# Improvements in the weather prediction over the Indian region using regional spectral model

Y. V. RAMA RAO, S. C. KAR*, T. S. V. VIJAYA KUMAR**, S. R. KALSI, H. R. HATWAR

and

S. K. ROY BHOWMIK

*India Meteorological Department, New Delhi – 110 003, India*

**National Centre for Medium Range Weather Forecasting (NCMRWF), NOIDA, U.P., India*

***Department of Meteorology, Florida State University, Tallahassee, USA*

(*Received 6 May 2003, Modified 13 May 2004*)

सार – भारत मौसम विज्ञान विभाग, नई दिल्ली में फ्लोरिडा राज्य विश्वविद्यालय द्वारा निर्मित क्षेत्रीय स्पेक्ट्रमी निदर्श (एफ. एस. यू. आर. एस. एम.) स्थापित किया गया है और इसके जाँच परीक्षण किए गए हैं। इस निदर्श का आरंभिक और परिसीमा स्तर के रूप में विश्लेषण और पूर्वानुमान के क्षेत्रों में उपयोग करने के लिए, राष्ट्रीय मध्यम अवधि मौसम पूर्वानुमान केन्द्र (एन. सी. एम. आर. डब्ल्यू एफ.) में स्थापित भूमंडलीय टी.–80 निदर्श से इस निदर्श के कोड में समुचित संशोधन किए गए हैं। क्षेत्रीय स्पेक्ट्रमी  निदर्श का विभेदन 0.75 डिग्री रूपान्तर ग्रिड है जो टी–170 भूमंडलीय निदर्श  के विभेदन के समान है। इस निदर्श को 3 दिनों के लिए समाकलित किया गया और इससे क्षेत्रीय निदर्श के कार्य–निष्पादन के परीक्षण के लिए दिसंबर 2002 और फरवरी 2003  के दौरान घटी कुछ प्रमुख मौसम घटनाओं के संदर्भ में अध्ययन किए गए हैं। ई. सी. एम. डब्ल्यू. एफ. और एन. सी. एम. आर. डब्ल्यू एफ. के आरंभिक विश्लेषणों का उपयोग करते हुए, निदर्श  की सहायता से किए गए पूर्वानुमानों पर आरंभिक क्षेत्रों के प्रभाव की भी इस शोध पत्र में जाँच की गई है। इस अध्ययन से पता चलता है कि क्षेत्रीय स्पेक्ट्रमी निदर्श  से किए गए पूर्वानुमान प्रेक्षित लक्षणों के यथोचित निकट रहे हैं। निदर्श अनुकरित प्रणालियों की प्रगाढ़ता और संचलन का प्रेक्षणों के साथ युक्तिसंगत सामंजस्य रहा है।

**ABSTRACT.** Florida State University Regional Spectral Model (FSURSM) has been installed at India Meteorological Department, New Delhi and test runs have been made. A suitable change in the model code were made to use analysis and forecast fields as initial and boundary conditions for the model from the global T-80 model run at the National Centre for Medium Range Weather Forecasting (NCMRWF). The resolution of the regional spectral model is 0.75° transform grid, which is equivalent to the resolution of a T-170 global model. The model has been integrated for 3 days and studies undertaken to test the performance of the regional model in respect of some of the major weather events that occurred during December 2002 and February 2003. Using initial analyses from ECMWF and NCMRWF, the impact of initial fields on model forecast is also investigated. The case studies show that the forecasts from the regional spectral model are reasonably close to the observed features. The intensity and movement of model simulated systems are in good agreement with the observations.

**Key words** – Spectral model, Western disturbance, Easterly wave, Forecast.

## 1. Introduction

In recent years global numerical weather prediction models at most of the operational weather forecasting centers have attained a reasonable level of accuracy and usefulness in the medium range weather prediction at planetary and synoptic scales. However due to the limited availability of computing capabilities in most of the developing countries horizontal resolution of global spectral weather models are restricted to about T-126 or T-170. With increasing availability of massively parallel computers, model integration at higher resolutions will eventually be possible. However, as we go to higher resolutions, modeling of physical processes tend to become more complex in order to represent more realistic atmosphere. As a result, the need for more computing resources still remains. An alternative approach is to use high-resolution regional models as a forecasting tool in the foreseeable future. Most regional models are based on grid point methods, particularly due to the difficulty in specifying the lateral boundary conditions in spectral method. However, a number of researchers (Tatsumi

1986; Hoyer 1987; Juang and Kanamitsu 1994) have successfully developed regional spectral models. Spectral models have a number of advantages, such as absence of phase and aliasing errors and ease of implementation of semi-implicit time integration and implicit horizontal diffusion schemes.

FSU global spectral model, at high resolution, have been used to study the tropical weather systems such as monsoon and track, intensities, landfall and recurvature dynamics of a number of tropical cyclones over different ocean basins. Florida State University research team has also developed a Regional Spectral Model (FSURSM) compatible with the global model and was first used in Atlantic hurricane prediction studies (Cocke, 1998). The studies have shown that the intensity and track forecasts of the regional spectral model are better than that predicted by the global model. With physical initialization, the forecast track of the storm is improved in both the global and regional models. However, the regional model predicted the best track, showing landfall within 100 km of the observed landfall. The model has undergone considerable enhancement to enable it for use in short-range numerical weather prediction as well as longer-term seasonal climate simulations. Using the FSURSM, Mayers *et al.* (2001) investigated the month-long forecasts for August 1998 over Eastern Caribbean region. The root mean square errors (RMSE) of the 850 hPa zonal and meridional wind for 1, 2 and 3 day forecast and the tracks of 2 hurricanes which occurred during the period were investigated. This study has shown the improvement in RMSE in zonal and meridional winds and also in the track prediction compared to the global model.

At present, India Meteorological Department (IMD) utilizes a limited area grid point model, based on the FSU limited area model for its short range weather prediction (Krishnamurti *et al.*, 1990, Prasad *et al.*, 1997b). To strengthen its operational numerical weather prediction system, recently IMD has adapted Florida State University Regional Spectral Model (FSURSM). Suitable changes in the model code have been incorporated to use initial analysis and forecast fields as initial and boundary conditions from the T-80 run at National Centre for Medium Range Weather Forecasting (NCMRWF) for model integration. Presently the model is being used to prepare forecasts upto 3-days routinely in semi-operational mode. The main goal of this study is to explore the predictive capability and suitability of the model for the weather systems over the Indian region. A preliminary study was undertaken in the case of intense Western Disturbances that occurred during the December 2002 and February 2003. In the 1$^{st}$ case an easterly wave present over the southeast Bay of Bengal moved westwards and caused good amount of rainfall over southern peninsula. In addition to the NCMRWF initial and boundary fields, initial analysis from ECMWF has also been used for the case of December 2002 to examine the impact of initial fields on model forecasts. In this case, using the ECMWF initial analysis FSUGCM (T-126) forecasts upto 3 days were produced and these fields at an interval of 6 hours were used as the boundary conditions for the regional model. The model forecasts are compared with those of NCMRWF global model and high resolution mesoscale Eta and MM5 model forecast which runs with same T-80 global model initial and forecast fields at NCMRWF (Das, 2002; Rajagopal and Iyangar 2003). In section 2 we introduce some of the technical details of the model. In section 3 we present detailed study of the weather events that occurred during December 2002 and February 2003. In section 4 concluding remarks are included. An outline of the FSURSM is given in Appendix I.

## 2. Regional spectral model

FSURSM uses a perturbation method similar to that used at NCEP (Juang and Kanamitsu, 1994) and ECMWF (Hoyer, 1987). However, FSURSM deviates largely from the NCEP and ECMWF regional spectral models, particularly in the areas of map projection, boundary relaxation procedure, finite differencing schemes etc. The FSURSM was designed to be compatible with the FSU global spectral model and more or less shares many of its features; it encompasses the same vertical coordinate system, horizontal diffusion, Asselin time filter, semi-implicit time integration and physical parameterization schemes and can share much of the same physics (Appendix I).

For running the RSM in operational forecasting at IMD, the model codes were modified to take the inputs from the T-80 global model operational at NCMRWF, New Delhi. In the original procedure at FSU, the ECMWF analyses (at a resolution of 1.125°) interpolated as per the FSU global model horizontal and vertical resolution. The regional fields are the sum of the global model solution and the perturbation field. Before the regional model is run the global model is first used to obtain the base field for the regional model at every nest interval of 3 to 6 hours. However, at IMD, because of limitations of computation power, the NCMRWF T80L18 analysis and forecast spectral coefficients linearly interpolated to T-126 (384 × 192 or about 0.925° resolution) horizontally and 14 vertical sigma levels. The surface pressure was calculated from global fields to the regional model using the regional spectral terrain and pressure perturbations, dry temperatures are evaluated after subtracting the global
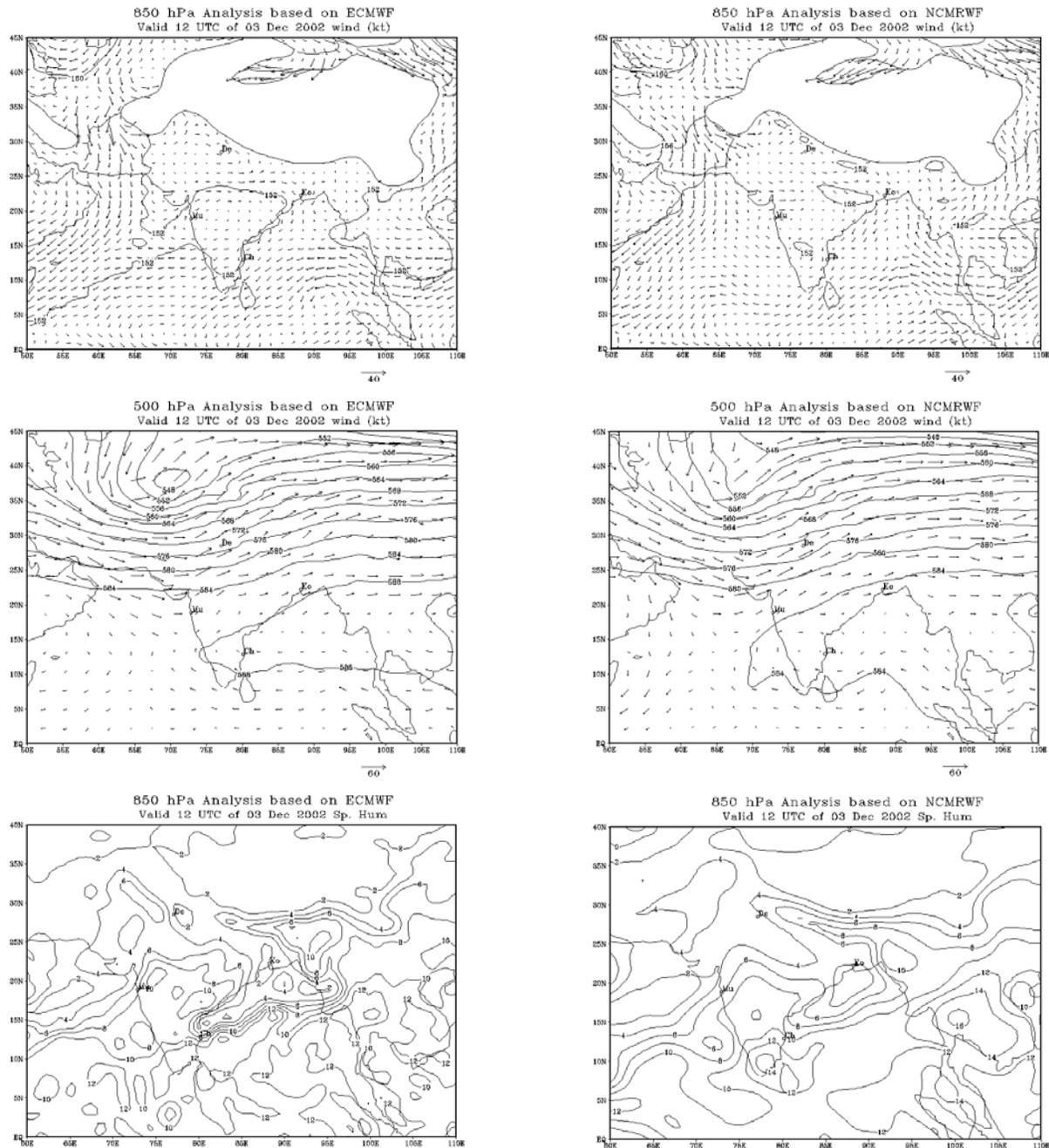
**Fig. 1.** Wind (kt) and height (gpm) at 850, 500 hPa of initial analysis and 850 hPa specific humidity (gm/kg). Left : Based on ECMWF, Right : Based on NCMRWF fields of 1200 UTC 3 December 2002

mean temperature and pressure values. In addition to the vorticity, divergence and specific humidity, these additional fields are also used as initial fields and T-80 global forecast fields at 6 hours interval as boundary conditions. These global fields are then linearly interpolated in time to the time steps of the regional model. At each time step, the perturbations are added to the global fields to obtain the full regional fields and the non-linear dynamical and physical tendencies are computed. The perturbation time tendencies are obtained
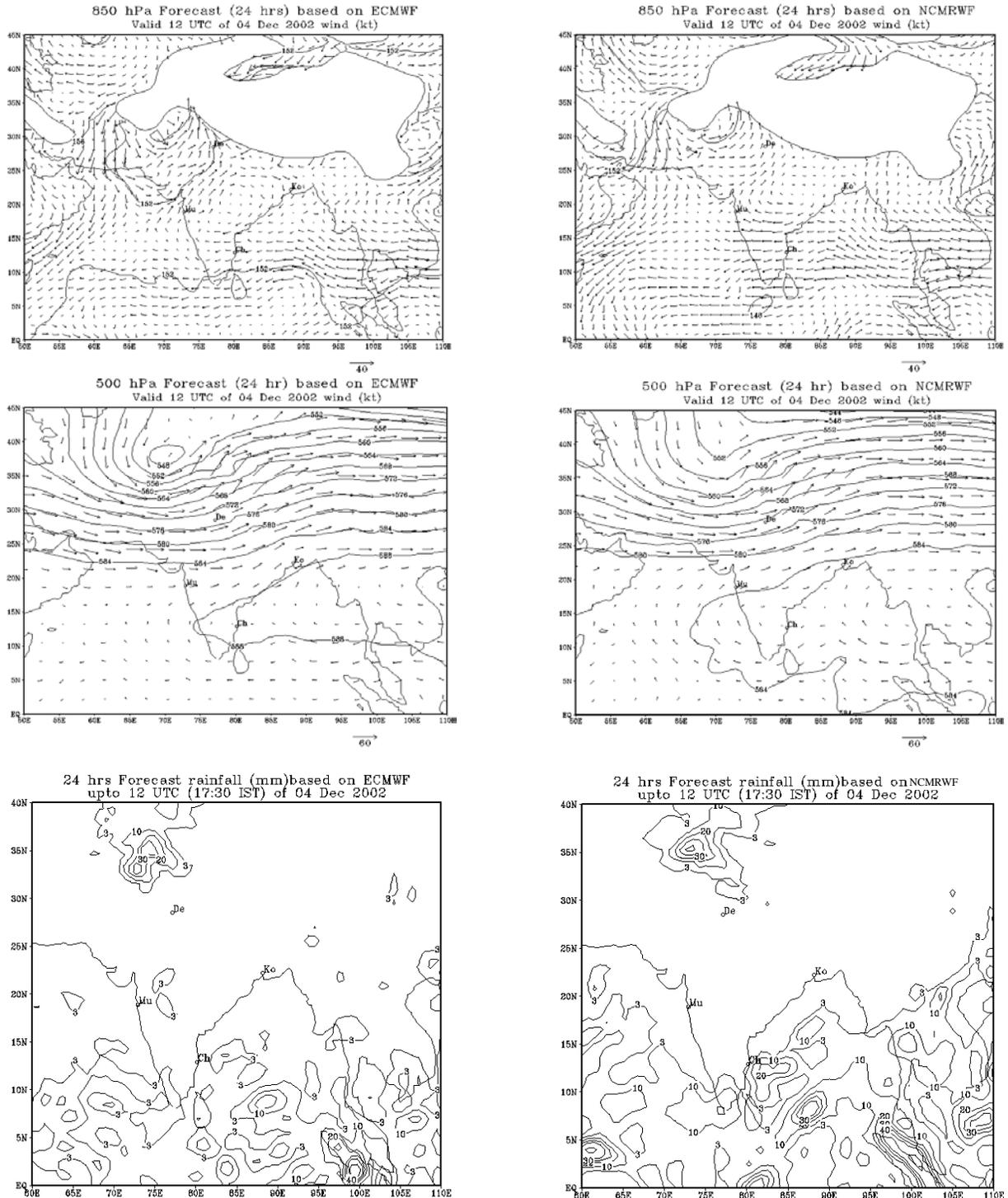
**Fig. 2.** 24 hours forecast wind (kt) and height (gpm) at 850, 500 hPa and precipitation  (CI : 3, 10, 20, 30, 40, 60, 80 mm/day) valid for 1200 UTC of 4 December 2002. Left : Based on ECMWF, Right : Based on NCMRWF fields

by subtracting the regional time tendencies from the global time tendencies. The perturbation tendencies are then spectrally analyzed and the perturbations at the next time step are solved using a semi-implicit time integration scheme. Currently, only one-way nesting is done; the regional solution does not feed back into the global model.
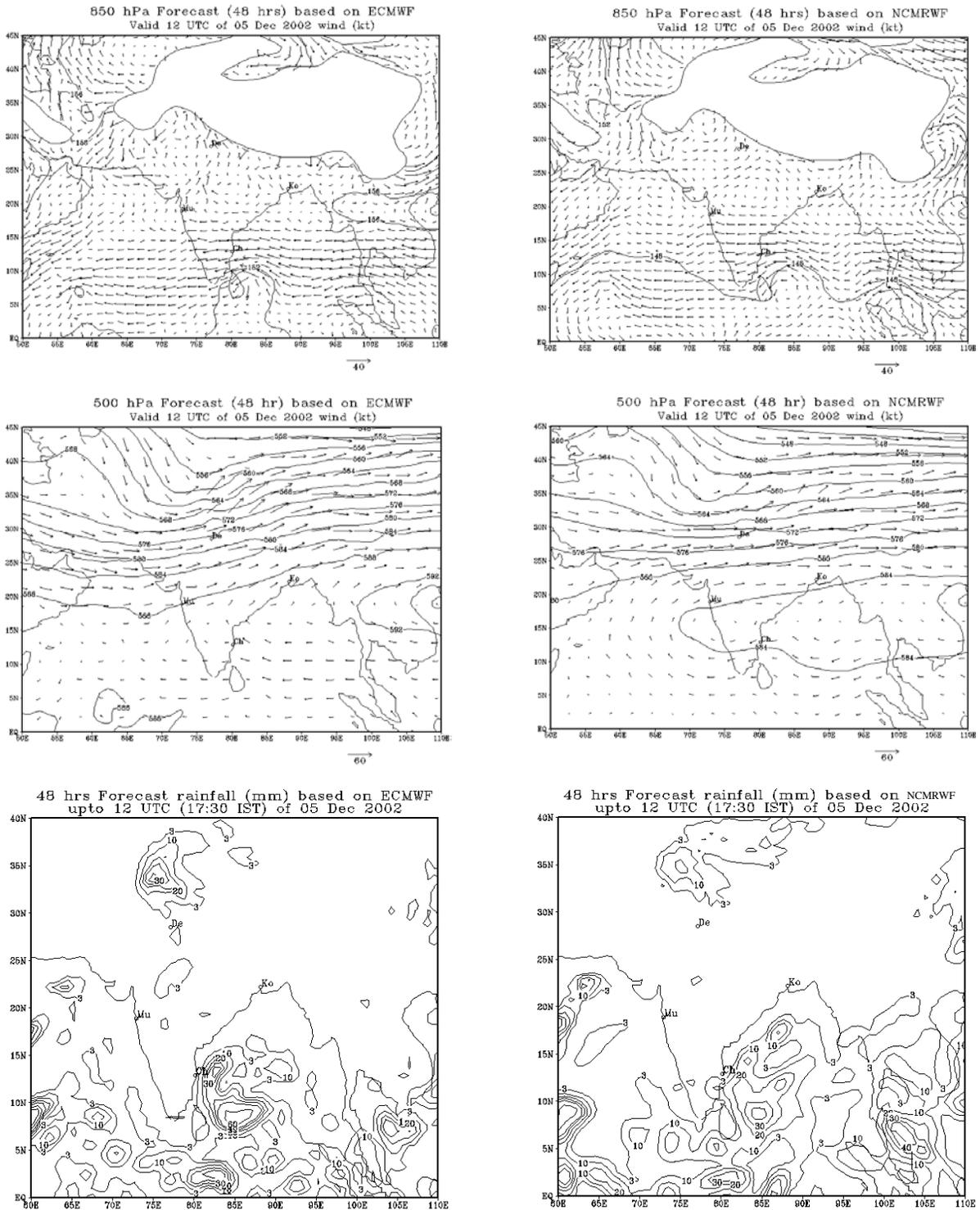
**Fig. 3.**  48 hours forecast wind (kt) and height (gpm) at 850, 500 hPa and precipitation (CI : 3, 10, 20, 30, 40, 60, 80 mm/day) valid for 1200 UTC of 5 December 2002. Left : Based on ECMWF, Right : Based on NCMRWF fields

The regional perturbations are represented as π periodic trigonometric series with perturbations are

relaxed at the boundary to approach the global model results. This relaxation scheme allows the regional
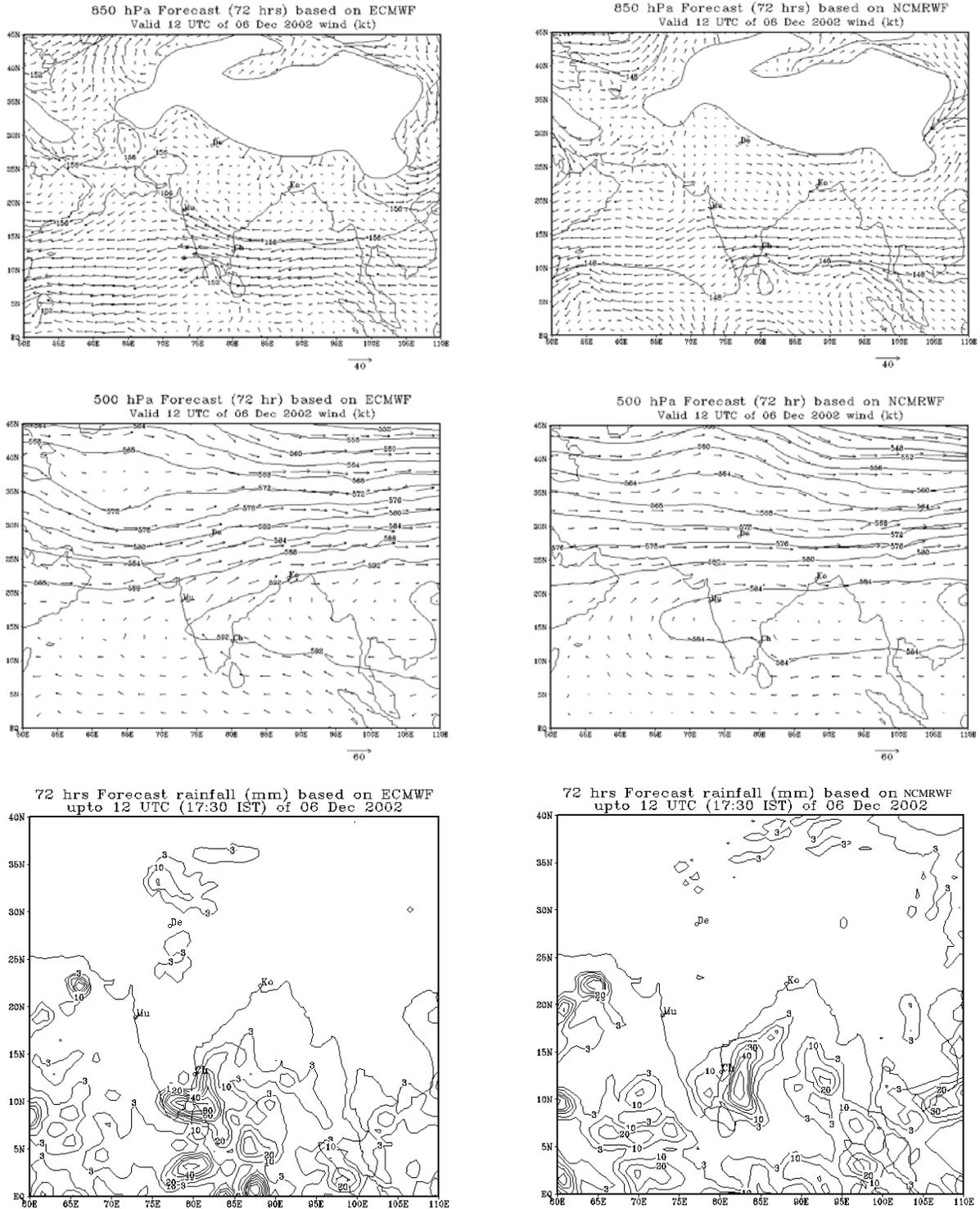
**Fig. 4.** 72 hours forecast wind (kt) and height (gpm) at 850, 500 hPa and precipitation  (contour interval (CI): 3, 10, 20, 30, 40, 60, 80 mm/day) valid for 1200 UTC of 6 December 2002. Left : Based on ECMWF, Right : Based on NCMRWF fields

model's values to converge to that of the global model, as the regional fields are denoted as the sum of the global and the perturbation fields. This scheme also prevents the accumulation of perturbations near the boundary, which
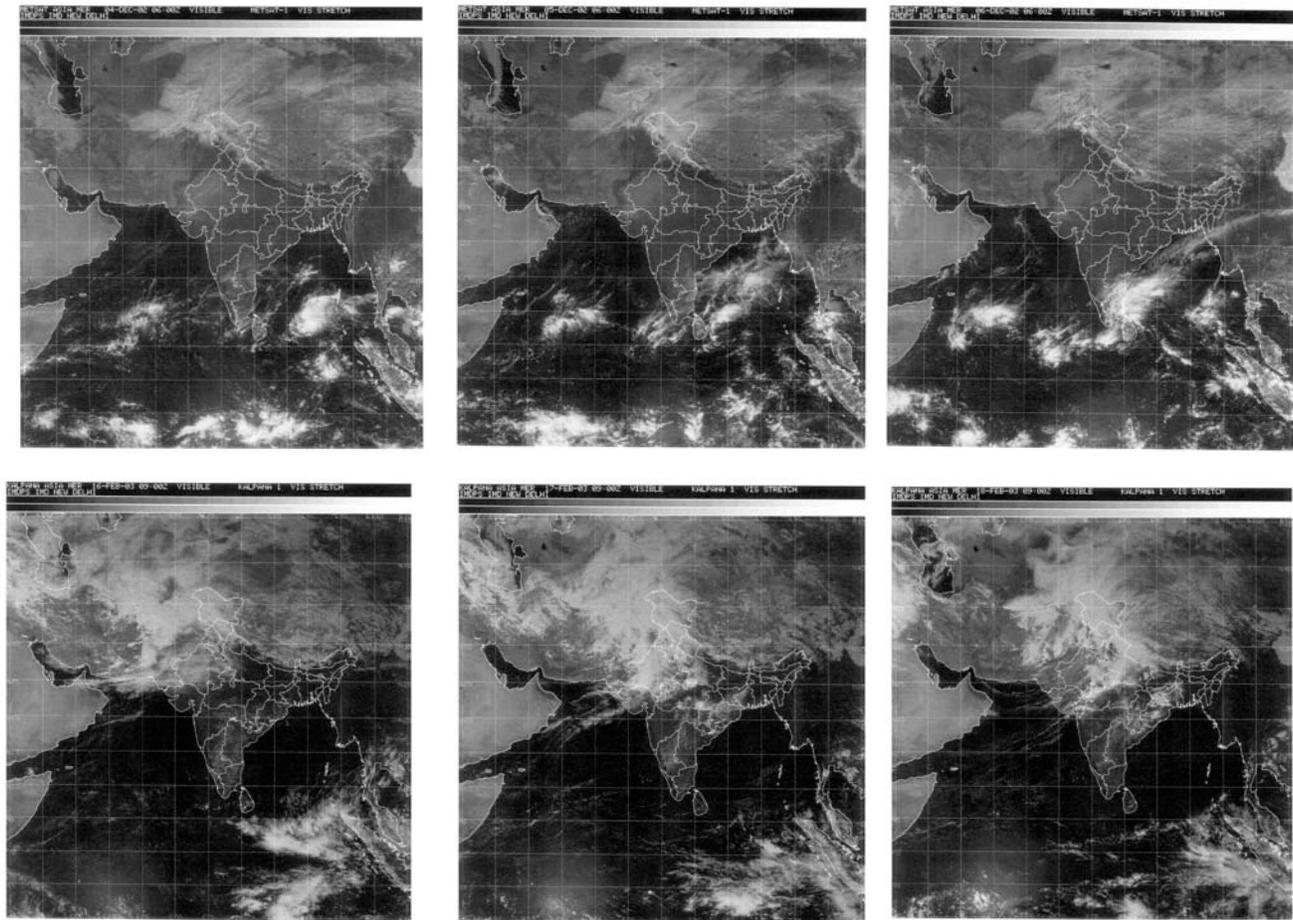
**Fig. 5.** Top: INSAT satellite picture for 0600 UTC of 4, 5 and 6 December 2002. Bottom : 0900 UTC of 16, 17 and 18th February 2003

minimize spurious reflections and Gibbs phenomena. The other details such as map projection, model integration and physical process are described in Cocke (1998).

### 3. Case study

#### 3.1. *Case-1 : 3-6 December 2002*

*Synoptic situation*

A western disturbance lay over north Pakistan and adjoining area of Jammu & Kashmir as an upper air cyclonic circulation extending upto 4.5 km above sea level at 1200 UTC of 3rd December 2002. In the subsequent three days the system moved northeastwards across Jammu & Kashmir. Also on 3rd December a trough of low pressure area lay over Andaman Sea/southeast Bay of Bengal. The system moved westwards subsequently and on 6th morning it lay over southwest Bay of Bengal and adjoining Tamil Nadu. The INSAT satellite picture of 4-6 December 2002 (Fig. 5) shows convective clouds over

southeast Bay of Bengal in association of easterly wave and over western Himalayas in association of western disturbance. Under the influence of these two systems light rain/snow occurred over western Himalayan region whereas Tamil Nadu & Pondicherry received good amount of rainfall with isolated heavy falls. The remaining parts of south peninsula and Andaman & Nicobar Islands received light rainfall.

*Numerical model experiment*

The initial analysis at 850 and 500 hPa wind fields of 3 December 2002 based on ECMWF and NCMRWF analyses are given in Fig. 1. ECMWF analysis at 850 hPa shows a cyclonic circulation over the southeast Bay of Bengal in the east-west shear zone and another trough along the Afghanistan extending to west Pakistan. At 500 hPa a deep trough over the Afghanistan to west Pakistan extending upto 200 hPa level was seen. The NCMRWF analysis shows similar features, however at 850 hPa level from the cyclonic circulation over the
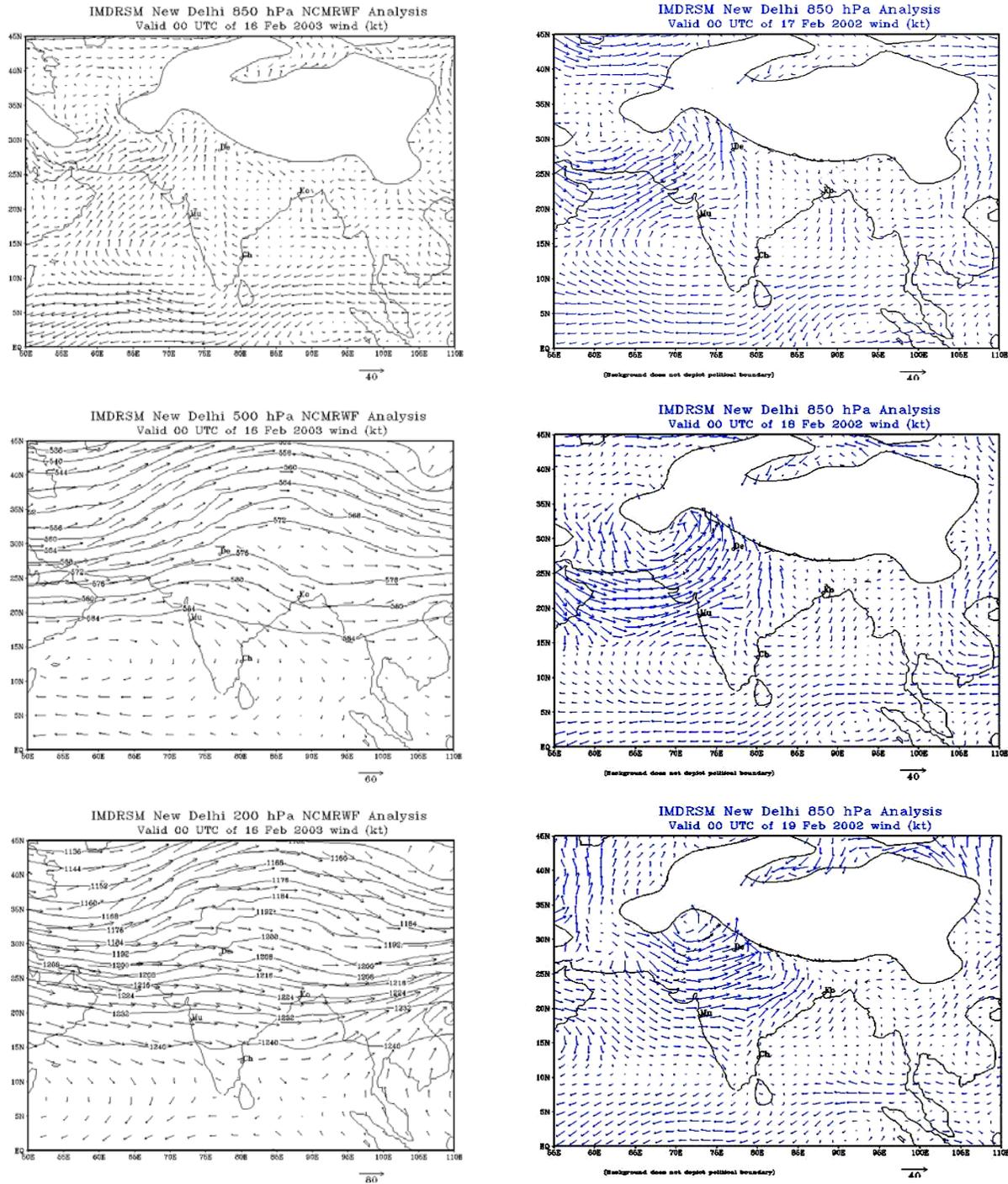
**Fig. 6.**   Left: NCMRWF initial analysis wind (kt) and height (gpm) at 850, 500, 200 hPa of 0000 UTC 16 February 2003. Right : Verifying
850 hPa analysis for 0000 UTC of 17, 18 and 19th February 2002 based on T-80 global model

southeast Bay of Bengal, a trough from this system extends to central parts of Bay of Bengal. Since, humidity is also one of the important parameter which has a significant impact on the intensity of the system and rainfall prediction, we also compared the specific

humidity fields of both the model analyses (Fig. 1). ECMWF and NCMRWF humidity fields show nearly similar features and location of maxima/minima are in agreement in both the analysis fields. However, in the ECMWF analysis, localized areas of maximum/minimum
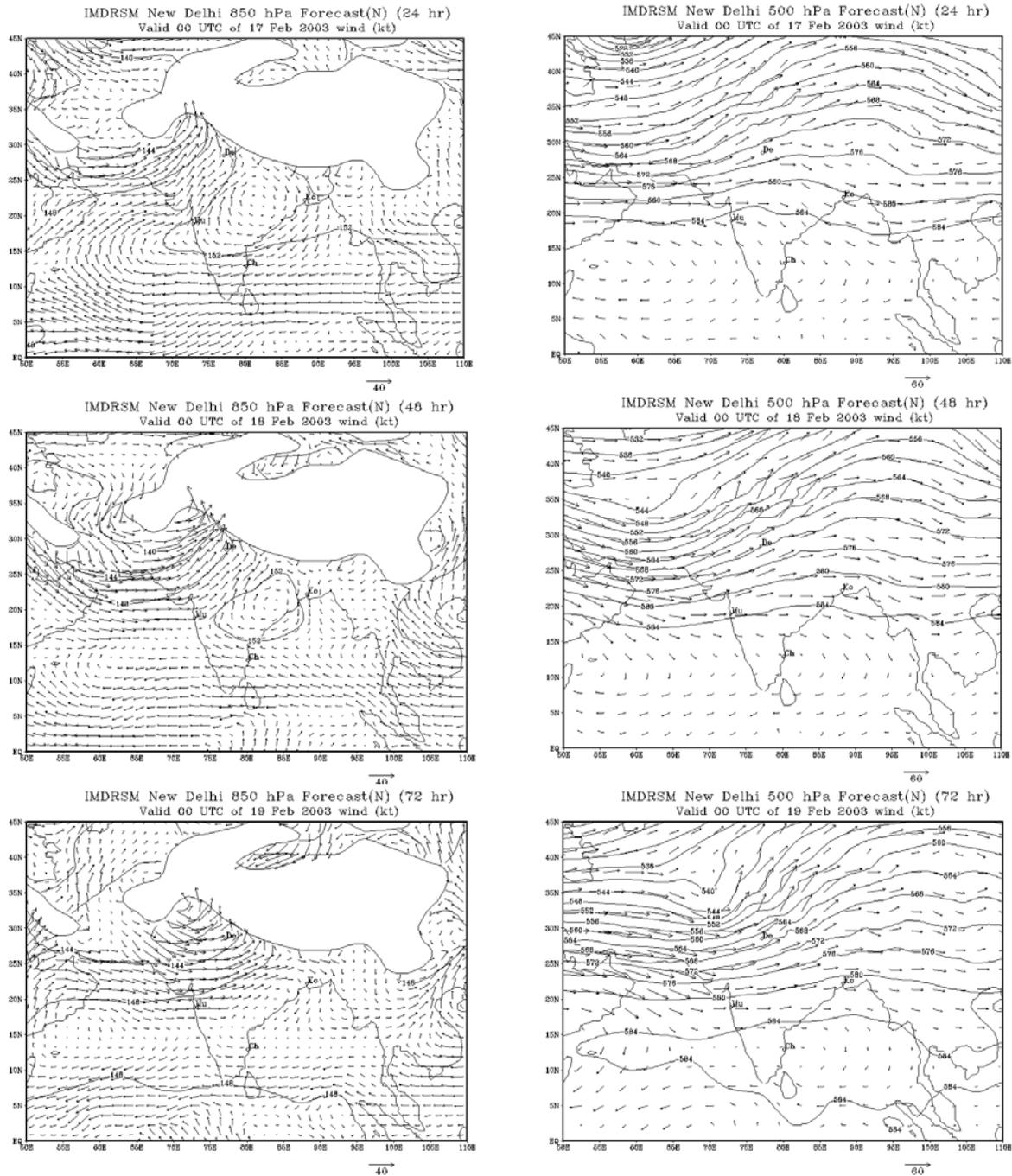
**Fig. 7.** Day 1, Day 2, Day 3 forecast wind (kt) and height (gpm) fields based on 0000 UTC 16 February 2003 NCMRWF T-80 initial data.
Left : 850 hPa, Right : 500 hPa

are better represented compared to the NCMRWF analysis. This may be due to the availability and assimilation of large number of satellite observations in the ECMWF analysis. The 850 hPa, 500 hPa flow fields and rainfall for day-1, day-2 and day-3 forecasts are given in Figs. (2-4). The INSAT satellite pictures for these

dates are shown in Fig. 5. The model predicted rainfall has been compared with the observed rainfall. The 24 hrs observed rainfall up to 1200 UTC of 6th December based on surface synoptic observations reported 3 to 5 cm rainfall over most parts of Tamil Nadu & Pondicherry and 1 to 2 cm over adjoining parts of south Andhra Pradesh

**Fig. 8.**  Day 1 (A1, A2), Day 2 (B1, B2) and Day 3 (C1, C2) precipitation (mm/day) forecast based on 0000 UTC 16 February.
2003 NCMRWF T-80 initial data. Left: Regional model (CI: 3, 10, 20, 30, 40, 60, 80 mm), Right: MM5 (CI: 1, 3, 5 ….cm)

Observed rainfall (cm) from 0300 UTC of 17 to 19 February 2003
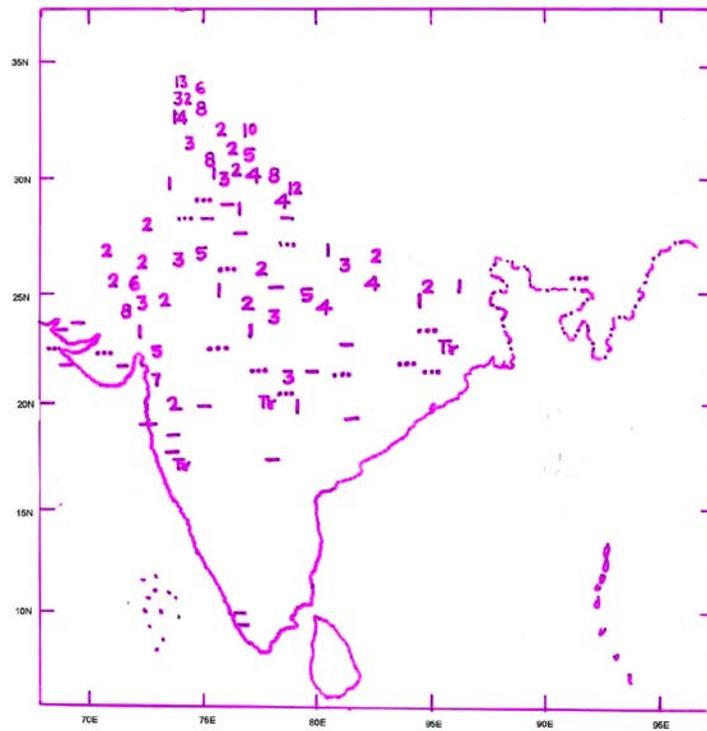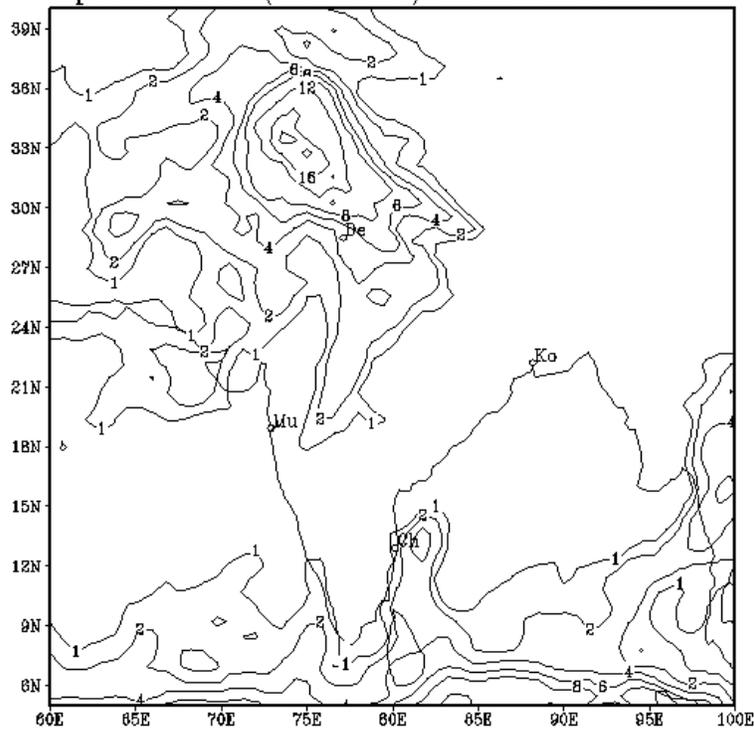


**Fig. 9.** Top : Accumulated 72 hours observed rainfall (cm) from 0300 UTC of 17-19 February 2003 based on surface observations and Bottom : Prediction by RSM for the same period (CI : 1, 2, 4, 6, 8, 12, 16, 20 cm)

and light rainfall over western Himalayas. The forecast based on ECMWF and NCMRWF analyses is able to capture both the systems and its movement. However, day-3 forecast based on ECMWF analysis is more realistic compared to the one based on NCMRWF analysis. The model was able to capture the heavy rainfall over the parts of southern peninsular India with ECMWF analysis as input. The precipitation forecast by model over western Himalayas is also close to its observed distribution (Fig. 4). The more realistic rainfall prediction over south peninsula with ECMWF input was due to the westward movement of easterly wave more realistically, due to which the low level convergence zone has moved from southwest Bay to interior southern peninsula. This was not the case in respect of NCMRWF input as such the predicted rainfall was seen more off the coast.

### 3.2. *Case-2 : 16-19 February 2003*

#### *Synoptic situation*

An active western disturbance moved across northern parts of the country from 16 to 19 February 2003. An induced cyclonic circulation also formed over western Rajasthan and neighborhood on 16th, became well marked on 17th. The pressure fall at 0300 UTC on 17th was about 4-6 hPa over Rajasthan, northern parts of Gujarat and adjoining west Madhya Pradash. On 18th the pressure departure was 10 to 12 hPa below normal over northwest Rajasthan and adjoining Pakistan. The south westerly wind of 30-40 kts at 0.9 km over Gujarat and south Rajasthan and 50-55 kts at 2.1 km was reported. While moving eastwards the system started weakening on 19th and became less marked on 20th. The INSAT satellite picture of 17-19 February 2003 (Fig. 5) shows intensive convective clouds over western Himalayas and convective clouds over northwest and adjoining central India. Under the influence of these systems, widespread rain/snow occurred over western Himalayan region. The rainfall belt also extended southward to central parts of India where Gujarat and Madhya Pradesh receiving good amount of rainfall.

#### *Numerical model experiment*

Using the NCMRWF analysis of 0000 UTC 16 February 2003, the regional spectral model forecasts for three days were produced. The initial wind analyses 850, 500, 200 hPa of 16th and 850 hPa analyses of 17, 18, and 19th February 2003 are shown in Fig. 6. The 850 hPa wind field on 16th shows a trough of low pressure area over the Pakistan extending to west Rajasthan and at 500 hPa level the trough in westerlies lies along 60° E north of 25° N. In day-1 forecast, the system moved eastwards (Fig. 7). However, subsequent forecast for two

days shows the low level trough at 850 hPa strengthening and extending to southwards from Jammu & Kashmir to Gujarat. At 500 hPa, the day-3 forecast shows a deep trough along 75° E extending upto north Maharashtra coast. The rainfall predicted by the regional spectral model and MM5 model for day-1 to day-3 is given in Fig. 8. The model predicted rainfall appears more realistic. The forecast rainfall belt extends to central parts of India over Gujarat and Madhya Pradesh in association with the strengthening of winds at low level with southward extension of trough matches with the observed features. As a part of inter comparison of the model forecast, the RSM forecast were compared with forecasts from global T-80, Eta and MM5 regional models. It was observed that the T-80 and Eta models are able to capture the rainfall in association with the system over northwest parts of India (not shown). However it was not able to capture the rainfall belt extending to central parts of India. The MM5 model was able to capture this observed feature as did the RSM, though the amount of rainfall is over estimated over parts of Jammu & Kashmir and Himachal Pradesh and much less over central parts of India (Fig. 8). In this case RSM was also able to capture the observed mesoscale localized rainfall. The 72 hours accumulated rainfall based on surface synoptic observations along with regional spectral model prediction for the same period is given in Fig. 9. The observed rainfall shows, rainfall of the order of 8-12 cm occurred over Jammu & Kashmir, Himachal Pradesh, Uttaranchal, parts of Punjab and 2-3 cm with isolated rainfall of 5-8 cm over Rajasthan and central parts of India. The regional model prediction was therefore more realistic, however there is an under estimation in amounts in case of isolated rainfall. A comparison of forecasts from various models at different resolutions suggest that the higher resolution models such as FSURSM, MM5 perform well over the region.

### 4.    **Concluding remarks**

FSURSM has been successfully implemented at IMD to prepare regional weather prediction over the Indian region. The case studies presented here show that the forecast of the regional spectral model was reasonably close to the observed features. The intensity and track forecasts of the WDs in the regional model in two cases are in good agreement with the observations. In the first case study, better forecasts with ECMWF analysis suggest that with the improvements in initial fields, the forecast accuracy increases. In the second case, model predicted rainfall, movement and intensity of the system were close to the observed fields. The comparison of RSM forecast with other high resolution model run with NCMRWF T-80 initial data shows, the regional spectral model rainfall forecast was superior to that of global model as well as other high resolution mesoscale models.

**References**

Businger, J. A., Wyngard, J. C., Izumi, Y. and Bradlay, E. F., 1971, "Flux profile relationship in the atmospheric surface layer", *J. Atmos. Sci.*, **28**, 181-189.

Cocke, S., 1998, "Case study of Erin using the FSU Nested Regional Spectral Model", *Mon. Wea. Rev.*, **126**, 1337-1346.

Das, S., 2002, "Evaluation and verification of MM5 forecasts over Indian region", 12th PSU/NCAR mesoscale model users workshop, 24-25 June 2002, Boulder C.O., USA, 77-81.

Juang, H. M. and Kanamitsu, M., 1994, "The NMC Regional Spectral Model", *Mon. Wea. Rev.*, **122**, 3-26.

Harshvardan and Corsetti, T. G., 1984, "Long-wave parameterization for the UCLA/GLAS GCM", NASA Tech. Memo., 86072, p52.

Hoyer, J. M., 1987, "The ECMWF spectral limited area model, Proc. ECMWF workshop on techniques for horizontal discretization in numerical weather prediction models", Shinfield Park, Reading, UK, ECMWF, 343-359.

Kanamitsu, M., Tada, K., Kudo, K., Sato, N. and Isa, S., 1983, "Description of JMA operational spectral model", *J. Meteor. Soc. Japan*, **61**, 812-828.

Krishnamurti, T. N., Low-Nam, S. and Pasch, R., 1983, "Cumulus parameterization and rainfall rate II", *Mon. Wea. Rev.*, **111**, 816-828.

Krishnamurti, T. N., Arun Kumar, Yap, K. S., Dastoor, Ashu, P., Davidson, Noel and Sheng, J., 1990, "Performance of a high resolution mesoscale tropical prediction model", Advances in Geophysics, 32, Academic Press, INC, 133-286.

Krishnamurti, T. N., Xue, J., Bedi, H. S., Ingles, K. and Oosterhof, D., 1991, "Physical initialization for numerical weather prediction over the tropics", *Tellus*, **43AB**, 53-81.

Lacis, A. A. and Hansen, J. E., 1974, "A parameterization of the absorption of solar radiation in the earth's atmosphere", *J. Atmos. Sci.*, **31**, 118-133.

Louis, J. F., 1979, "A parametric model of vertical eddy fluxes in the atmosphere", *Bound. Layer Meteor.*, **17**, 187-202.

Mayers, M., Krishnamurti, T. N., Depradine, C. and Moseley, L., 2001, "Numerical weather prediction over the Eastern Caribbean using Florida State University (FSU) global and regional spectral models and multi-model/multi-analysis super-ensemble", *Meteorol. Atmos. Phys.*, **78**, 75-88.

Prasad, K., Rama Rao, Y. V. and Sanjib Sen, 1997b, "Tropical cyclone track prediction by a high resolution limited area model using synthetic observations", *Mausam*, **48**, 3, 351-366.

Rajagopal, E. N. and Iyangar, G. R., 2003, "Performance of mesoscale Eta model over Indian region, weather and climate modeling", Ed. Singh, S. V., Swati Basu, Krishnamurti, T. N., New Age Int. Ltd., New Delhi.

Tatsumi, Y., 1986, "A spectral limited area model with time dependent lateral boundary conditions and its application to a multi-level primitive equation model", *J. Meteor. Soc. Japan.*, **64**, 637-663.

Tiedke, M., 1984, "The sensivity of the time-mean large-scale flow to cumulus convection in the ECMWF model : Workshop on cumulus convection in the ECMWF model", Workshop on convection in large scale numerical Models, ECMWF, Reading, UK, 297-316.

Wallace, J. H., Tibaldi, S. and Simmons, A. J., 1983, "Reduction of systematic forecast errors in the ECMWF model through the introduction of envelope orography", *Quart. J. Roy. Meteor. Soc.*, **109**, 683-718.

## Appendix I

### An outline of the FSU nested regional spectral model

(a)  Independent variables : $(x, y, \sigma \ t)$.

(b)  Dependent variables : vorticity, divergence, surface pressure, vertical velocity, temperature and humidity.

(c)  Horizontal resolution: $0.68° \times 0.75°$ Lat./Long. (Elliptic truncation with maximum E-W waves : 86, N-S waves : 64) Domain : 20° S - 46° N; 30° E-126° E.

(d)  Vertical resolution : 15 layers between roughly 50 and 1000 hPa.

(e)  Semi-implicit time-differencing scheme.

(f)  Envelope orography (Wallace *et al.*, 1983).

(g)  Centered differences in the vertical for all variables except humidity, which is handled by an upstream differencing scheme.

(h)  Fourth-order horizontal diffusion (Kanamitsu *et al.*, 1983).

(i)  Kuo-type cumulus parameterization (Krishnamurti *et al.*, 1983).

(j)  Shallow convection (Tiedke, 1984).

(k)  Dry convective adjustment.

(l)  Large scale condensation.

(m)  Surface fluxes *via* similarity theory (Businger *et al.*, 1971)

(n)  Vertical distributions of fluxes utilizing diffusive formulation where the exchange coefficients are functions of the Richardon number (Louis, 1979).

(o)  Long and shortwave radiative fluxes based on band model (Harshvardan and Corsetti, 1984; Lacis and Hansen, 1974).

(p)  Diurnal cycle (day/night by variation of zenith angle)

(q)  Parameterization of low, middle and high clouds based on threshold relative humidity for radiative transfer calculations.

(r)  Surface energy balance couple to the similarity theory (Krishnamurti *et al.*, 1991).

(s)  Nonlinear normal mode initialization - five vertical modes.

————————