MAUSAM, 52, 4 (October 2001), 647-654

551.509.313

A case study of the impact of INSAT derived humidity profiles on precipitation forecast by limited area model

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(Received 20 July 2000, Modified 24 January 2001)

सार - इस शोध-पत्र में इनसैट अंकीय आई. आर. मेघ बिम्बावली के आंकडों के आधार पर आकलित किए गए आर्द्रता प्रोफ़ाइलों के भारत मौसम विज्ञान विभाग द्वारा संचालित सीमित क्षेत्रीय पूर्वानुमान प्रणाली के आरम्भिक आर्द्रता विश्लेषण पर पड़ने वाले प्रभाव की जाँच की गई है। कृत्रिम प्रेक्षणों के लिए अपनाई गई आर्द्रता प्रोफ़ाइलों के आंकडों के समीकरण की पद्धति को विकसित करके इस क्षेत्रीय विश्लेषण योजना में लागू किया गया है। इन आँकड़ों से आर्द्रता विश्लेषण की जाँच करने से उष्णकटिबंधों के आँकड़ा विरल क्षेत्र के नमी के विश्लेषणों में मौलिक सुधार का पता चला है। निदर्श पूर्वानुमानित वर्षा पर संशोधित विकसित आर्द्रता विश्लेषणों के प्रभाव की जाँच की गई है। इन प्रयोगों से वर्षा के बेहतर पूर्वानुमान का पता चला है।

ABSTRACT. The impact of humidity profiles estimated from INSAT digital IR cloud imagery data on initial moisture analysis in the IMD's operational limited area forecast system has been investigated. Method for assimilation of humidity profiles data as pseudo observations in the analysis scheme has been developed and implemented in the regional analysis scheme. Verification of humidity analysis with this data has shown substantial improvements in the moisture analysis over the data sparse region of tropics. Impact of the improved humidity analysis on model predicted rainfall is examined. The experiments show improved rainfall prediction.

Key words – Humidity profiles, INSAT, Assimilation, Rainfall prediction.

1. Introduction

Difficulties and inaccuracies in numerical weather prediction over low latitudes are mainly attributed to data problems and inadequacies and thus to the overall treatment of diabatic processes. Tropical general circulation is mainly governed by convective heating. Thus NWP over low latitudes is sensitive to the four dimensional structure of parameterized convective heating. In the initial fields, there is a greater degree of uncertainty in the quality of the divergence and moisture fields on which this convective heating depends. In spite of the use of vast amount of a synoptic and non-conventional data sets from satellites, large data gaps are evident over both land and ocean areas of tropics. The initialization of surface fluxes of moisture and heat, precipitation and clouds suffers from sparsity of data. The distribution of humidity is very important in this regard. Analysis of humidity variables relies only on available radiosonde network, which is very sparse over tropics. Unlike mass and velocity fields, humidity variables are very much discontinuous over tropical deep convective regions. The sparsity of data also results in large errors in divergent wind which, in turn, usually compounds the moisture errors through moisture convergence, resulting in erroneous specification of diabatic forcing.

The Japan Meteorological Agency (JMA) operationally derives moisture data from the GMS satellite based on co-located radiosondes and satellite radiance observations (Baba 1987), and the use of this data has been shown to be beneficial to model performance in the tropics. Proceedures similar to those at JMA have also been developed at the Bureau of Meteorological Research Centre (BMRC) by Mills and Davidson (1987) which have shown the impact of this data in a limited area model covering the Australian region. Studies have also shown that the use of Satellite special Sensor Microwave/Imagery (SSM/I) instruments derived rainrate in diabatic or physical initialisation can

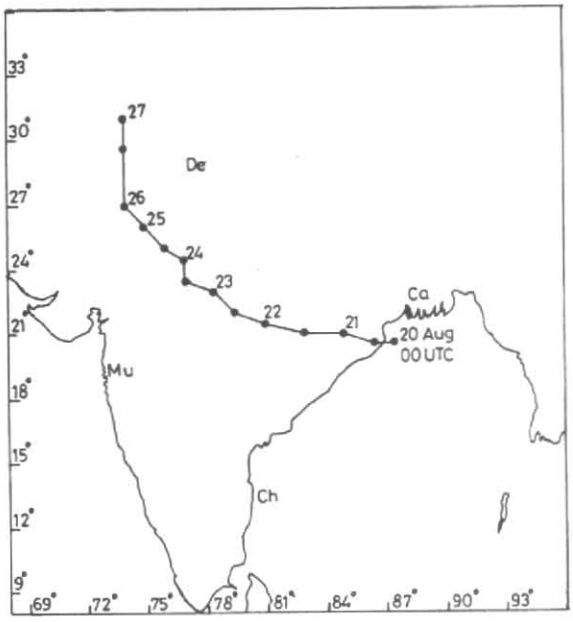
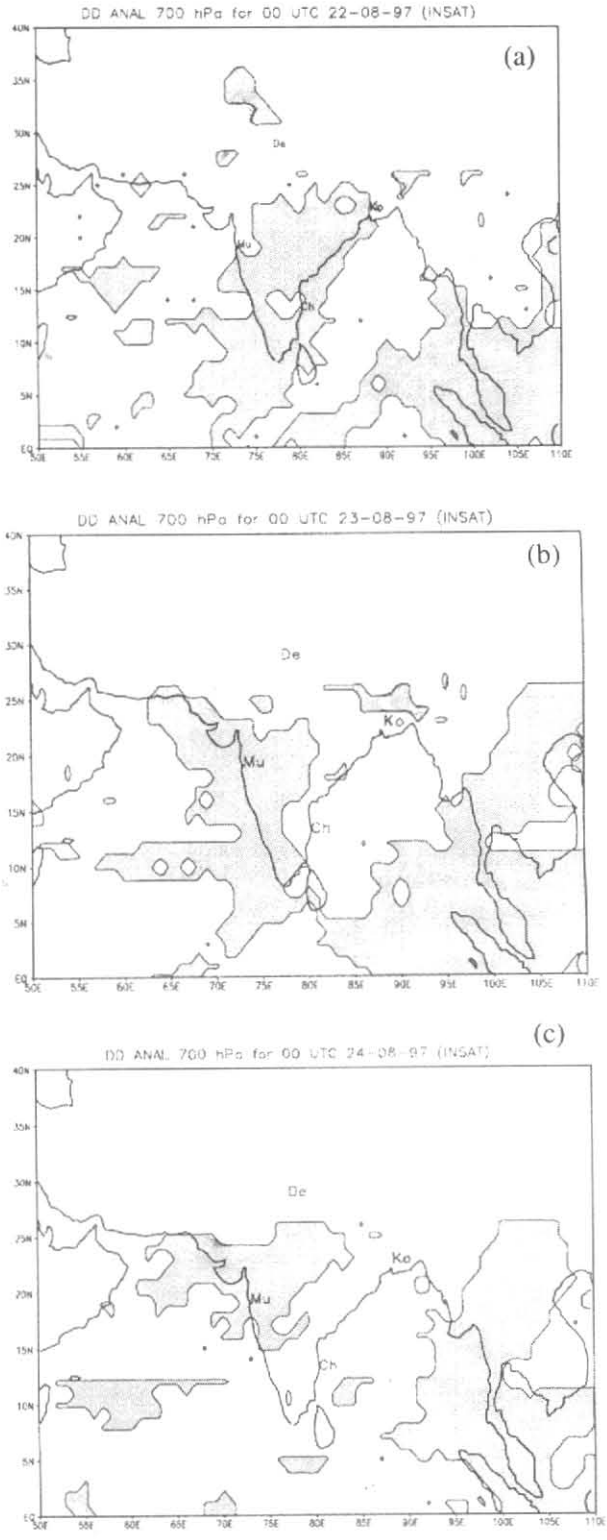


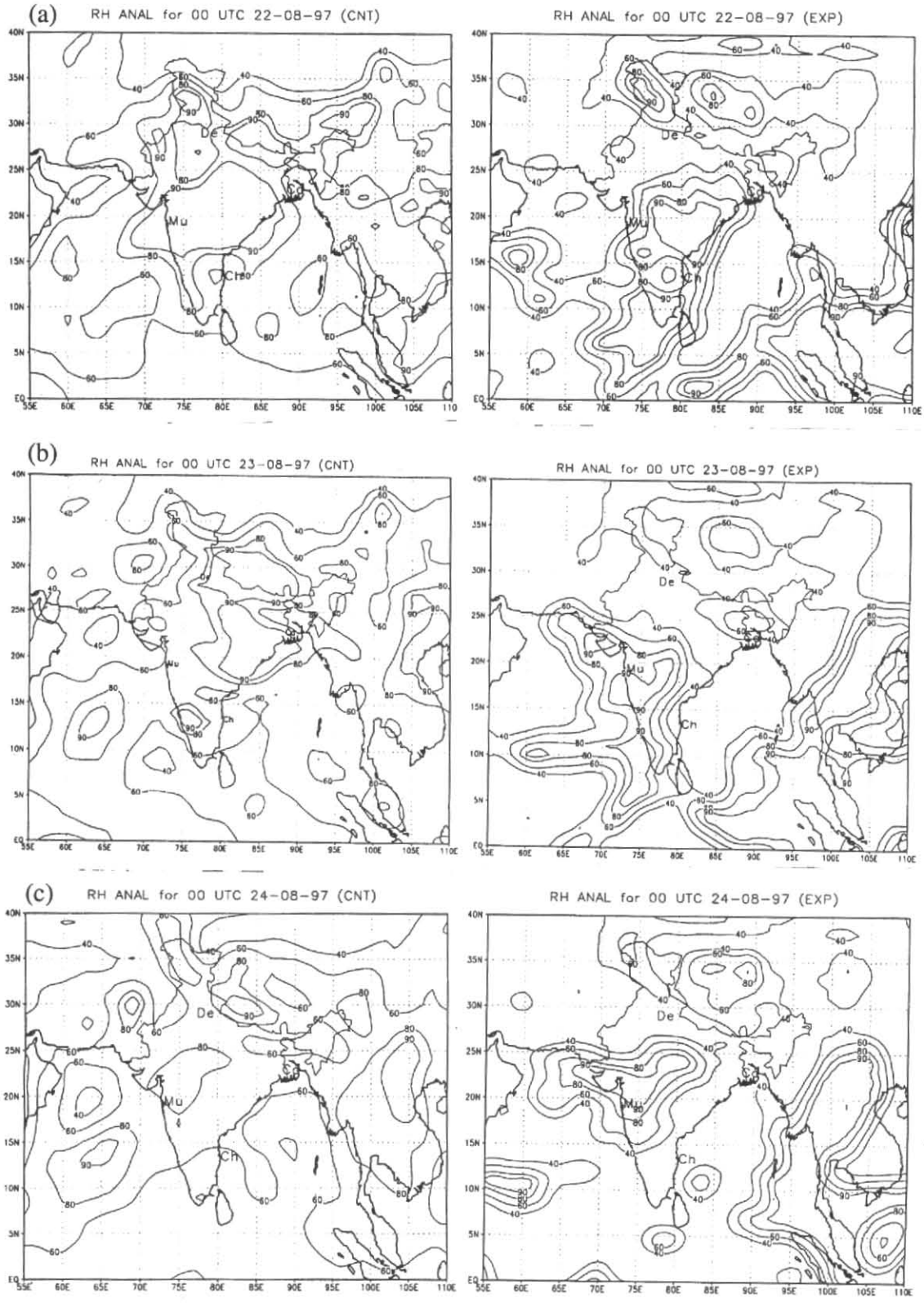
Fig. 1. Observed track of deep depression 19-27 August 1997

reduce model spinup and improve the short range forecast, which in turn, can improve the first guess for the analysis (Krishnamurti *et al.* 1993, Arthur Y. Hou *et al.*, 2000). While improving the quality of tropical analysis is crucial to the utility of global analysis in climate applications, the lack of rainfall observations in the tropics have made it difficult to quantify the errors in precipitation and their impact on the analysis. In the past decade the use of satellite-borne microwave instruments has improved the quality and coverage of physically derived rainfall and Total Precipitable Water (TPW) estimates. The recent launch of US-Japan Tropical Rainfall Measuring Mission (TRMM) and ATOVS Advanced Microwave Sounding Units (AMSU) data is expected to further improve observations of tropical rainfall in the coming years. The full utilization of this data will require the development of cloud and precipitation assimilation techniques. Assimilation of satellite derived rainfall and related data types offer a way to compensate for model deficiencies and better estimates of tropical atmospheric parameters given by different assimilation systems.

The forecasting of synoptic disturbances such as tropical cyclones is highly sensitive to convective processes and hence on the initial moisture analysis. Prasad *et al.* (1997) have shown that prescription of saturation relative humidity fields in the vortex area substantially improves the track prediction by NWP model. Absence of saturation level



Figs. 2(a-c). The 700 hPa dew point depression (°K) analysis estimated from INSAT cloud imagery data for 0000 UTC of (a) 22, (b) 23 and (c) 24 August 1997



Figs. 3(a-c). The analysed relative humidity (%) plots at 700 hPa for 0000 UTC of (a) 22, (b) 23, and (c) 24 August 1997 based on control (without humidity profiles) and experiment (with humidity profiles)

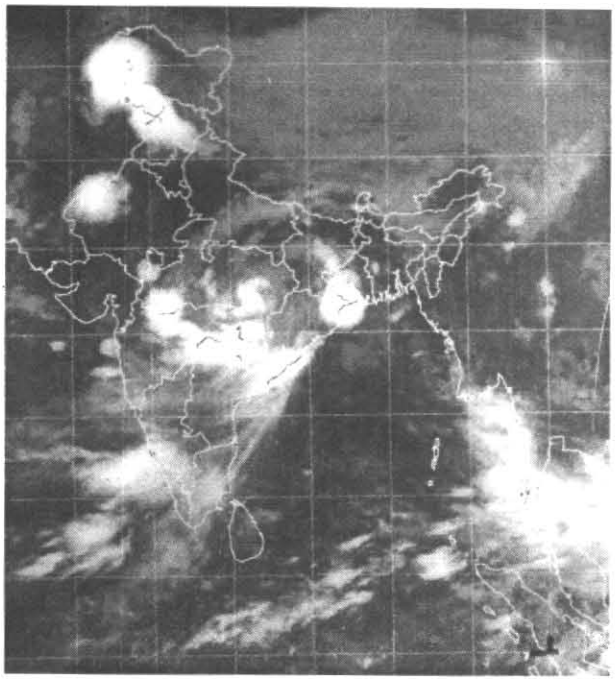


Fig. 4(a). INSAT IR cloud picture for 0000 UTC of 22 August 1997

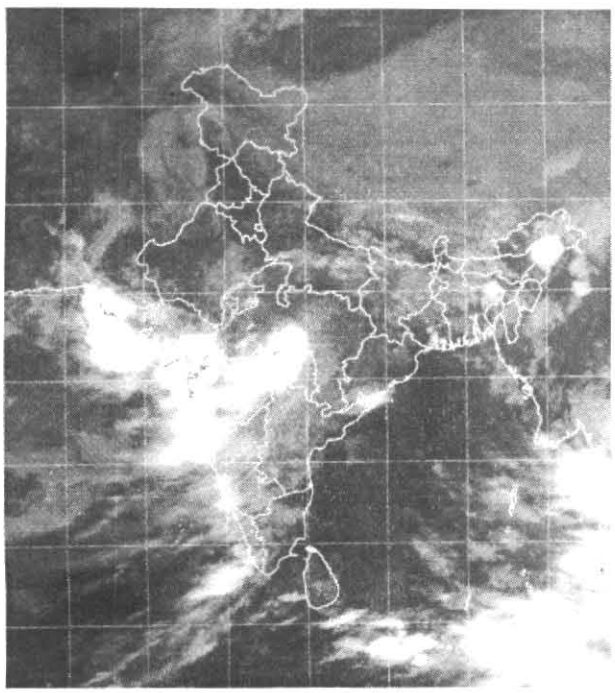


Fig. 4(b). INSAT IR cloud picture for 0000 UTC of 23 August 1997

humidity causes large errors in the predicted movement. In view of the importance of accurate initial humidity fields in tropical NWP, it is necessary to maximise these data from non-conventional sources. With this end in view, the present

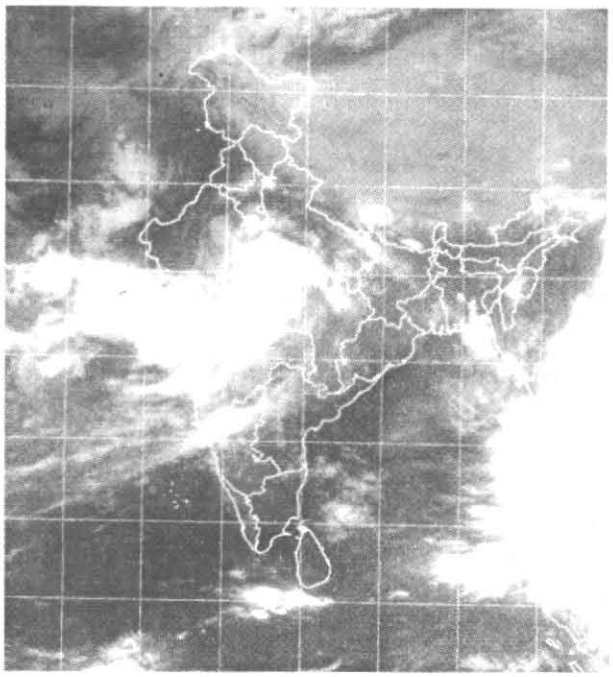


Fig. 4(c). INSAT IR cloud picture for 0000 UTC of 24 August 1997

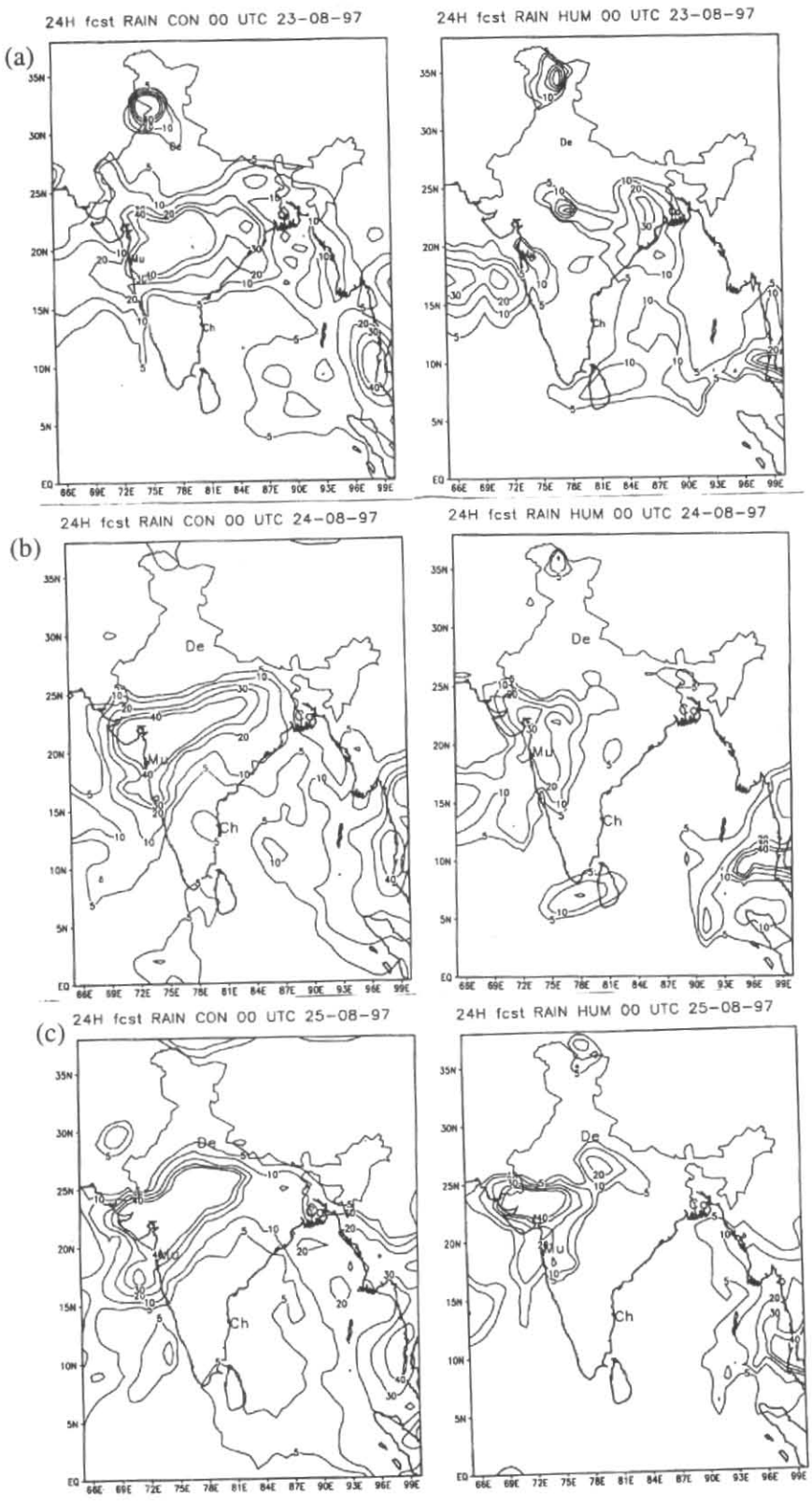
study was taken up to study the impact of pseudo humidity profiles estimated from INSAT infrared cloud imagery data.

2. Data and analysis procedure

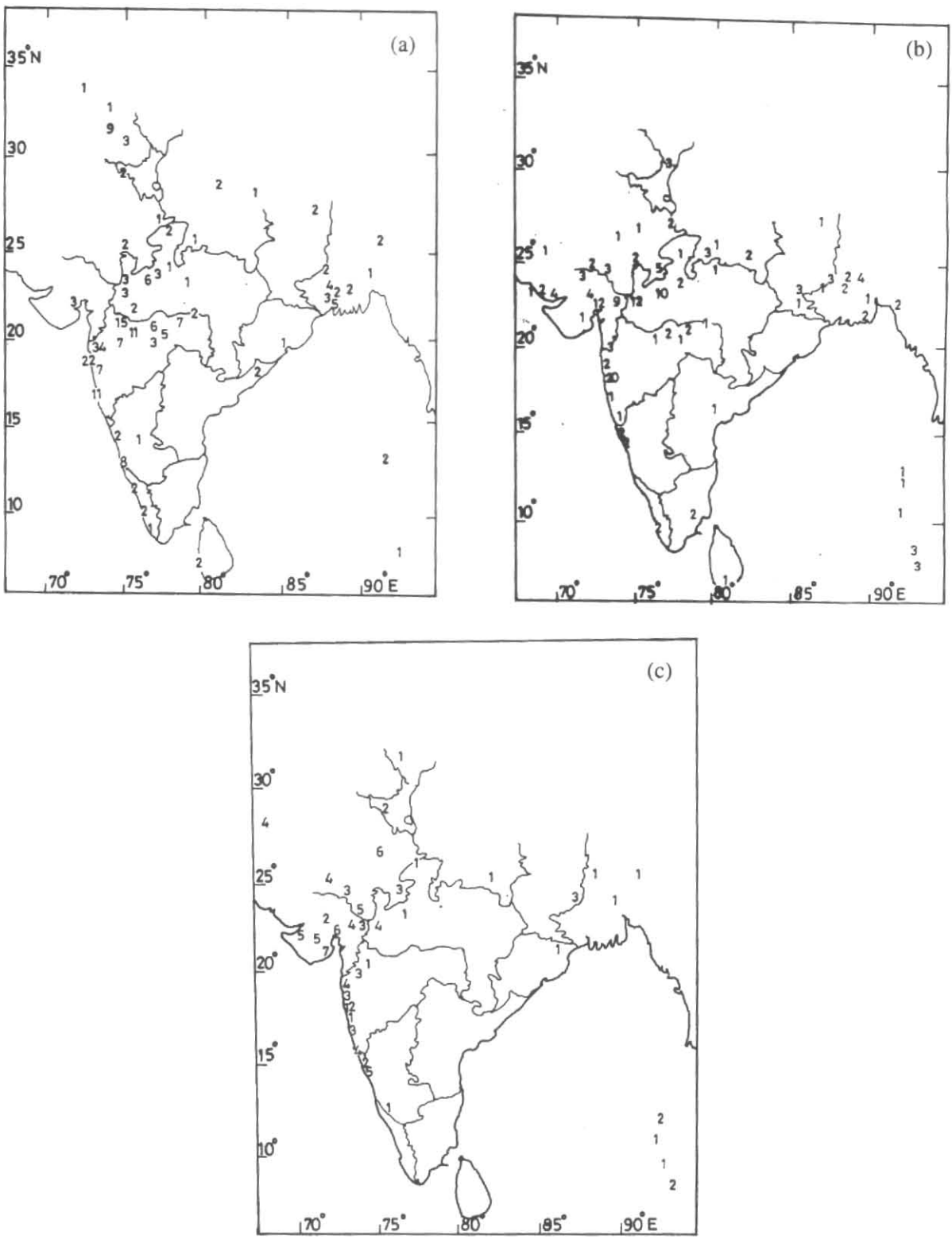
2.1. *Humidity profiles*

The humidity profiles are estimated from INSAT cloud imagery data using the modified version of Mills and Davidson (1987) method adopted by Prasad *et al.* (1998). The method involves diagnosing cloud characteristics (amount, height and standard deviation of cloud top temperature over a 50 km radius circle) for a specified latitude-longitude grid and then assigning a dewpoint depression profile corresponding to the diagnosed clouds. Using current temperature analysis the dewpoint is recovered. The matchup gives dewpoint depression profiles for 19 groups, namely, clear and broken clouds below 850 hPa, scattered clouds below 850 hPa, and two cloud types and amounts for four higher levels.

The method yields the values of dew point depression (DD) at different levels from 850 to 300 hPa. These data are provided over the region 40° N to 40° S; 40° -127° E at 850, 700, 500 and 300 hPa levels. An examination of these profiles by Prasad *et al.* (1997) during the period May-June 1994 showed that the profiles are able to clearly delineate the buildup of moisture in the vertical and its northward propagation associated with the onset of southwest monsoon.



Figs. 5(a-c). Model predicted 24 hrs forecast rainfall (mm/day) valid for 0000 UTC of 23, 24, and 25 August 1997 based on control (without humidity profiles) and experiment (with humidity profiles). Contour interval is 5,10,20,30 & 40



Figs. 6 (a-c). Observed 24 hr rainfall (cm/day) ending at 0300 UTC for 23, 24 and 25 August 1997

2.2. *IMD's operational NWP system*

IMD operational NWP is based on a Limited Area analysis and Forecasting system (LAFS) which consists of real time processing of data received on Global Telecommunication System (GTS), objective analysis by 3-D multivariate Optimum Interpolation (OI) scheme and limited area forecast model.

2.2.1. *Input data*

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

2.2.2. *Analysis procedure*

The objective analysis is carried out by three dimensional multivariate optimum interpolation procedures. The variables analysed are the geopotential, u and v components of wind and specific humidity. Temperature fields are derived from the geopotential fields hydrostatically. Analysis is carried out on 12 sigma surfaces from 1.0 to 0.05 in the vertical and 1°×1° horizontal lat/long. grid for limited area horizontal domain of 30° S to 70° N ; 0° to 150° E. The generated INSAT dew point depression data are converted to relative humidity using the first guess temperature and included into the regional OI scheme as bogus observations. The observations are generally horizontally consistent over synoptic scales, and very few are rejected by the analysis system. Only in those cases where small scale isolated cloudiness is diagnosed from the imagery then observations are rejected.

2.2.3. *Forecast model*

The forecast model is a semi-implicit semi-Lagrangian multilayer primitive equation model cast on sigma co-ordinate system and Arakawa C-grid in the horizontal. The present version of the model has a horizontal resolution of 1°×1° lat./long. (domain 106×81; 30° S to 50° N and 25° E to 130° E) in horizontal and 12 sigma levels (1.0 to 0.05) in vertical. The detailed description of model formulation, horizontal and vertical descretization and time integration scheme used in the experiment is given in Prasad *et al.* (1997), Krishnamurti *et al.* (1990). The lateral boundary conditions are obtained from the global forecasts of the National Centre for Medium Range Weather Forecasting, New Delhi.

3. The impact study

The impact study was carried out for the period 22-24 August 1997 corresponding to the movement of a monsoon depression across central parts of the country. The track of the depression is shown in Fig.1. The dew point depression (DD) contour analysis for 22-24 August 1997 at 700 hPa level derived from the INSAT satellite cloud imagery are presented in Figs. 2 (a-c). We have selected charts of 700 hPa for illustration as the tropical systems are best represented at this level. The area where the dew point depression values are less than 6° K are shaded. The humidity analysis at 700 hPa for the above days in the Control run (without using pseudo humidity profiles left panel) and Experiment (with humidity data included right panel) are presented in Fig.3. The difference in the control run and experiment are clearly visible and inclusion of pseudo humidity observations has substantially modified the analysis. On each day from 22 to 24 August the humidity analysis in the right hand panel maps has sharpened and well delineated features, matching the cloud imageries may be seen (Fig.4). The most prominent change is seen on 23 August with the depression located over central Madhya Pradesh where a maxima along the west coast appears as against a poorly defined pattern in the control run. Likewise on 24 also a prominent change is the appearance of a well defined maxima covering Gujarat, west M.P. and north Maharashtra, corresponding to heavy clouding in this region associated with monsoon depression located over northwest M.P. The 24 - hour predicted rainfall by limited area model on 23, 24 and 25 August 1997 are presented in Fig.5, control in the left panel and experiment in the right panel. A marked improvement is seen in the predicted rainfall pattern. In particular, a comparison of the predicted rainfall in the control run and experimental run valid for 24 August and satellite imagery of 23 August shows that the experimental run predicted rainfall pattern closely matches the satellite imagery. The experimental run shows emergence of localised features, which are absent in the control run. A similar inference holds good for rainfall prediction on 25 August and satellite imagery of 24 August. The verifying rainfall maps based on surface observations available from GTS data are presented in Fig.6. Qualitatively speaking, the rainfall predicted by the model closely matches the observed rainfall.

4. Concluding remarks

The study has brought out a distinct positive contribution of the INSAT derived humidity profile data, used as pseudo observations in the limited area analysis

scheme, on the initial moisture analysis, which suffers in the tropical regions due to sparsity of conventional data, not only over the oceans but also over the continental regions. The forecast model runs to study the impact of these additional data on the rainfall predictions have shown a considerable improvement, as seen from the corresponding satellite imagery and observed rainfall. Maximisation of such satellite based observations are expected to considerably improve the initial humidity analysis and subsequent forecasts produced by NWP models.

Acknowledgements

The authors are grateful to Dr. R.R. Kelkar, Director General of Meteorology, Shri A.M. Sud, Deputy Director General of Meteorology, for their encouragement . Thanks are due to Shri S.K. Roy Bhowmic for useful discussions.

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