

Impact of KALPANA-1 cloud motion vector in the analysis and forecast of IMD operational NWP system

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सार – 12 सितम्बर 2002 से मौसम विज्ञान के लिए समर्पित भारत के पहले उपग्रह कल्पना-1 के क्रियाशील होने के साथ ही हिंद महासागर के अनुपलब्ध आँकड़ों वाले क्षेत्र के उपग्रह से प्राप्त पवनों के आँकड़ों के क्षेत्र विस्तार से सुधार हुआ है। इन आँकड़ों के उपलब्ध हो जाने से भारत मौसम विज्ञान विभाग (भा.मौ.वि.वि.) की प्रचालनात्मक एन. डब्ल्यू. पी. प्रणाली में इनके प्रभाव की जाँच करने की एक नई संभावना उत्पन्न हुई है। इस शोध पत्र में वर्ष 2003 की मानसून वर्षा पर किए गए प्रयोगों के आधार पर भारत मौसम विज्ञान विभाग की एन. डब्ल्यू. पी. प्रणाली में कल्पना-1 से प्राप्त हुए सी. एम. वी. आँकड़ों के प्रभाव के बारे में बताया गया है। इस निदर्श से प्राप्त हुए पवन के अतिरिक्त आँकड़ों का प्रभाव सार्थक और लाभकारी पाया गया है।

ABSTRACT. The coverage of satellite derived winds over the data gap Indian Ocean region has improved with the operation of India's first dedicated satellite for meteorology KALPANA-1 since 12 September 2002. Availability of these data has opened up a new possibility to examine the impact of these data in the operational NWP system of India Meteorological Department (IMD). In this paper, impact of KALPANA-1 CMV data in the NWP system of IMD has been presented based on the experiments carried-out for the monsoon 2003. The impact of additional wind data in the model is found to be significant and beneficial.

Key words – Numerical weather prediction, Cloud motion vector, Data impact, Summer monsoon.

1. Introduction

A major problem in the use of Numerical Weather Prediction (NWP) model over tropics is the near absence of data over the large oceanic region. In view of the importance of these data in the tropical numerical weather prediction, continuous efforts are being made by NWP community to maximize utilization of various non-conventional data. Although satellite derived wind has been in use in numerical weather prediction for more than a decade now, recent advances in spatial resolution and radiometric sensitivity have significantly improved the accuracy and density of wind products (Velden *et al.*, 1997). In India, recently a number of attempts (Bohra *et al.*, 1998; Prasad, 2003; Das Gupta *et al.*, 2003, Kar *et al.*, 2003) have been made towards improving model initial condition and predictions using satellite derived meteorological parameters in global models. But no study is yet to be reported demonstrating the impact of INSAT (Indian Satellite) derived cloud motion vectors (CMV) in NWP models.

With the operation of India's first dedicated satellite for meteorology KALPANA-1 that was launched to its orbital slot of Longitude 74° E on 12 September 2002, the coverage of satellite-derived winds over the data gap Indian Ocean region has improved further. Cloud Motion Vectors (CMV) are derived for three layers, namely lower, middle and upper troposphere using three half hourly images (2330 UTC, 0000 UTC and 0030 UTC for the 0000 UTC observation) through a detailed pattern matching technique. Two sets of computed vectors from triplet of images are then passed through a two steps of quality control involving automated and manual controls. Automatic control (Merrill, 1989) involves tests based on absolute threshold speed, time and space consistency and comparison with NWP model generated forecast fields. Height is assigned using model temperature of IR image for identified cloud type. Day to day comparison of these data with respect to Meteosat-5 and RS/RW observations suggests that the quality of data is fairly accurate and acceptable for use in application. Presently these data are available in the GTS (Global Telecommunication System)

transmission. The KALPANA-1 CMV data based on 0000 UTC observations were used daily during southwest monsoon 2003 in the NWP system of IMD on experimental mode. In this paper, impact of KALPANA-1 CMV data in the NWP system of IMD has been discussed based on the experiments carried-out for the monsoon 2003.

2. Design of experiment

To evaluate the impact of additional CMV data, two data sets of experiments performed are: (i) Control run: In this experiment, no CMV data (KALPANA-1) is used and the analysis procedure is run only with the operationally available GTS data and (ii) Experiment run: In this the analysis procedure is run with the additional CMV data together with all data used in operational run. With each of these two sets of analysis fields based on 0000 UTC observations, model is run every day upto 24 hours forecast for the months of June, July and August of monsoon 2003.

Impact of forecast is also evaluated through the model rainfall forecasts. For comparison of forecast rainfall with the observed rainfall, objective analysis (Roy Bhowmik *et al.* 2005) of daily rainfall at the model resolution is carried-out from the use of daily land rainguage data and INSAT (KALPANA-1) derived rainfall estimates. The error statistics (mean error, root mean square errors, threat score) of the rainfall forecasts are computed for the entire data period based on the daily rainfall analysis.

2.1. Analysis procedure

The operational NWP system of India Meteorological Department (IMD) consists of real time processing of data received on Global Telecommunication System (GTS), decoding and quality control procedure and a multivariate optimum interpolation scheme. The first guess field for running the analysis is obtained online from the global forecast (T-80/18L) run at National Centre for Medium Range Weather Forecasting (NCMRWF), New Delhi. The input data used for the analysis consist of Surface – SYNOP/SHIP; Upper air – TEMP/PILOT, SATOB; Aircraft reports – AIREP, AMDAR, CODAR. These are extracted and decoded from the raw GTS data sets. All the data are quality controlled and packed into a special format for objective analysis. The methodology applied for objective analysis scheme is the statistical 3-dimensional multivariate Optimum Interpolation (OI) scheme (Dey and Morone, 1985). The scheme is based on applying correction to a first guess, the corrections being the weighted average of (observation-first guess) residuals at the observation locations. The

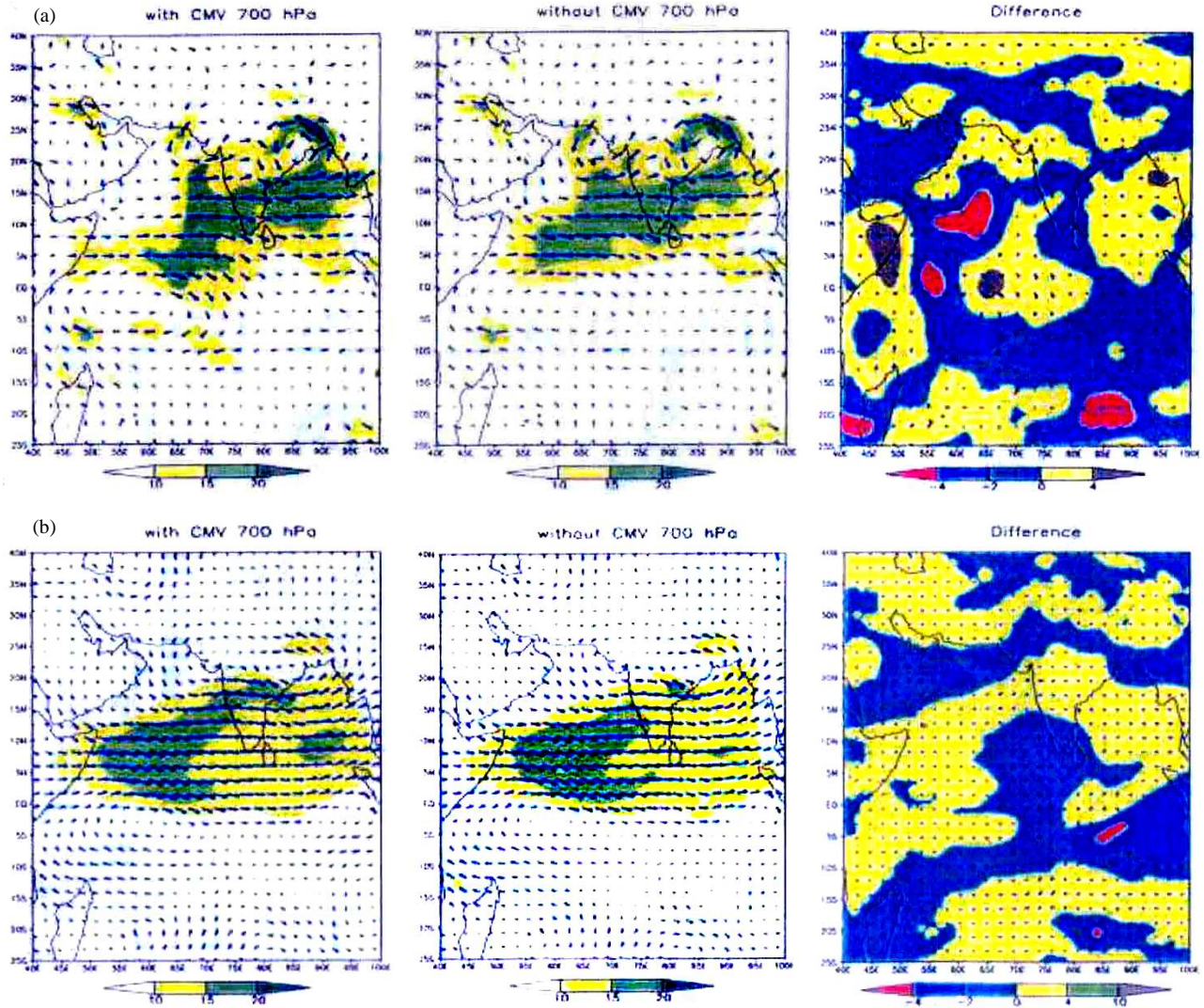
variable analyzed in this scheme is geopotential (z), u and v components of wind and specific humidity. Temperature (T) field is derived from geopotential field hydrostatically. Analysis is carried out on 12 sigma (pressure divided by surface pressure) surfaces 1.0, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 0.07, 0.05 in the vertical and on $1^\circ \times 1^\circ$ horizontal Lat./Long. grid for a regional or limited horizontal domain covering Lat. 30° S to 60° N and Long. 0° to 150° E.

2.2. Description of the model

The forecast model is a semi-implicit, semi-Lagrangian, multi level primitive equation model cast in sigma co-ordinate and staggered Arakawa C-grid in the horizontal. The model consists of the usual equations of motion, thermodynamic energy equation, mass continuity equation, moisture continuity equation, hydrostatic equation and equation of state. The model includes number of physical processes such as cumulus convection (modified Kuo; Krishnamurti *et al.*, 1983), shallow convection (Tiedke, 1984), large scale condensation, atmospheric boundary layer (Monin-Obukhov formulation of surface layers with stability dependent vertical diffusion in mixed layer), radiation (Harshvardan and Corsetti, 1984; Lacis and Hansen, 1974) and envelope orography (Wallace *et al.*, 1983)). Further details of the model formulation can be found in Krishnamurti *et al.* (1989). Horizontal resolution of the coarser grid (operational) model is $0.75^\circ \times 0.75^\circ$ Latitude/Longitude and 16 sigma levels in the vertical. The orography prescribed in the model is smoothed by a nine point smoother to prevent instability due to steep gradients of terrain over the Himalayan region. The other features of the model include time dependent lateral boundary conditions and dynamic normal mode initialization (Sugi, 1986). Model is run up to 48 hours, twice daily initialized with 0000 UTC and 1200 UTC observations. Lateral boundary conditions of the model are from the global spectral model (T-80/18L) run of the National Center for Medium Range Weather Forecasting (NCMRWF), New Delhi and are updated every 12 hours. The time step of the model is 900 seconds.

3. Results of impact studies

Monsoon depressions are the main rain producing system of Indian summer monsoon which forms over the north Bay of Bengal and move across the country along northwesterly direction. A case study of a monsoon depression is discussed in section 3.1. The presence of low level westerly jet over the south Arabian Sea and upper tropospheric tropical easterly jet over the southern peninsular India are other two important components of monsoon system. In section 3.2, the monthly features of these components are examined and discussed. Impact of



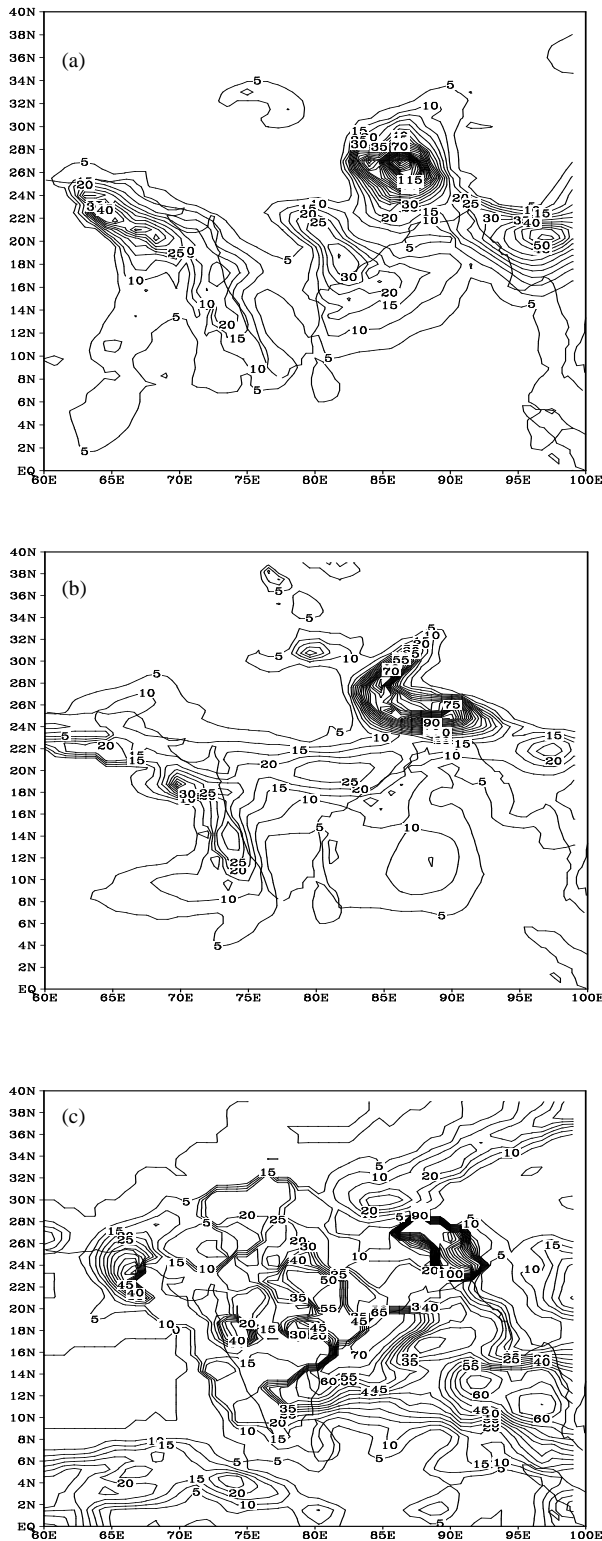
Figs. 1. (a&b). (a) Wind field (ms^{-1}) at 700 hPa for 0000 UTC of 26 July 2003 based on analysis with and without CMV and the difference (with-without); (b) Same as (a) except for the 24 hours forecast valid for 0000 UTC of 26 July 2003

CMV data in the model rainfall forecast is described in section 3.3.

3.1. Case study of a monsoon depression

During 23-24 July, a low pressure area formed over the northwest Bay of Bengal. On 25 July evening, the system intensified into a monsoon depression and lay over the northwest Bay of Bengal and adjoining coastal areas of Orissa with associated upper air cyclonic circulation extending upto midtropospheric levels. Another low pressure area formed over north Gujarat region and adjoining areas of north east Arabian Sea during 24 and 25 July. On 26 July morning, the depression crossed north

Orissa coast and lay over north Orissa and adjoining states. The other low pressure area lay over Saurashtra & Kutch and adjoining Arabian Sea. Fig. 1(a) represents wind analysis of 700 hPa at 0000 UTC of 26 July based on CMV and with out CMV. The third column represent difference of respective fields with and without CMV. Though both the analysis (with and without CMV) could capture circulation features associated with both the systems, strengthening (higher by about 4 ms^{-1}) of wind over the Bay of Bengal, in the southern sector of the depression, over the area of monsoon low pressure area in north-east Arabia Sea and adjoining Saurashtra & Kutch and the cross equatorial flow over the South Arabian Sea and adjoining north Indian Ocean are captured better in



Figs. 2(a-c). 24 hours rainfall (mm) valid at 0000 UTC of 27 July for the forecast with (a) CMV, (b) without CMV and the (c) rainfall analysis

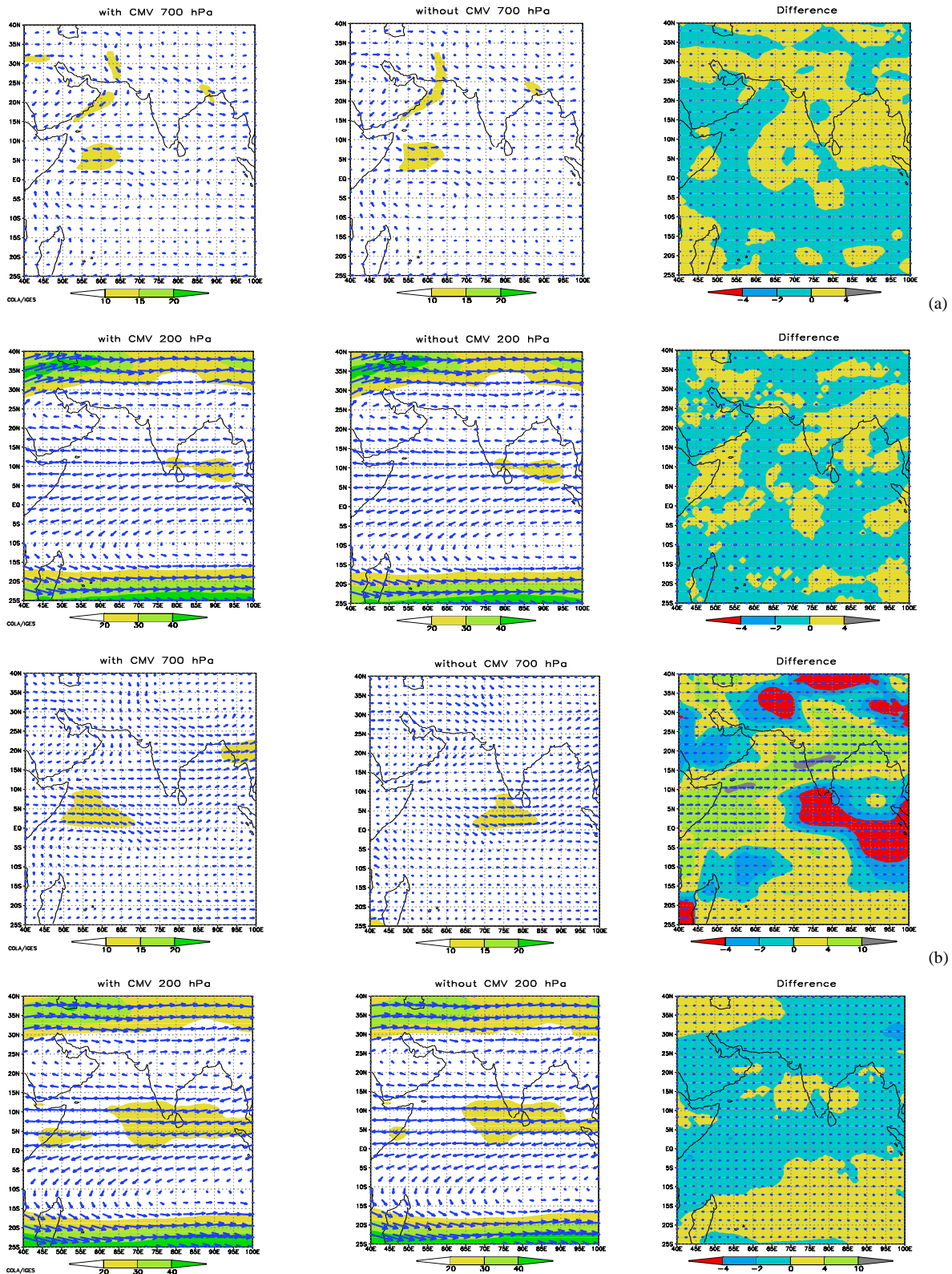
the analysis with CMV. Fig. 1(b) shows corresponding 24 hours forecast valid for 0000 UTC of 26 July. Strengthening of low level westerly jet is comparatively better simulated in the forecast with CMV. The most important aspect to note here is that in the experimental run, the easterly flow in the northern sector and westerly flow in the southern sector of the monsoon trough is stronger. Otherwise no change is noticed in the flow pattern and in the location of the systems.

Figs. 2 (a&b) shows 24 hours rainfall forecast valid at 0000 UTC of 27 July based on experimental run and control run respectively. The corresponding rainfall observations are shown in Fig. 2(c). Comparative studies of rainfall figures indicates that there is no significant change in the rainfall pattern. The experimental run shows relatively more rainfall compared to control run over the areas of these two monsoon low pressure systems and that matches with the observation reasonably well. The relatively smooth and higher rainfall pattern in the experimental run is probably due to large scale lower tropospheric convergence from the ocean. The convergence of oceanic air mass is found to be stronger in the initial condition with the use of INSAT CMV. It is to be noted that no satellite derived moisture field is inducted in the model initial condition.

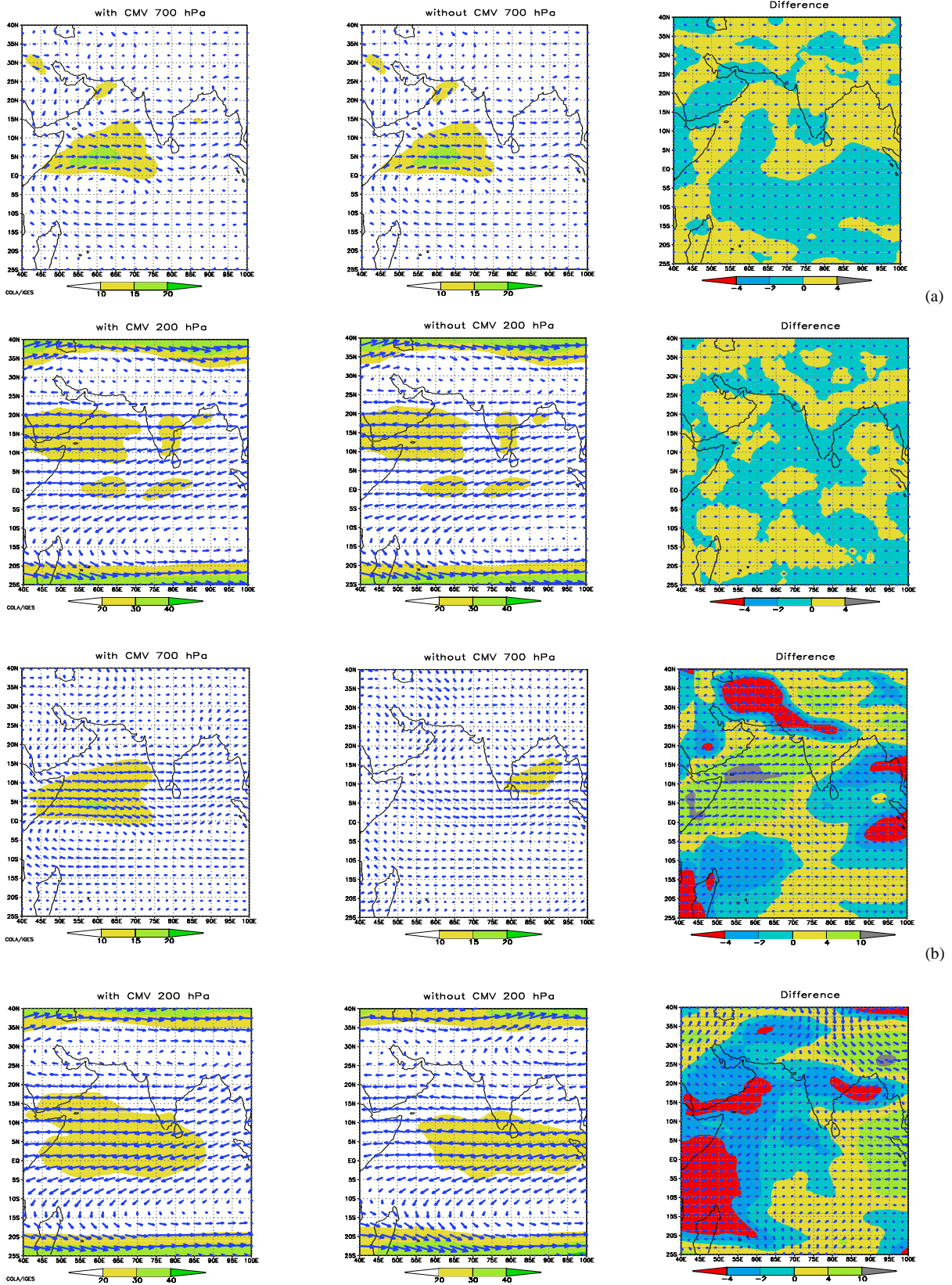
3.2. Monthly mean features

(i) Lower and upper tropospheric flow

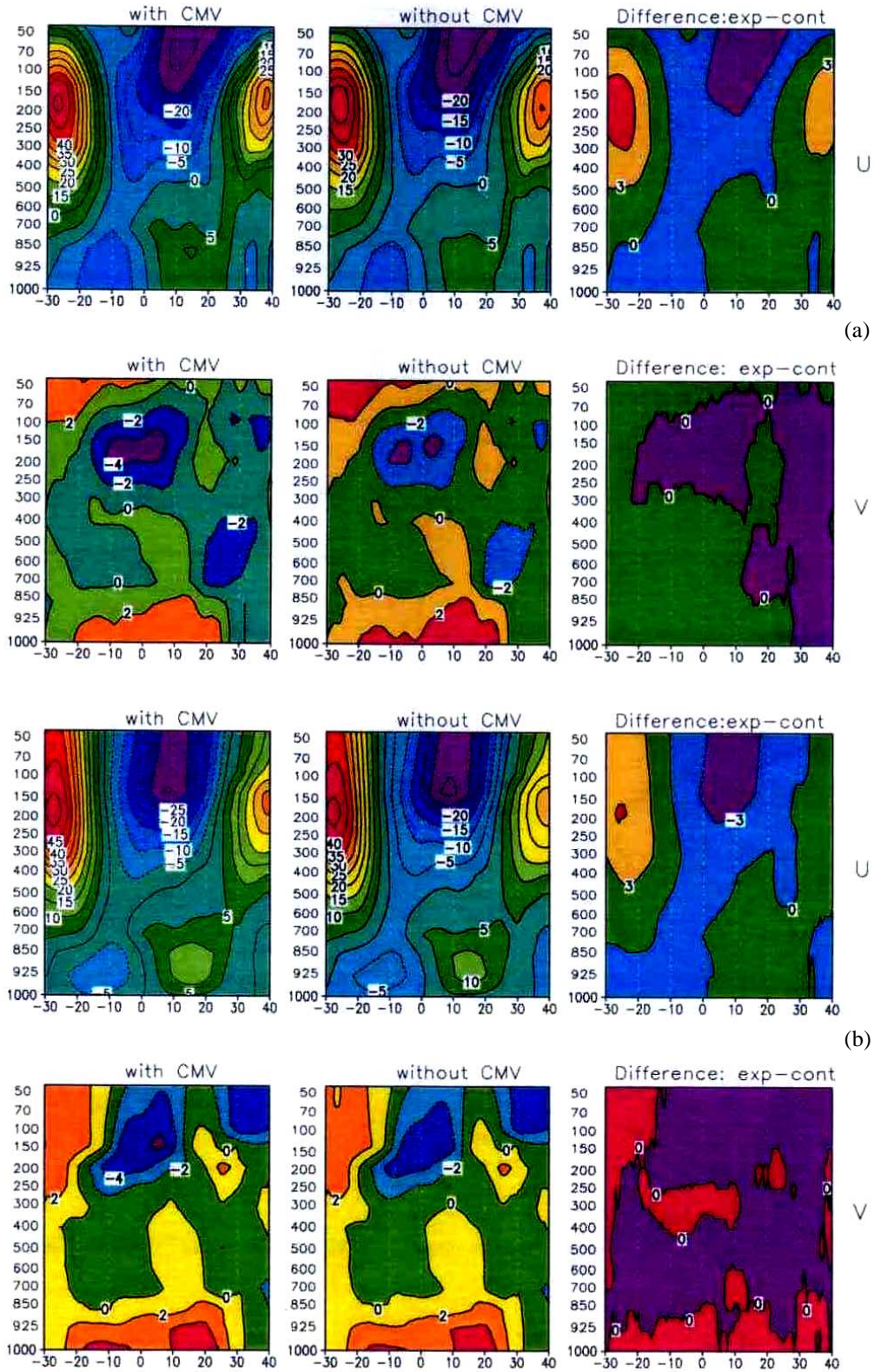
Fig. 3(a) presents the mean wind field at 700 hPa and 200 hPa for the month of June based on daily analysis fields (with and without CMV). The third column shows the difference of respective fields with and without CMV. Though both the analysis (CMV and without CMV) could captured the onset features like strengthening of lower tropospheric (700 hPa) south westerly flow near Somali coast and over the south east Arabian Sea and Bay of Bengal, comparison reveals (third column in the figure) that strength of southwesterlies over these regions were more when CMV data are used in the analysis. The corresponding mean wind field based on 24 hours forecast is shown in Fig. 3(b). The comparison clearly shows that in the forecast with CMV, the strength of lower tropospheric cross equatorial flow along Somali coast is better represented. This has been more consistent with the corresponding analysis field. Where as in the forecast with out CMV, an area of stronger south-westerlies is noticed along south west of Srilanka. An appreciable difference is noticed between the two forecasts. The southwesterlies over the monsoon domain starting from Somali coast to north-eastern states across the south Arabian Sea, were stronger in the forecast with CMV. At 200 hPa, both analysis and forecast (with and without CMV) could



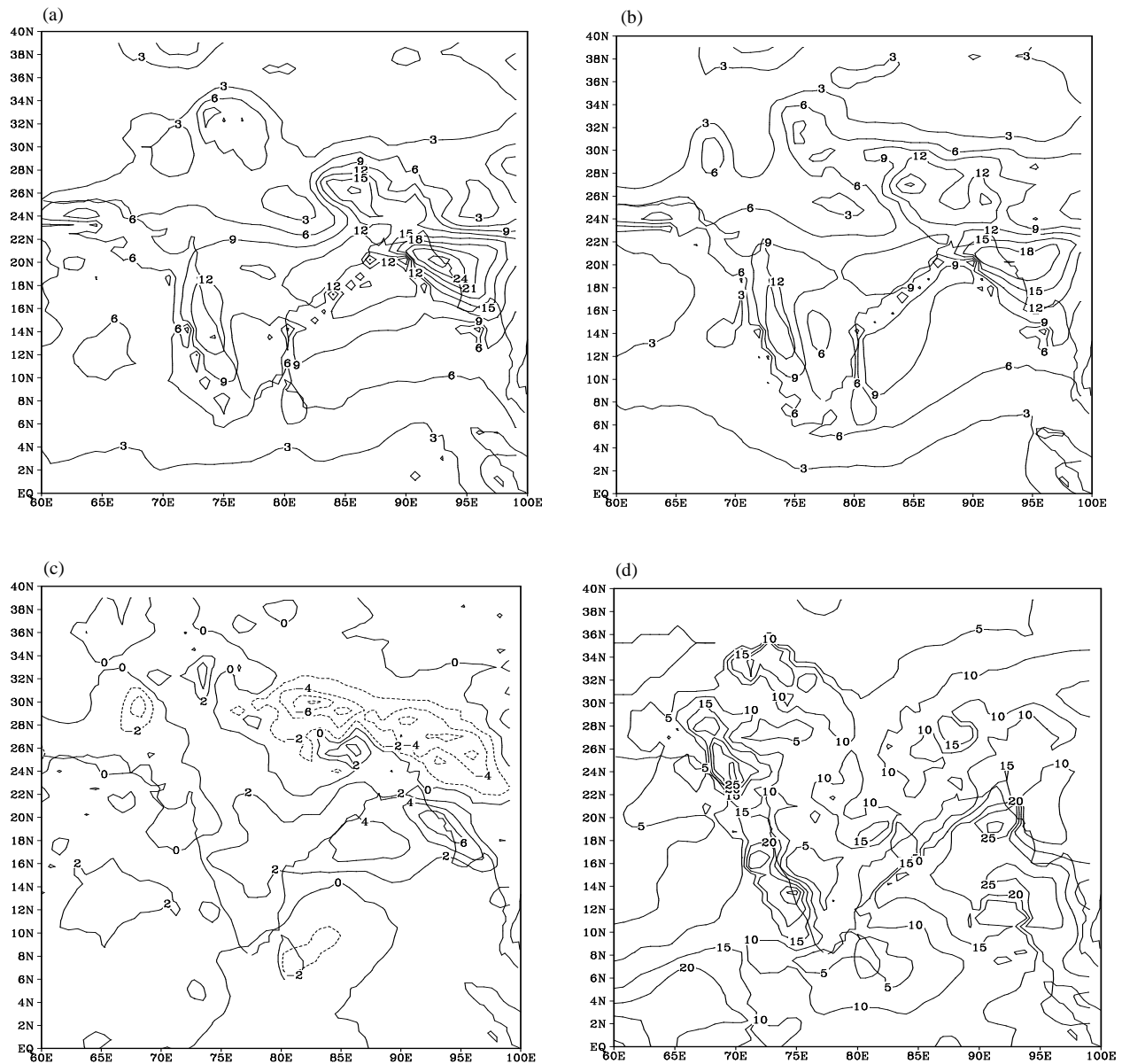
Figs. 3(a&b). (a) Mean wind field (ms^{-1}) at 700 hPa and 200 hPa for the month of June 2003 based on analysis with and without CMV and the difference (with-without); (b) Same as (a) except for the 24 hours forecast



Figs. 4 (a&b). Same as Figs. 3(a&b) except for the month of July



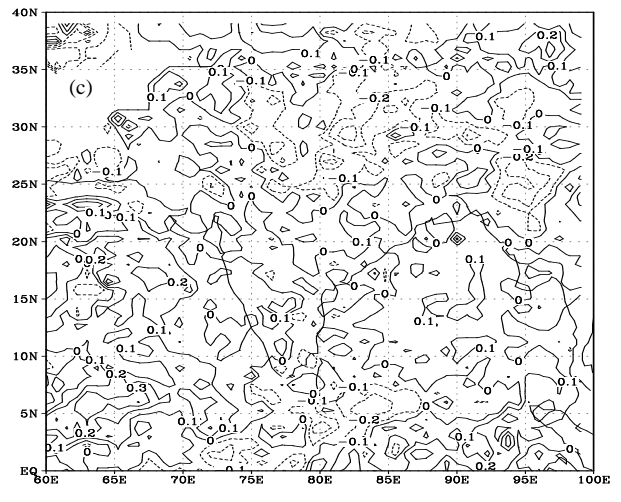
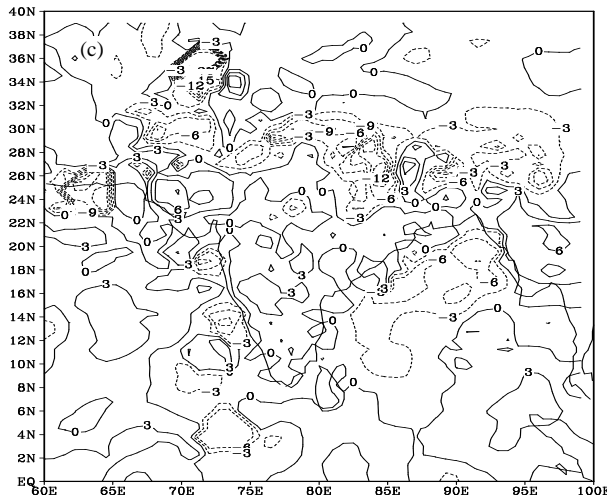
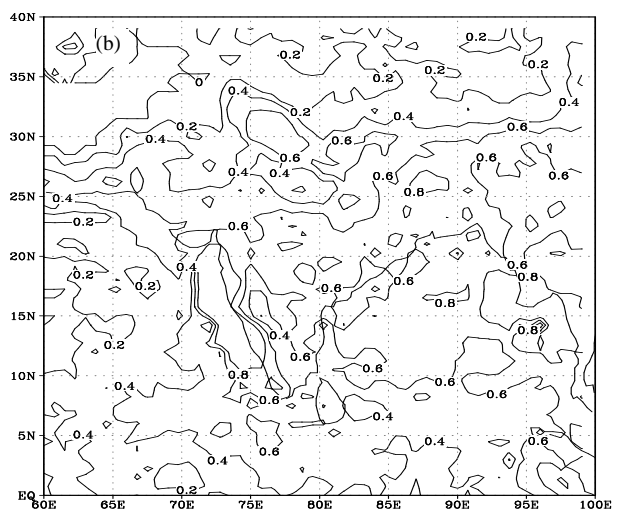
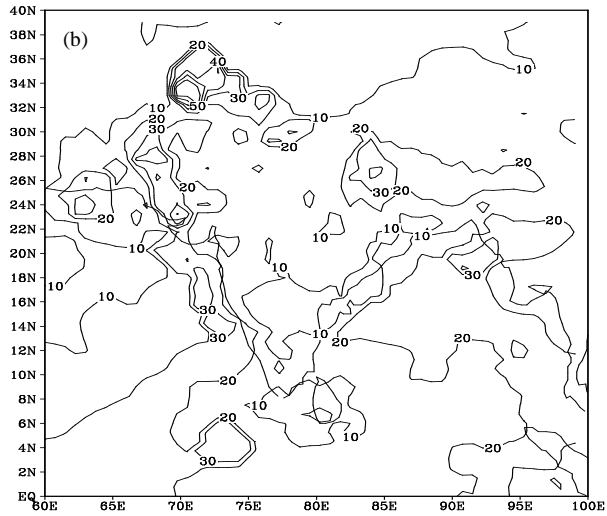
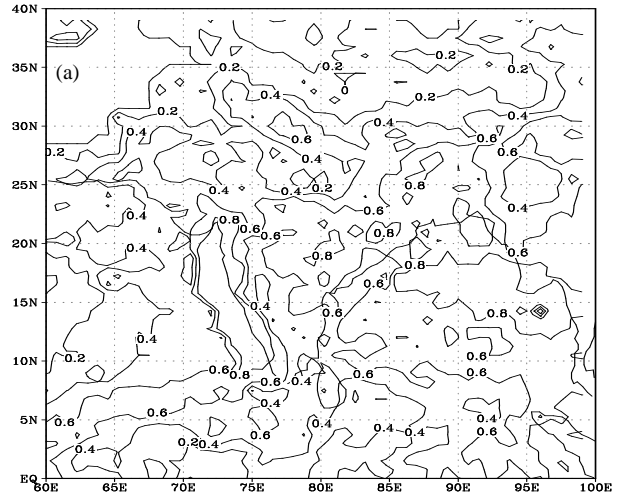
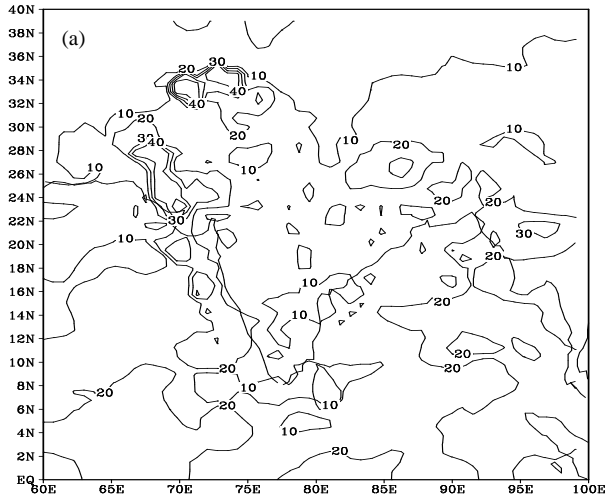
Figs. 5 (a&b). Vertical cross section of mean zonal and meridional components (ms^{-1}) of wind field for the month of June 2004 based on analysis with and without CMV and the difference (with-without); (b) Same as (a) except for the 24 hours forecast. Dotted line indicates easterlies and solid lines westerlies. The X-axis is the latitude 30° S to 40° N and Y-axis is the pressure levels in hPa



Figs. 6(a-d). Mean rainfall field (mm/day) for the period June to August, 2004 based on forecast (a) with CMV, (b) without CMV, (c) the difference (mean error) and (d) the corresponding rainfall analysis

capture stronger easterlies over Srilanka and adjoining areas. But strength of easterlies, particularly in the forecast, over these areas have been slightly stronger when CMV data are used. Thus, it is encouraging to note that impact of KALPANA-1 CMV data, both in the analysis and forecast has been quite significant to reproduce the onset flow features of Indian summer monsoon.

Fig. 4(a) presents the mean wind fields at 700 hPa and 200 hPa for the month of July based on both the analysis. Again we notice that both the analysis (CMV and without CMV) look identical and could capture large scale monsoon features like strong lower tropospheric south westerly flow along Somali coast, extending upto the south east Arabian Sea. But the strength of southwesterlies over Somali coast, South Arabian Sea and



Figs. 7(a-c). RMSE (mm/day) for the (a) forecast with CMV (b) without CMV and (c) the difference for the period June to August 2003

Figs. 8 (a-c). Same as Figs. 7(a-c) except for the threat score of 2 mm rainfall

Bay of Bengal has been comparatively better reflected when CMV is used. The corresponding mean wind field based on 24 hours forecast is shown in Fig. 4(b). It is interesting to note that the forecast with CMV is more consistent with corresponding analysis field where stronger south-westerlies over the areas of Somali coast extending upto south Arabian Sea are better reproduced. At 200 hPa [Fig 4(b)], strength of easterlies over the Indian monsoon region is relatively stronger in the analysis as well as in the forecast with CMV.

For the month of August (figure not shown) stronger winds over most parts of the Arabian Sea and adjoining land areas of the country extending upto the west Bay of Bengal are noticed in the analysis when CMV data is used. The forecast with CMV shows similar to the analysis with one belt of stronger winds over the south Arabian Sea and another over the South Bay of Bengal. The forecast with CMV indicates strengthening of south-westerlies over the Arabian Sea at 700 hPa and strengthening of easterlies over Srilanka and adjoining areas at 200 hPa.

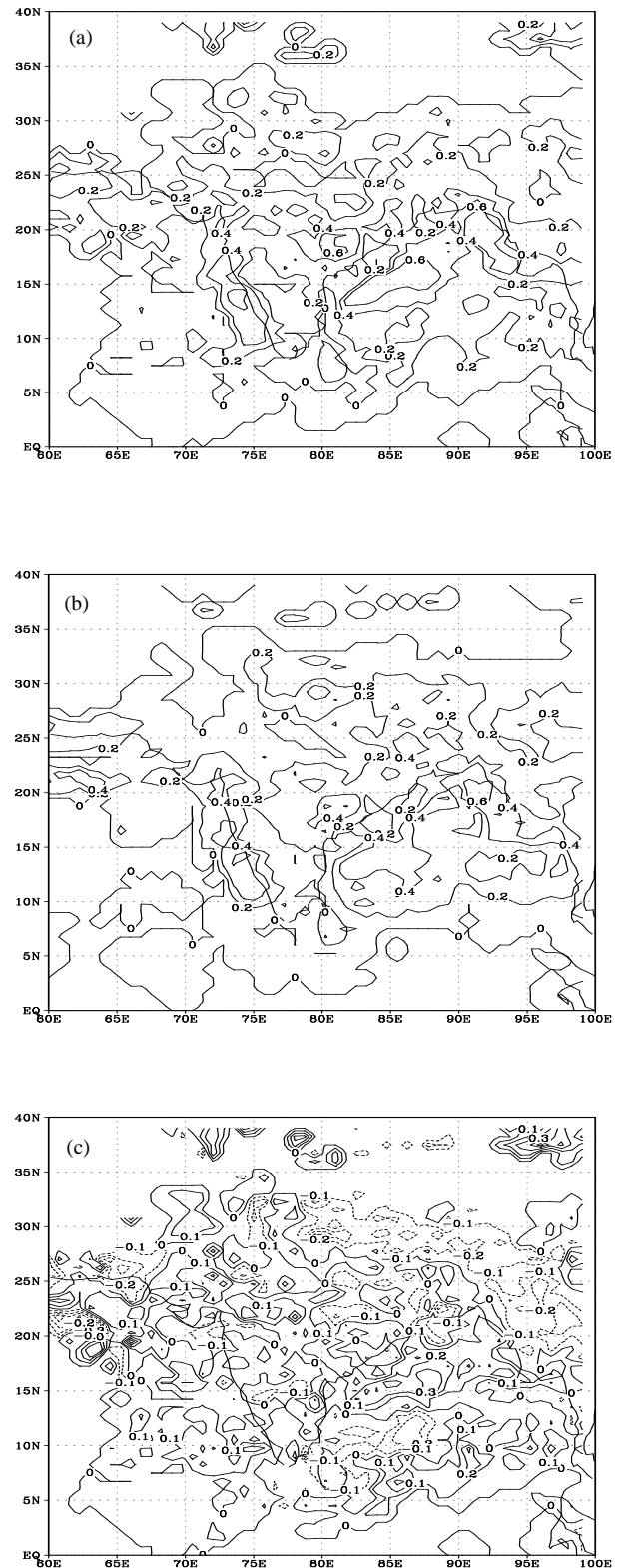
(ii) *Vertical latitudinal cross section of zonal and meridional winds*

The vertical cross section of mean zonal and meridional components of winds based on analysis and forecast are shown in Figs. 5(a&b) respectively. The longitudinal mean is taken between longitude 60° E to 100° E. Positive impact of CMV data is noticed both in the analysis and forecast. Strength of the sub-tropical westerly jets in both the hemispheres, tropical easterly jet over the southern latitudes of India is found to be increasing trend with the use of CMV data. Some marginal increase in the lower tropospheric westerlies over the southern latitudes of India is also noticed when CMV data is used. However, no appreciable impact of CMV data is noticed in case of meridional component of wind both in the analysis and forecast.

July and August continued to show similar features, such as strengthening of the sub-tropical westerly jets in both the hemispheres and tropical easterly jet over the southern latitudes of India both in the analysis and forecast when CMV is used (figure not shown).

(iii) *Rainfall distribution*

The mean rainfall fields based on two forecasts (with and without CMV) for the entire data period (June to August) are presented in Figs. 6(a&b). Both the forecasts could capture heavy rainfall belts over the area of monsoon low, monsoon trough and Western Ghats of India. But the comparison (as reflected in the mean error)



Figs. 9(a-c). Same as Figs. 8(a-c) except for the threat score of 1 cm rainfall

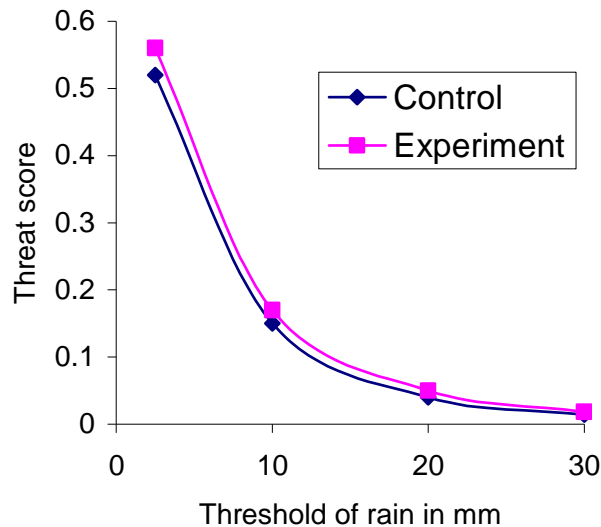


Fig. 10. Domain averaged values of threat score for different rain thresholds

reveals [Fig. 6(c)] that there is some increase (2 to 4 mm) of rainfall over the central parts of Arabian Sea, over north and central parts of the Bay of Bengal, over most parts of land areas in the domain of monsoon circulations when CMV is used. Some decrease of rainfall (4 to 6 mm) occurs along the foot hills of Himalayas with the use of CMV. The corresponding mean rainfall analysis (observation) shows that both the forecast considerably under-estimates rainfall over the Bay of Bengal, most parts of the Arabian Sea, along the west coast of India and northwest India [Fig. 6(d)].

The root mean square errors (RMSE) for the forecasts based on CMV, without CMV and the their difference are shown in Figs. 7(a-c) respectively. RMSE ranges between 30 to 40 mm over north west India and around 10 mm over most part of the country in both the forecast. But from the difference it is clear that the RMSE values of experimental run are less compared to the corresponding values of control run over the north west Bay of Bengal and along the foot hills of Himalayas. The threat score (Stanski *et al.*, 1989) for the threshold value of 2 mm rainfall over most parts of the country has been between 0.6 to 0.8 for both the cases [Figs. 8 (a&b)]. But the difference [Fig. 8(c)] indicates that threat score over most part of the monsoon domain marginally improves (positive values) when CMV is used. The similar features are also noticed in the threat score for 1 cm rainfall in Figs. 9(a-c). This feature is also reflected in the domain averaged (equator to 40° N and 60° to 100° E) values of threat scores for different rain thresholds (Fig. 10) where the threat scores are found to be slightly higher for the case when CMV data is used.

4. Conclusions

The study has brought out a distinct positive contribution of CMV data in the analysis and forecast of the limited area model of IMD, which suffers in the oceanic region due to sparsity of data. Though both the wind analysis (CMV and without CMV) look identical and could captured large scale monsoon features, but the strength of southwesterlies (at 700 hPa) over Somali coast, South Arabian Sea and Bay of Bengal has been comparatively better captured when CMV is used. It is very encouraging to note that the corresponding forecast (at 700 hPa) with CMV is more consistent with the analysis where regions of stronger south-westerlies are better reproduced. The strength of lower tropospheric cross equatorial flow, subtropical westerly jets and tropical easterly jet are better captured both in the forecast with utilization of the additional CMV data. This also contributed towards improving the quality of analysis and forecast on the synoptic scale which has been demonstrated through a case study of monsoon depression. The most important aspect noticed here is that in the experimental run, the easterly flow in the northern sector and westerly flow in the southern sector of the monsoon trough is stronger. Quantitative assessments through the computation of various error statistics such as mean error, root mean square error and threat skill scores of rainfall forecast, clearly demonstrated some improvement in the forecast skill after inclusion of additional INSAT CMV data in the operational limited area model of IMD. The impact of these data is found to be quite significant and useful.

It is worth to mention that in the 48 hours forecast no appreciable difference was found between the control run and experimental runs (results not shown). Perhaps it is an inherent problem arises in a hydrostatic model due to the dominance of large scale characteristics over local features present in the initial condition with the progress of time integration. It is to be noted that no INSAT derived moisture field is introduced as model initial condition in this experiment. In the near future, with the launching of new meteorological application INSAT, satellite derived moisture profile is expected for the Indian monsoon domain. The INSAT CMVs along with moisture profile derived from the new Indian satellite promise to provide improved initial analysis in a more consistent manner and there by further improving the NWP capabilities over Indian monsoon region.

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