
Rate of change of moist static energy	1000-500

3. VERIFICATION OF THE FORECAST

3.1 SKILL SCORES USED FOR VERIFICATION.

The scores used for verification of rainfall forecast are the ratio score and Hanssen and Kuipers(H.K) skill scores. The ratio score (RS) measures the percentage of correct forecasts out of total forecasts issued. The Hanssen and Kuipers' discriminant (HK) is the ratio of economic saving over climatology.H.K Score can be explained by the following contingency table.

	Observed	
Forecasted	Rain	No Rain
Rain	YY	YN
No Rain	NY	NN

Ratio Score = (YY+NN) / N

H.K.Score = (YY*NN-YN*NY)/(YY+YN)*(NY+NN)

If the H.K Score is closer to 1 then the forecasts are the best and when the H.K Score is near 0 or less than 0 then the forecasts are bad. In the case of MAX/MIN temperatures, cloud amount, wind speed and wind direction the correlation and RMSE values are calculated for evaluating the skill of the forecast.

3.2 VERIFICATION RESULTS(MONSON-2008)

In case of rainfall, minimum temperature and maximum temperature, skill scores are calculated for each of the final forecast, SI forecast, DMO forecast based upon T-80 model and T-254 model issued from NCMRWF and are given in Table-III, Table-IV , Table-V and Table-VI respectively.

Ratio score and H.K. scores for rainfall shows that skill for SI forecast is better than that of DMO forecast based upon T-80 model for almost all the stations, whereas it is comparable to that of final forecast and DMO forecast based upon T-254 model for some of the stations and better for some stations.

Correlation and RMSE for maximum/minimum temperature as given shows that skill for SI forecast is better than that of DMO forecast based upon T-80 model for many of the stations, whereas it is comparable to that of final forecast and DMO forecast based upon T-254 model and skill of the final forecast is up to the mark..

It is hereby could be noticed that rmse's for maximum temperature based upon T-254 model are some what higher i.e. in the range of greater than 2 for more number of stations as compared to other forecasts, which needs further to be looked into.

For Cloud amount, Wind speed and Wind direction, skill scores are calculated for the final forecast issued from NCMRWF . As forecast for these parameters are based upon mainly DMO forecast only, depending upon the local synoptic conditions and are given in Table-VII.

Correlation and RMSE for cloud amount and wind speed are quite good and upto the mark baring few stations. But for wind direction correlations are not very good and RMSE values are high for some of the stations. Hence forecast for wind direction needs improvement and also the verification method may required to be changed..

4. PROSPECTS :-

The forecast skill during monsoon 2008 are more stable and up to the mark, as compared with the skill scores shown in the earlier reports. The ratio skill scores for monsoon season for the period from 1998 to 2008 are given in Table-VIII.

There are some of the points which needs to be considered as the basis for future plans.

This reflects that the operational version of the NWP model must not be changed for at least two years. It may be required to have simultaneous runs of the NWP model, one operational and one research & development model.

As the forecast has become stable and has sustainable skill scores over last decade almost. So, the operational forecast regularly obtained from the models has the potential of being disseminated to AAS units and also to any user agency.

It would be better for NCMRWF to give emphasis on improving the forecast using better logic and robust mathematical and statistical rules.

District wise rainfall has also been made operational for 602 districts, using the temperature trend and area wise estimates of the threshold value for rainfall based upon T-254 model.

Bias free forecast using kalman filter and threshold values for rainfall is obtained on operational basis for 70 major cities of India, using GTS data and T-80 and T-254 models output respectively. Only last forty day data is being considered for every day run. This forecast gives the direct forecast value on a particular day, for all the forecast days.

Calibrated DMO forecast based upon T-254 model has the comparable skill to that of final forecast and SI forecast issued from NCMRWF. This forecast has been corrected for threshold values for rainfall so as to have maximum skill and temperature trends have also been calibrated for the higher values of trends to a lower value. It is expected to give the better input to the final operational forecast being issued from NCMRWF to AAS units and also for the Kalman filtered City forecast and trend based temperature forecast for the districts of India.

5. FUTURE PLANS:-

#SI forecast models would be developed for probability of precipitation and probability of precipitation type using output from T-254 model, which had been implemented last year.

#SI and other bias free forecasts would be generated by using the NWP forecast obtained by two way interaction between global and regional model.

Better verification procedures would be tried for clod amount, wind speed and wind direction.

Table-III

Skill score for final operational (man-machine-mix approach) maxt , mint and rainfall forecast Monsoon (Jun.-Sep)-2008

Sn.	Station	Rain		Min		Max	
		Ratio	HK	RMSE	Corr	RMSE	Corr
1.	Akola	55	0.17	1.48	0.66	2.44	0.55
2.	Allahabad	68	0.35	1.89	0.51	2.55	0.69
3	Anantpur	43	0.10	1.46	0.43	2.04	0.53
4.	Bhubaneshwar	80	0.25	1.66	0.14	2.50	0.30
5.	Bangalore	55	0.15	1.28	0.31	2.02	0.39
6.	Chennai	55	0.10	1.50	0.48	2.28	0.39
7.	Coimbatore	67	0.38	1.09	0.18	1.86	0.40
8.	Delhi	66	0.31	1.76	0.48	2.56	0.43
9.	Hisar	68	0.41	2.16	0.51	2.95	0.57
10.	Hyderabad	65	0.36	2.63	0.40	2.28	0.68
11.	Jabalpur	58	0.12	1.53	0.39	2.34	0.66
12.	Jagadalpur	69	0.12	2.03	0.13	2.81	0.42
13.	Jammu	72	0.42	2.74	0.38	2.19	0.45
14.	Jaipur	60	0.29	1.78	0.58	2.48	0.61
15.	Parbhani	58	0.20	1.25	0.72	3.32	0.42
16.	Pune	75	0.29	1.27	0.63	1.83	0.72
17	Ranchi	72	0.12	1.30	0.35	1.88	0.55
18	Raipur	65	0.16	1.51	0.47	2.68	0.60
19	Srinagar	60	0.29	1.94	0.89	3.52	0.37
20	Tirupati	36	-0.07	2.28	0.28	2.03	0.42
21	Udaipur	56	0.23	1.46	0.76	2.29	0.57

RATIO :Ratio Score(precentage of correct forecast)
HK Score :Hanssen and Kuipers Score

Table-IV
Skill score for Statistical Interpretation maxt , mint and rainfall forecast
Monsoon (Jun.-Sep)-2008

Sn.	Station	Rain		Min		Max	
		Ratio	**HK**	**RMSE**	**Corr**	**RMSE**	**Corr**
1.	**Akola**	60	0.16	1.74	0.54	2.52	0.67
2.	**Anantpur**	73	0.12	1.50	0.40	2.29	0.39
3.	**Bhubneshwar**	60	0.10	1.63	0.16	2.44	0.43
4.	**Bangalore**	60	0.05	1.19	0.45	1.56	0.53
5.	**Chennai**	64	0.14	1.60	0.32	2.29	0.43
6.	**Coimbatore**	76	0.12	1.26	0.28	1.54	0.52
7.	**Delhi**	61	0.21	1.79	0.52	2.81	0.30
8.	**Hisar**	64	0.13	2.11	0.62	2.30	0.74
9.	**Hyderabad**	59	0.16	1.77	0.61	2.54	0.61
10.	**Jabalpur**	62	0.24	1.40	0.45	2.59	0.63
11.	**Jagadalpur**	66	0.19	1.18	0.49	2.96	0.21
12.	**Ludhiana**	62	0.21	1.89	0.67	2.76	0.43
13.	**Parbhani**	55	0.05	1.25	0.69	2.40	0.63
14.	**Pune**	81	0.49	1.19	0.67	1.83	0.69
15.	**Ranchi**	67	0.30	1.10	0.33	2.22	0.62
16.	**Raipur**	59	0.21	1.61	0.45	3.33	0.35
17.	**Srinagar**	74	0.22	1.90	0.88	3.37	0.48
18.	**Udaipur**	75	0.44	1.52	0.70	2.83	0.51

RATIO :Ratio Score(precentage of correct forecast)
HK Score :Hanssen and Kuipers Score

Table-V

Skill score for calibrated direct model output maxt , mint and rainfall forecast based upon T-80 model Monsoon (Jun.-Sep)-2008

Sn.	Station	Rain		Min		Max	
		Ratio	HK	RMSE	Corr	RMSE	Corr
1.	Akola	55	0.16	1.80	0.55	2.17	0.75
2.	Allahabad	58	0.14	1.87	0.48	2.43	0.73
3.	Anantpur	60	0.17	1.57	0.39	2.05	0.44
4.	Bhubaneshwar	69	0.06	1.75	- 0.10	2.78	0.10
5.	Bangalore	62	0.19	1.42	0.10	1.57	0.52
6.	Chennai	46	-0.01	1.79	0.22	2.27	0.43
7.	Coimbatore	58	0.08	0.90	0.34	1.77	0.36
8.	Delhi	58	0.15	2.12	0.46	2.71	0.37
9.	Hisar	61	0.25	2.40	0.51	2.78	0.62
10.	Hyderabad	48	-0.04	1.96	0.52	2.49	0.64
11.	Jabalpur	61	0.21	1.72	0.34	2.33	0.67
12.	Jagadalpur	70	0.05	1.43	0.37	3.06	0.44
13.	Jaipur	48	0.16	2.25	0.38	2.90	0.60
14.	Jammu	59	0.16	2.82	0.29	2.31	0.58
15.	Parbhani	57	0.17	1.34	0.70	2.14	0.72
16.	Pune	75	0.34	1.27	0.40	1.81	0.73
17.	Ranchi	74	0.13	1.07	0.45	2.23	0.60
18.	Raipur	67	0.24	1.73	0.41	3.28	0.50
19.	Srinagar	65	0.19	2.12	0.84	3.10	0.46
20.	Tirupathi	54	0.14	2.28	0.17	1.69	0.60
21	Udaipur	67	0.15	1.51	0.70	2.58	0.54

RATIO :Ratio Score(precentage of correct forecast)
HK Score :Hanssen and Kuipers Score

Table-VI

Skill score for calibrated direct model output maxt , mint and rainfall forecast based upon T-254 model Monsoon (Jun.-Sep)-2008

Sn.	Station	Rain		Min		Max	
		Ratio	HK	RMSE	Corr	RMSE	Corr
1.	Akola	54	0.10	1.69	0.58	2.27	0.75
2.	Allahabad	61	0.20	1.78	0.53	2.37	0.72
3.	Anantpur	78	0.28	1.59	0.41	2.41	0.41
4.	Bhubaneshwar	73	0.22	1.80	0.18	2.30	0.35
5.	Bangalore	61	0.10	1.23	0.10	2.04	0.52
6.	Chennai	71	0.19	1.75	0.31	2.34	0.45
7.	Coimbatore	73	0.13	1.63	0.21	1.98	0.37
8.	Delhi	67	0.34	2.07	0.41	2.75	0.32
9.	Hisar	75	0.49	2.26	0.46	2.77	0.60
10.	Hyderabad	58	0.12	1.87	0.59	2.49	0.68
11.	Jabalpur	65	0.28	1.63	0.33	2.46	0.66
12.	Jagadalpur	70	0.24	1.48	0.38	2.75	0.54
13.	Jaipur	62	0.33	2.17	0.38	2.24	0.72
14.	Jammu	63	0.30	2.45	0.41	2.63	0.59
15.	Parbhani	64	0.27	1.30	0.73	2.40	0.71
16.	Pune	76	0.37	1.27	0.44	2.05	0.67
17.	Ranchi	74	0.19	1.19	0.38	2.10	0.65
18.	Raipur	64	0.23	1.69	0.38	2.90	0.61
19.	Srinagar	43	0.15	2.02	0.85	3.02	0.46
20.	Tirupathi	62	0.14	2.18	0.28	2.34	0.43
21	Udaipur	55	0.27	1.44	0.73	2.56	0.57

RATIO :Ratio Score(precentage of correct forecast)
HK Score :Hanssen and Kuipers Score

Table-VII

Skill score for final operational (man-machine-mix approach) forecast for cloud amount, wind direction and wind direction Monsoon (Jun.-Sep)-2008

Sn.	Station	Cloud amt.		Wind speed		Wind direc.	
		RMSE	Corr	RMSE	Corr	RMSE	Corr
1.	Akola	2.12	0.52	4.66	0.14	65.27	0.29
2.	Allahabad	2.11	0.68	4.83	0.38	95.48	0.06
3.	Annatpur	2.57	0.32	4.34	0.36	53.19	0.17
4.	Bhubaneshwar	1.68	0.43	2.59	0.24	72.16	0.22
5.	Bangalore	2.35	0.19	3.93	0.35	55.79	-0.09
6.	Chennai	3.10	0.33	5.36	0.05	79.62	0.11
7.	Coimbatore	2.48	0.39	4.61	0.17	45.11	0.12
8.	Delhi	2.43	0.55	3.88	0.26	99.75	0.27
9.	Hisar	2.14	0.61	4.42	0.17	101.25	0.26
10.	Hyderabad	2.39	0.42	4.17	0.31	57.26	0.42
11.	Jabalpur	1.91	0.63	4.43	0.09	80.20	0.07
12.	Jagadalpur	2.24	0.40	5.05	0.10	87.77	0.24
13.	Jammu	1.98	0.65	4.95	0.20	112.23	-0.01
14.	Jaipur	2.50	0.50	3.91	0.15	89.79	0.27
15.	Parbhani	2.29	0.42	5.14	0.01	63.28	-0.09
16.	Pune	1.79	0.61	4.86	0.18	31.36	0.17
17.	Ranchi	1.57	0.47	3.59	0.22	87.31	0.32
18.	Raipur	1.91	0.60	3.88	0.26	66.28	0.10
19.	Srinagar	1.95	0.51	4.86	0.20	97.65	0.32
20.	Tirupati	1.60	0.41	4.50	0.01	73.46	0.16
21.	Udaipur	2.30	0.56	5.25	0.37	72.16	0.11

RATIO :Ratio Score(precentage of correct forecast)
HK Score :Hanssen and Kuipers Score

Table-VIII.
Ratio score (%) of yes/no rainfall forecast
for monsoon seasons(Jun., Jul., Aug, &Sep.) of 1998-2008

STATION	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
AKOLA	51	61	51	57	69	57	--	---	---	66	55
COIMBATORE	56	71	65	65	58	62	84	---	54	---	67
DELHI	67	79	62	61	62	71	73	---	65	57	66
HISAR	49	75	68	66	71	66	--	---	72	72	68
HYDERABAD	49	58	64	-	68	57	--	59	---	59	65
JABALPUR	57	69	65	74	74	---	--	---	---	62	58
LUDHIANA	65	67	58	63	67	58	--	---	59	65	--
PANTNAGAR	75	67	71	66	--	74	--	---	---	60	--
PUNE	71	75	67	79	67	70	63	--	--	---	75
RAIPUR	60	63	60	66	64	76	--	67	--	63	65
TRICHUR	81	75	77	81	60	77	--	---	---	---	--
UDAIPUR	61	67	62	62	78	---	--	81	---	---	56

Ashok Kumar & Parvinder Maini 1996: Statistical interpretation of general circulation model: A prospect for automation of medium range local weather forecast in India., *Mausam,* 47(3): 229-236.

Ashok Kumar, Parvinder Maini & Singh, S. V., 1999: An operational model for forecasting probability of precipitation and YES/NO forecast. *Wea. and Forecasting,* 14**:** 38-48.

Ashok Kumar, Parvinder Maini, Rathore,L.S. and S.V.Singh, 2000: An operational medium range local weather forecasting system developed in India *Int. J. Climatol*.**,** 20: 73- 87.

Ashok Kumar**,** Parvinder Maini, Rathore, L.S. and S.V.Singh, 2002: Skill of statistical interpretation forecasting system during monsoon season in India. *Atmospheric Science Letters* ,3/1**:** 25-37.

Maini, Parvinder, Ashok Kumar, Singh S V and L S Rathore, 2002: Statistical interpretation of NWP products in India. *Meteorl. Appl.*, 9 **:** 21-31.

Maini Parvinder , Kumar A**,** Rathore L.S. and Singh, S.V.(2003): Forecasting maximum and minimum temperature by statistical interpretation of numerical weather prediction model output *Wea. Forecasting, 18:938-952.*

Maini Parvinder, Kumar A**.**, Singh S.V. and Rathore, L.S.(2004): Operational model for forecasting location specific Quantitative Precipitation and Probability of precipitation over India.*J.Hydro.,288,170-188.*

Rashmi Bhardwaj, Ashok Kumar, Parvinder Maini, S.C. Kar and L.S. Rathore, 2007, **'**Bias free rainfall forecast and temperature trend based temperature forecast based upon T-170 model during monsoon season' *Meteorolgical Applications* 14**(**4) **,**pp 351-360.

Kumar A, Parvinder Maini ,Rathore, L.S. and S.V.Singh, 1997: An objective medium range precipitation forecast from NCMRWF. Proc. of the "International Symposium on Asian monsoon and Pollution over the Monsoon Environment", *INTROMET(2-5 DEC.,1997),*IIT,New Delhi,India.Published in *Vayu mandal*;Vol.29 No.1-4:158-162.

Mohanty, U. C. et al., 1999: Medium Range Prediction of Atmospheric System over Indian Region by NCMRWF Forecasting System. Proc. of the national symposium in " Advanced Technologies in Meteorology ", (Ed: R.K.Gupta & S. Jeevananda Reddy) organized by Indian Met. Society, Hyderabad, 131-139.

Ashok Kumar**,** Parvinder Maini ,Rathore, L.S. and S.V.Singh2002: An objective medium range precipitation forecast from NCMRWF. Proc. of the "INDO-US workshop on weather and climate modeling" project*"(7-9 feb.2002),*New Delhi,India. (4. 14 to 4. 19).

Statistical and synoptic interpretation of model output and preparation of final forecasts, Chapter-II, 15-24, in the book entitled "Guide for Agrometeorological Advisory Service", 1999 (Published by NCMRWF,DST, New Delhi, India).

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