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Impact of Satellite Data on the Objective Analysis of Wind Field

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ABSTRACT
Potential utility of satellite derived winds is investigated for better depiction of circulation patterns over Indian region. Daily satellite derived upper tropospheric Water Vapour Wind Vectors (WVWV) obtained from GMS-5 satellite over Port Blair at 151-250 and 251-350 hPa layers were compared with radiosonde (RS) winds of Port Blair (11.7°N, 92.7°E) for the year 1997 (00 and 12 Z). Making use of this algorithm, upper tropospheric winds at 150, 200, 250, 300 and 350 hPa levels were generated for the complete life cycle of a tropical cyclone (14-21 May, 1997) over the Bay of Bengal. Using this data an algorithm was developed to relate satellite derived moisture winds and RS winds. A highly significant correlation between satellite derived moisture winds and radiosonde winds was observed at 150, 175, 200, 250, 300 and 350 hPa levels for both u and v components. Root Mean Square (rms) errors of satellite derived winds were generally less than 6 mps as compared to RS data, for all the levels. Impact of these winds on objective analysis using Optimum Interpolation (OI) scheme during various stages of the above tropical cyclone (TC) was evaluated. These analysed winds were compared with subjective and NCEP/NCAR reanalyses. It was found that there was positive impact of WVWVs on wind speed, circulation and centre of anticyclone than NCEP/NCAR reanalyses and analyses with RS data only.

INTRODUCTION

Technological advances in satellites have proved to be of great help in monitoring and prediction of weather to its ultimate limit. Over the last four decades technological and scientific innovations have been revolutionizing the process of weather observations and forecasting. Together they have resulted not only in global weather monitoring, but also in global weather analysis and global Numerical Weather Prediction (NWP). The lack of observation over oceanic area is difficult to manage for forecasters. But for NWP it is very difficult to get good analysis with such a gap in the observing network. That is why satellite data are incorporated in different analysis schemes. Satellite derived physical parameters viz. temperature, humidity profiles are prone to observational errors. To include sounding information from satellites, radiances can be used directly rather than attempting to retrieve temperature and moisture profiles before use in the analysis (Derber & Wu 1998). Winds are also derived from movement of clouds and water vapour from geostationary satellites using visible, infrared and water vapour channels.

The impact of conventional satellite retrievals on the quality of numerical weather prediction has been mixed. Although positive impact has been found in the southern hemisphere, it has not been possible to show a consistent positive impact in the northern hemisphere (Tracton et al.1980; Mo et al.1995). Substantial improvement in the use of the data has become necessary to enhance the impact of the satellite sounding data.

For tropical cyclone we can measure very steep gradient of wind that can hardly be taken into account in NWP assimilation scheme and even with good measurement at the right place the assimilation scheme can reject good observations (as too far from the background or initial guess field). Also in regions of poor data coverage, it is often useful to include "bogus" observations derived from human interpolation or empirical relationships to provide an indication of major weather patterns that would otherwise go unobserved.

Large coverage and good quality of remotely sensed upper tropospheric moisture parameters have encouraged the deployment of a new generation of operational geostationary meteorological satellites over the different parts of the globe. The GMS-5 satellite has on board payloads with visible and infrared Spin Scan Radiometers (VISSR). Visible radiometer scans through 0.55-0.90 μm with pixel resolution of 1.25 km. Infrared (IR) radiometer is in three split spectral bands. Two atmospheric window bands IR1: 10.5-11.5 μm, IR2: 11.5-12.5 μm, while third one is water vapour absorption band (IR3: 6.5-7.0 μm). Pixel resolution of IR band is 5.0 km. CMW (Cloud Motion Winds) are derived from the displacement of Cirrus and Cumulus clouds using both IR & visible images at 30 minute interval. WVWVs are derived from displacement of WV distribution or Cirrus cloud in water vapour images. GMS-5 water vapour imaging capabilities have increased due to improved radiometric sensitivity and higher spatial resolution.

Winds at different levels were compared by developing regression relation between moisture winds during 1997 obtained from GMS-5 satellite and RS upper tropospheric winds over Port Blair. As the satellite data was available at different thickness layers, it was interpolated to standard isobaric levels using regression relation fitted between the satellite observed wind and RS wind. These interpolated satellite observed wind along with RS wind were utilized in the analysis scheme to produce better analysis. Although the winds were at upper tropospheric levels it could be easily found that there is positive impact of these data on the analyses. The circulation features (anticyclones) were depicted very well at these levels.

DATA AND SYNOPTIC SITUATION

As the interest of this study is on the pre-monsoon period, daily upper air wind of five May months (1980-85, except 1984) from RS stations over Indian region were collected. Wind field being vector field, it was resolved into u and v components and considering them as two separate parameters the autocorrelation functions and the structure functions were computed separately. GMS-5 water vapour wind data available at 151-250 and 251-350 hPa thickness layers along with RS data over Port Blair during 1997 were utilized for comparison.

In this study we have taken up the case of a tropical cyclone which formed during 14-21 May, 1997 over Bay of Bengal. For carrying out the objective analysis an area bounded between 10°S to 40°N and 40°E to 120°E with a grid resolution of 2.5° was considered. In this experiment monthly climatology and daily average wind values of NCEP/NCAR reanalyses were used as initial guess field. The climatological values were based on 27 years of reanalyzed data (1959-1985). The daily average values were mean of 00, 06, 12 and 18 Z reanalyzed winds. The experiment was carried out in two stages. In the initial case, only RS data was used and in the second case RS data along with GMS-5 satellite data were used. The analyses were performed at 150, 200, 250 and 300 hPa pressure levels.

A low pressure area which was formed over southeast Bay of Bengal and adjoining south Andaman Sea on 14 May 1997 lay as a well marked low pressure area over the same region till 15 morning. This well marked low pressure area concentrated into a depression probably deep depression at 09 Z of 15 May. It lay as a deep depression centred at 12 Z within half a degree of lat. 7.5°N and lon. 90.5°E about 570 kms southsouthwest of Port Blair. It intensified into a cyclonic storm and lay centred at 03 Z of 16 May within a half degree of lat. 9.0°N and lon. 90.5°E about 400 kms southwest of Port Blair. Moving in a northerly direction, it intensified into a severe cyclonic storm at 09 Z on 17 May and was near lat. 13.5°N and lon. 91.0°E and at 12 Z within a half a degree of lat. 14°N and lon. 91°E about 300 kms northwest of Port Blair. It moved northwards and intensified into a severe cyclonic storm with a core of hurricane winds and lay centred at 03 Z within half a degree of lat. 16.5°N and lon. 90.5°E about 700 kms southsoutheast of Kolkata. Moving further in a northerly direction it lay at 12 Z near lat. 18°N and lon. 90.5°E about 580 kms southeast of Kolkata. It then, moved in a northnortheasterly direction and lay centred at 03 Z near lat. 20.3°N and lon. 91.2°E about 380 kms southeast of Kolkata. It crossed Bangla Desh coast and lay centred at 12 Z close to Chiitagong. It weakened rapidly into a well marked low pressure area and lay over Nagaland and Manipur area on 20 and it became less marked on 21 May.

OPTIMUM INTERPOLATION SCHEME

The analysis scheme used in this study is based on Gandin's (1963) Optimum Interpolation method. He derived an expression for the weighting function for the observing stations with respect to the grid points incorporating the physical characteristics of the parameter over the region. This is done by computing the structure functions and autocorrelation functions. Here, the covariances over the analysis domain are assumed to be both homogeneous and isotropic and the variances to be homogeneous.

Rajamani et al. (1983) have applied the OI scheme to analyse wind field over Indian region. Sinha et al. (1989) have used this scheme to perform the wind analysis using multiweighting functions over India and adjoining region.

Let the scalar field f denotes correlated variables such as wind (u and v components). The OI scheme utilises an analysis equation of the form

$$f_x^a = f_x^p + \sum_{i=1}^{n} W_i \left(f_i^o - f_i^p\right) \qquad (1)$$

Where n is the number of observations affecting a particular grid point. $(f_i^o - f_i^p)$ denotes the difference between observed and the initial guess at the ith location, f_x^p is the initial guess value at the grid point and f_x^a is the resulting grid point analysis. The W_i's are the so called "weights" which are chosen in such a manner that the mean square of the analysis error is minimised. The weights satisfy the n equations

$$\sum_{j=1}^{n} (\mu_{ij} + \lambda^2 \delta_{ij}) W_j = \mu_{xi} \qquad (i = 1, 2, \ldots n) \qquad (2)$$

subscripts (i,j) refer to the observation points and x refers to the grid point. $\mu_{ij} = \overline{(\hat{f}_i' \hat{f}_j')} / \sigma_0^2$ is the spatial correlation coefficient. μ_{xi} is the vector correlation between grid and observation point. $\lambda^2 \left(= \sigma_{\varepsilon_i}^2 / \sigma_0^2\right)$ is the normalised observational error variance, $\sigma_{\varepsilon_i}^2$ is the observational error variance. $\sigma_0^2 = \sigma_i^2 - \sigma_{\varepsilon_i}^2$ is the corrected variance and δ_{ij} is the kroneckar delta. The covariances $\overline{\hat{f}'_i \hat{f}'_j}$ denote the value of, $\overline{(f_i^o - f_i^p)(f_j^o - f_j^p)}$ where bar represents average over number of cases. The observational error variance $\sigma_{\varepsilon_i}^2$ required for calculation of λ^2 is obtained from structure function. The true structure function

$$\beta(\rho) = \overline{\left(f_i' - f_j'\right)^2}$$

and the estimated structure function

$$\hat{\beta}(\rho) = \overline{\left(\hat{f}_i' - \hat{f}_j'\right)^2}$$

are related through the following relation.

$$\hat{\beta}(\rho) = \beta(\rho) + 2.\sigma_{\varepsilon_i}^2$$

Where f_i' and f_j' are the anomalies of the true values f_i and f_j at ith and jth locations. $\beta(\rho)$ becomes zero when ρ becomes zero but $\hat{\beta}(\rho)$ need not become zero at the same location. So, when ρ becomes zero, $\hat{\beta}(0) = 2\sigma_{\varepsilon_i}^2$. In other words $2\sigma_{\varepsilon_i}^2$ is estimated by fitting a curve to the computed structure function plotted

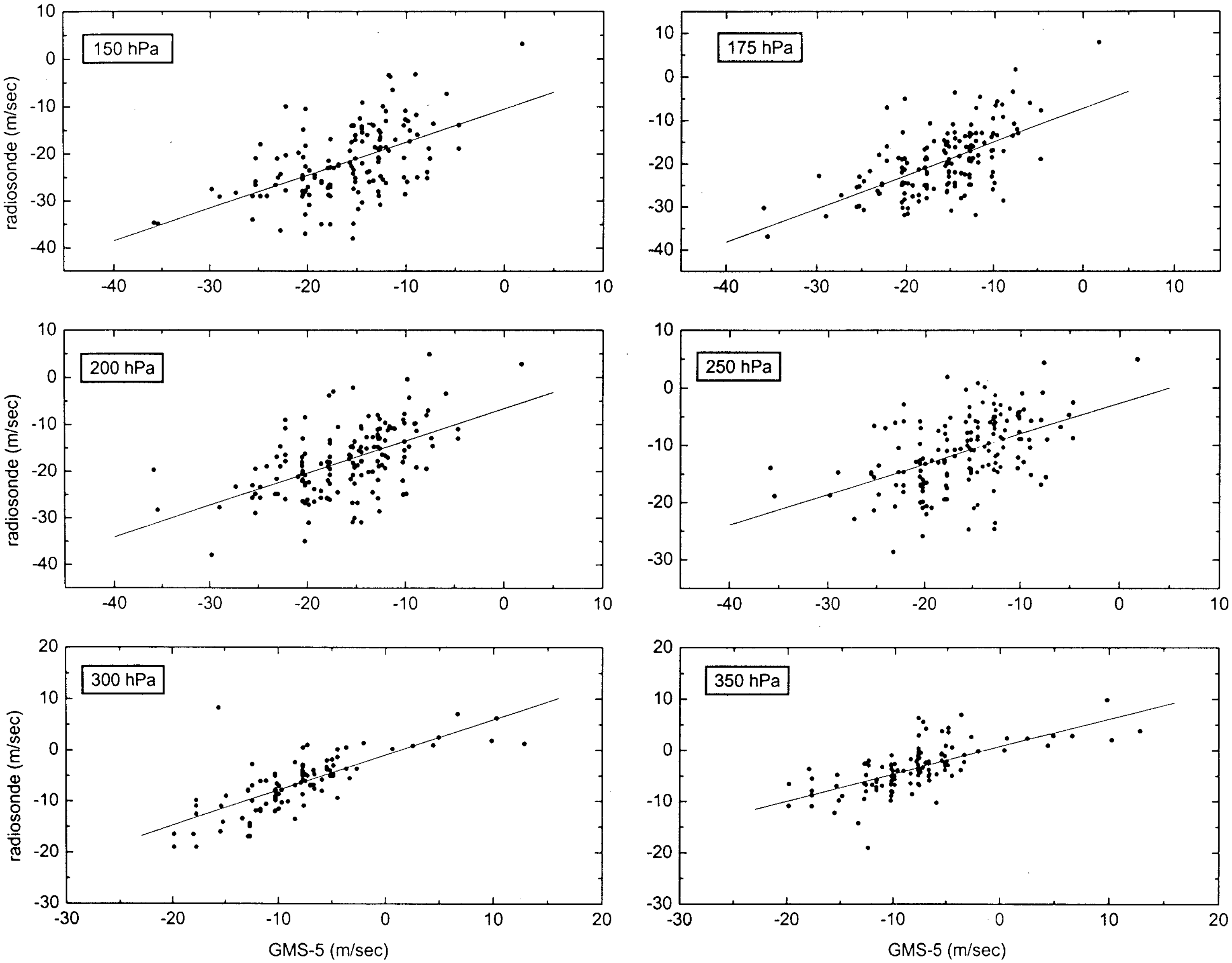

Figure 1(a). Scattered plot of GMS-5 and RS wind-u component for different pressure levels.

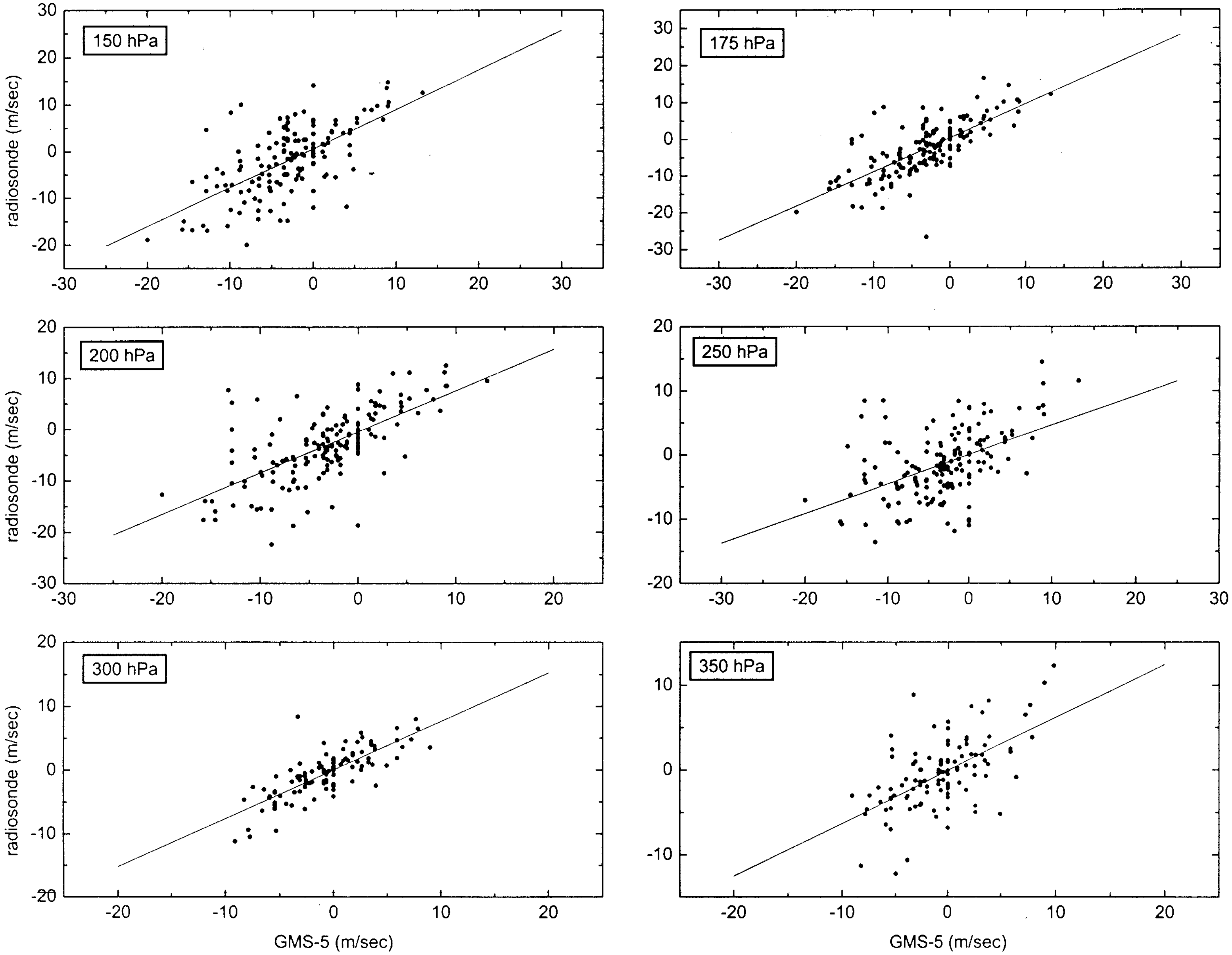

Figure 1(b). Same as Fig.1(a) but for v component.

against distance ρ and extrapolating the curve until it intersects the axis of $\hat{\beta}(\rho)$ at $\rho = 0$. The covariances $\hat{f}_i'\hat{f}_j'$ for u and v components of the wind are computed for every station with respect to every other station over the domain of the study. They are normalised by dividing by σ_0^2 before plotting them against distance. These are scattered points. Hence points within 4° segment are averaged with middle points located at a distance d=2,3,4,...30° and determine values of $\mu(d)$ in each interval by means of a function from Petersen & Truske (1969). As stated earlier the objective analysis has been carried out over an area bounded by 10°S to 40°N and 40°E to 120°E with a grid resolution of 2.5° for the period 14-21 May 1997, 12 Z.

DISCUSSION AND RESULTS

Development of Regression Relation

Moisture winds during 1997 (00 and 12 Z) obtained from GMS-5 satellite at 151-250 hPa and 251-350 hPa layers have been compared with the coincidental radiosonde upper tropospheric winds reported by Port Blair station. Figs 1(a,b) show scatter plot between GMS-5 and radiosonde u and v winds respectively at various pressure levels. To evaluate the closeness between GMS-5 and RS data rms errors were calculated. Correlation Coefficients (CC) between these two types of winds were also computed and are given in Table 1. All the CCs were significant at 0.5% level. The rms errors varied from 3.3 to 6.3 mps and 2.3 to 5.6 mps for u and v components respectively. From the Table 1 it can be seen that CCs were in the range 0.5 to 0.8 for both the wind components. Linear regression equation of the form $y = a + bx$ was developed between satellite derived moisture wind (y) and radiosonde wind (x). The regression constants a and b obtained for different levels are given in Table 1. The number of observations utilized to develop the regression relation at different levels are also shown in the Table 1. Figs 1(a, b) show regression lines along with scattered points for u and v components at different levels respectively.

Structure Function and Autocorrelation Function

Based on five years (1980-85, except 1984) of daily May month RS wind data, structure functions and autocorrelation functions for the above levels were computed. Fig.2 shows the structure function curves for the u and v components of the wind at different levels. Estimate of $\sigma_{\varepsilon_i}^2$ and λ^2 (noise to signal ratio) for different levels were given in Table 2. The correlations which were averaged within 4° segment were modelled by polynomials of different degree and the fitted correlations along with observed correlations are shown in Figs 3 (a,b) for u and v-component respectively. It was observed from Figs 3 (a,b) that the correlation approaches zero at large distance (approximately 15 to 20°). The fitted polynomial was of the form $\mu(\rho) = a_0 + \sum_{i=1}^{n} a_i \rho^i$. The values of the constants involved in polynomials along with their degrees were given in Table 3. Computations of these parameters (structure function and autocorrelation function) were necessary for the objective analysis using optimum interpolation scheme.

Objective Analysis

To test the impact of satellite derived winds on objective analyses, analyses were made in two stages. In the first case the analyses were made for different days and levels using only RS data. In the second case the analyses were performed using above RS data and GMS-5 moisture winds. These two experiments were performed using two types of Initial Guess (IG) fields viz, climatology and daily average reanalyses of previous day (Persistancy) from NCEP/NCAR. These GMS-5 moisture winds were derived from the layer winds using the regression relation described earlier in development of regression relation for various standard levels and days. The analyses were carried out for 150, 200, 250 and 300 hPa levels. To investigate the impact of inclusion of the WVWVs at various stages of the TC, analyses were carried for 13 to 22 May. Carefully drawn subjective analyses based on RS wind data of India Meteorological Department were included here for comparison. Analyses obtained with OI scheme using only RS data and RS plus GMS-5 data using both the types of IGs compared fairly well with the corresponding subjective analyses. But it can be seen from the analyses that there were some inconsistencies in the analysis when only RS data was used. This was specifically observed over oceanic region. When the satellite data was incorporated in the analyses along with RS data substantial improvement in the inconsistencies of the wind was seen. To illustrate this, a few cases of the analyses viz. 150 hPa for 14 and 19 May and 200 hPa for 15 and 17 May were shown here (Figs 4,5,6,7) respectively. The positions of the centres of the system in both the analyses for both the experiments agreed fairly well with the subjective analyses. From Fig.4 (150 hPa, 14 May) it can be seen that the anticyclone over Myanmar which was very prominent in subjective analysis was very well captured in the analyses produced when the GMS-5 winds were added to RS data with climatology as well as persistency as IG. However, this feature was not seen in the analysis made with only RS data as well as in NCEP/NCAR reanalysis. Similar features were also observed at 150 hPa of 19 May (Fig.5). In another case of 15 May, 200 hPa (Fig.6), the anticyclone which was observed in subjective analysis over east central Bay of Bengal (centred around 9°N, 96°E), the NCEP/NCAR reanalysis could not reproduce this feature. Objective analysis using climatology and persistency as IG with only RS data, the actual position of anticyclonic centre was at south of actual position. Strong anticyclonic outflow having speed of 25 to 30 knots towards the west of

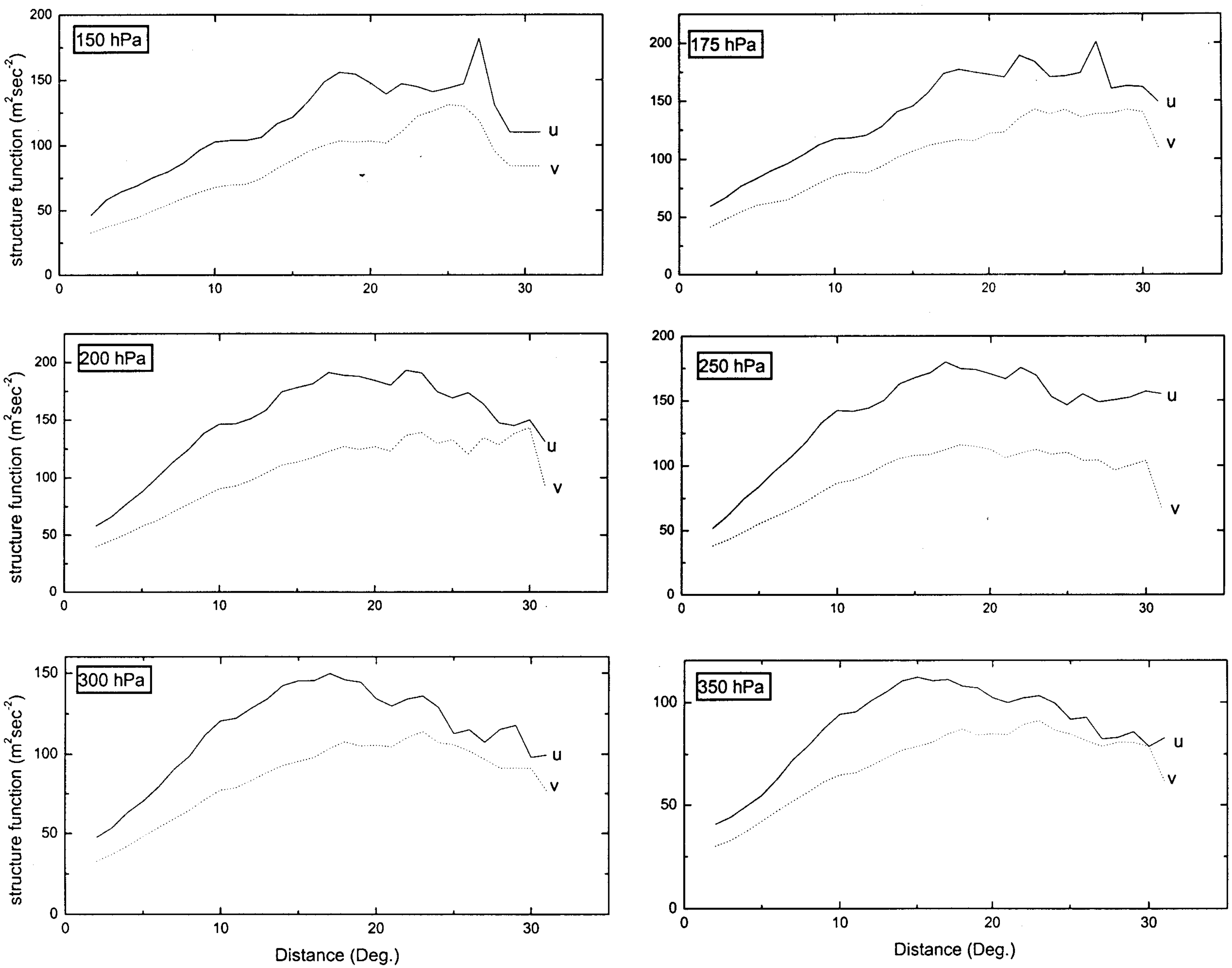

Figure 2. Structure function for u and v components of wind for different pressure levels.

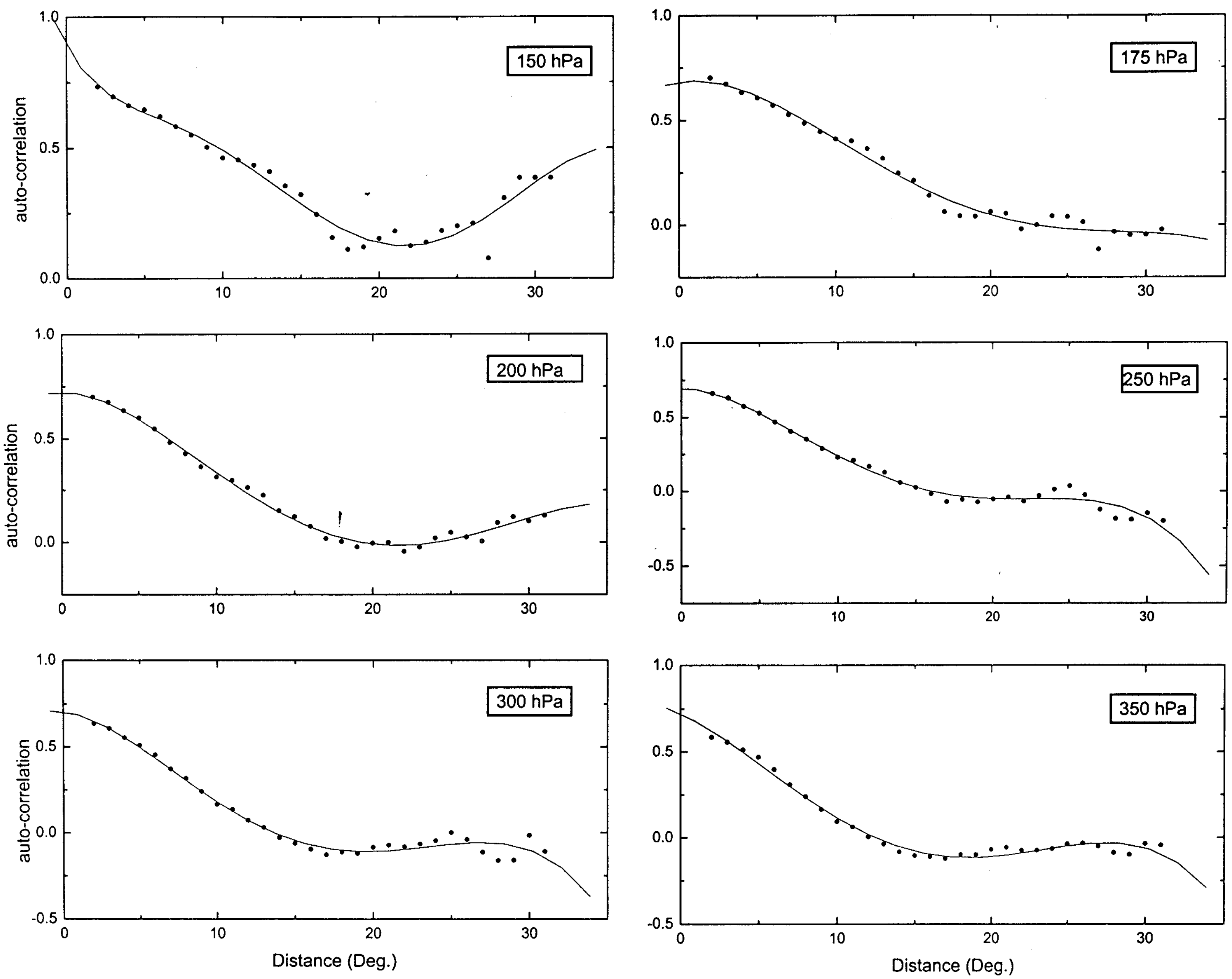

Figure 3(a). Observed auto-correlation along with modelled curve (solid line) for u component for different pressure levels.

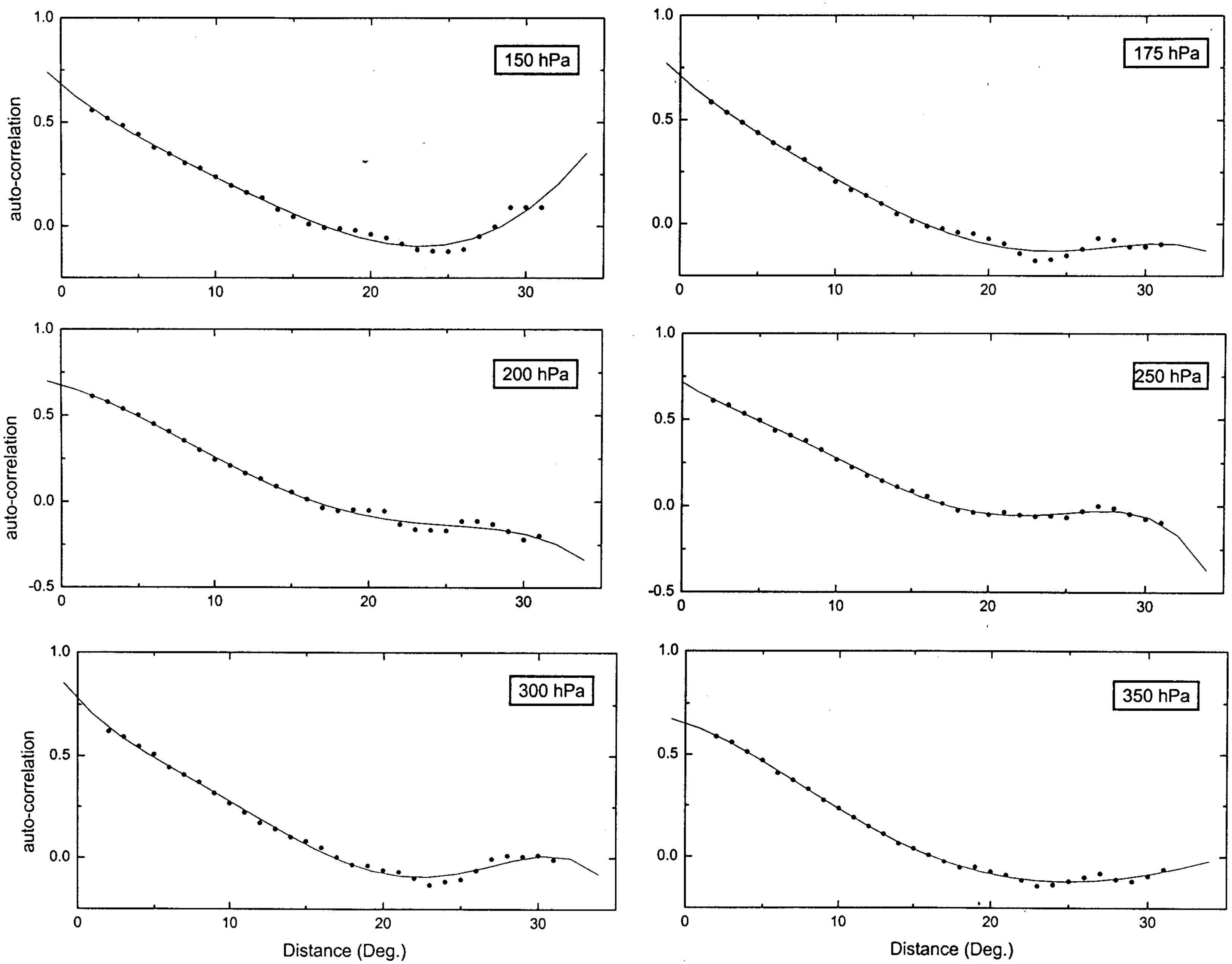

Figure 3(b). Same as Fig.3(a) but for v component.

Table 1. Root Mean Square errors(m/s), C.C. between Satellite wind and RS wind and values of regression constants at different levels

Pressure (hPa)	u- component of wind					v-component of wind				
	r.m.s.	C.C.	a	b	no. of obs.	r.m.s.	C.C.	a	b	no. of obs.
150	6.3	0.54	-10.44	0.70	145	5.6	0.65	0.64	0.84	145
175	5.9	0.60	-7.18	0.77	155	4.9	0.73	0.45	0.93	155
200	6.0	0.54	-6.59	0.69	160	5.1	0.66	-0.44	0.60	160
250	5.5	0.48	-2.64	0.53	167	4.5	0.50	0.07	0.46	167
300	3.5	0.75	-0.91	0.69	109	2.3	0.78	0.03	0.76	109
350	3.3	0.67	0.76	0.54	112	3.3	0.59	-0.05	0.62	112

Table 2. Random errors for different Pressure levels

Pressure (hPa)	u- component of wind		v-component of wind	
	$\sigma^2_{\varepsilon_i}$ (m^2/s^2)	λ^2	$\sigma^2_{\varepsilon_i}$ (m^2/s^2)	λ^2
150	17.5	0.227	11.5	0.306
175	23.5	0.323	15.5	0.382
200	22.5	0.300	15.5	0.345
250	18.5	0.292	13.0	0.298
300	18.5	0.387	13.0	0.355
350	17.5	0.541	12.5	0.456

Table 3. Values of Polynomial coefficients for u and v components for different Pressure levels

Pressure (hPa)	u- component of wind		v-component of wind	
	Degree of poly. (n)	Polynomial coefficients	Degree of poly. (n)	Polynomial coefficients
150	6	$a_0 = 0.8886$, $a_1 = -0.10447$ $a_2 = 0.01795$, $a_3 = -0.00182$ $a_4 = 8.169\text{x}10^{-5}$, $a_5 = -1.5921\text{x}10^{-6}$ $a_6 = 1.09559\text{x}10^{-8}$	5	$a_0 = 0.68067$, $a_1 = -0.06288$ $a_2 = 0.00359$, $a_3 = -2.51337\text{x}10^{-4}$ $a_4 = 8.35099\text{x}10^{-6}$, $a_5 = -7.96187\text{x}10^{-8}$
175	4	$a_0 = 0.68368$, $a_1 = 0.01169$ $a_2 = -0.00633$, $a_3 = 2.80149\text{x}10^{-4}$ $a_4 = -3.62937\text{x}10^{-6}$	5	$a_0 = 0.70843$, $a_1 = -0.06578$ $a_2 = 0.00351$, $a_3 = -2.8971\text{x}10^{-4}$ $a_4 = 1.2212\text{x}10^{-5}$, $a_5 = -1.67218\text{x}10^{-7}$
200	4	$a_0 = 0.72484$, $a_1 = -8.01388\text{x}10^{-5}$ $a_2 = -0.00686$, $a_3 = 3.42638\text{x}10^{-4}$ $a_4 = -4.54391\text{x}10^{-6}$	5	$a_0 = 0.67636$, $a_1 = -0.02637$ $a_2 = -0.0025$, $a_3 = 8.05835\text{x}10^{-5}$ $a_4 = -2.28541\text{x}10^{-6}$, $a_5 = -7.60383\text{x}10^{-8}$
250	4	$a_0 = 0.69836$, $a_1 = -0.00287$ $a_2 = -0.0086$, $a_3 = 5.16026\text{x}10^{-4}$ $a_4 = 8.61737\text{x}10^{-6}$	5	$a_0 = 0.71439$, $a_1 = -0.05511$ $a_2 = 0.00389$, $a_3 = -4.69962\text{x}10^{-4}$ $a_4 = 2.28575\text{x}10^{-5}$, $a_5 = -3.4782\text{x}10^{-7}$
300	4	$a_0 = 0.70693$, $a_1 = -0.01169$ $a_2 = -0.00842$, $a_3 = 5.17328\text{x}10^{-4}$ $a_4 = -8.44647\text{x}10^{-6}$	5	$a_0 = 0.77558$, $a_1 = -0.08147$ $a_2 = 0.00778$, $a_3 = -7.05604\text{x}10^{-4}$ $a_4 = 2.81478\text{x}10^{-5}$, $a_5 = -3.73563\text{x}10^{-7}$
350	4	$a_0 = 0.72327$, $a_1 = -0.04145$ $a_2 = -0.00526$, $a_3 = 4.01777\text{x}10^{-4}$ $a_4 = -6.98135\text{x}10^{-6}$	5	$a_0 = 0.65485$, $a_1 = -0.02506$ $a_2 = -0.00357$, $a_3 = 2.286\text{x}10^{-4}$ $a_4 = -4.67049\text{x}10^{-6}$, $a_5 = 3.44938\text{x}10^{-8}$

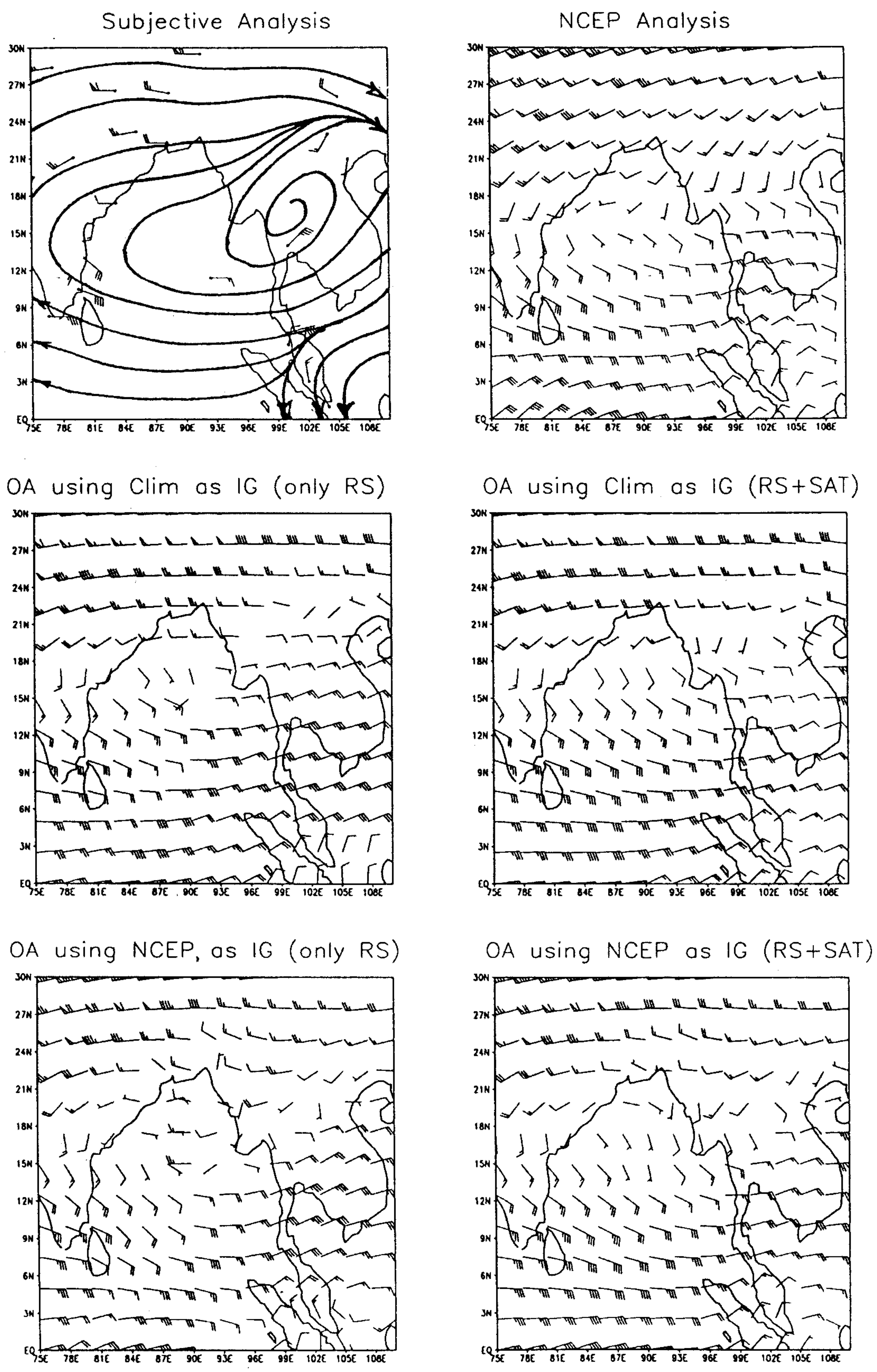

Figure 4. Analyses of 150 hPa level for 14 May 1997.

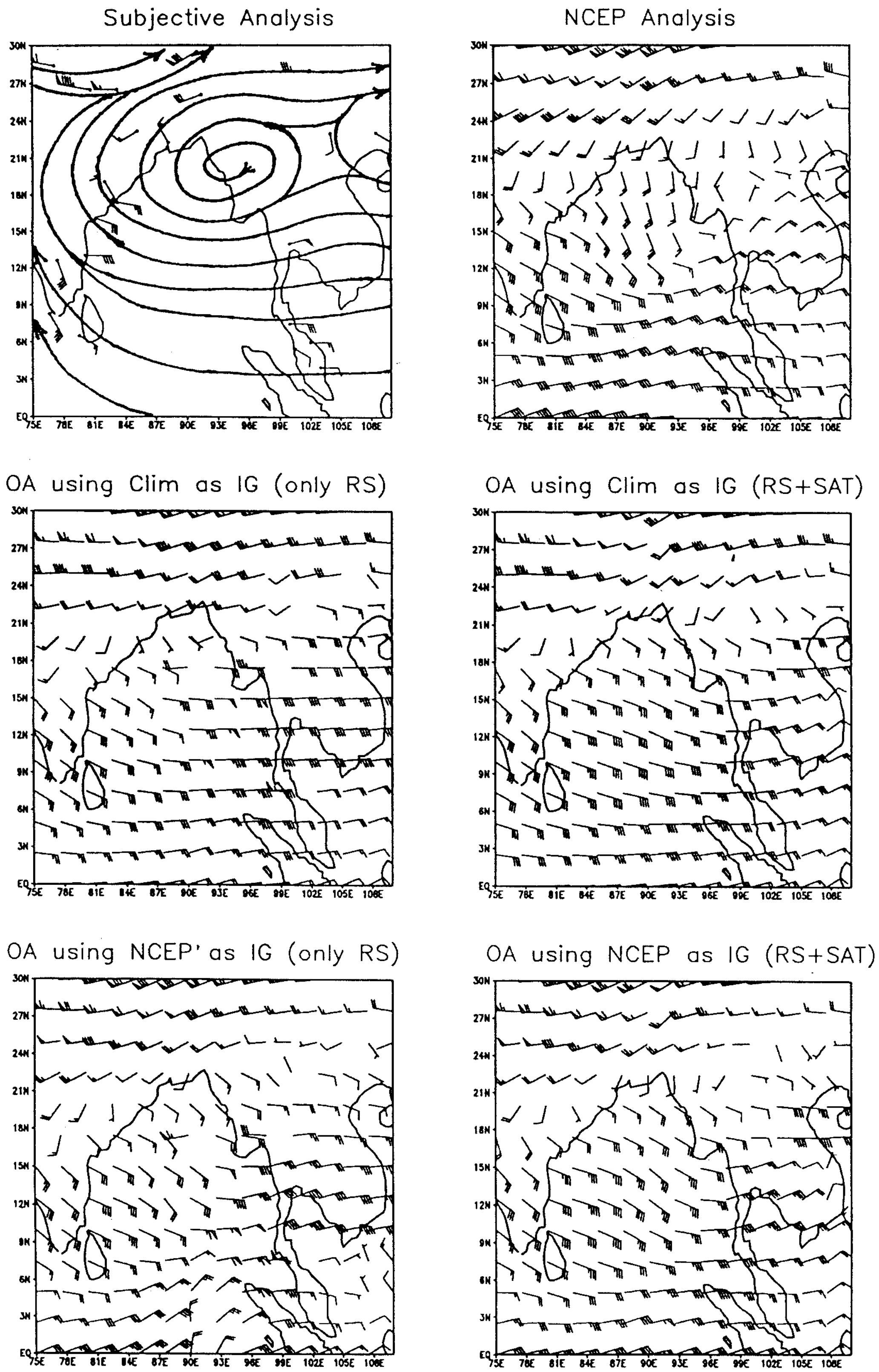

Figure 5. Same as Fig.4 but for 19 May 1997.

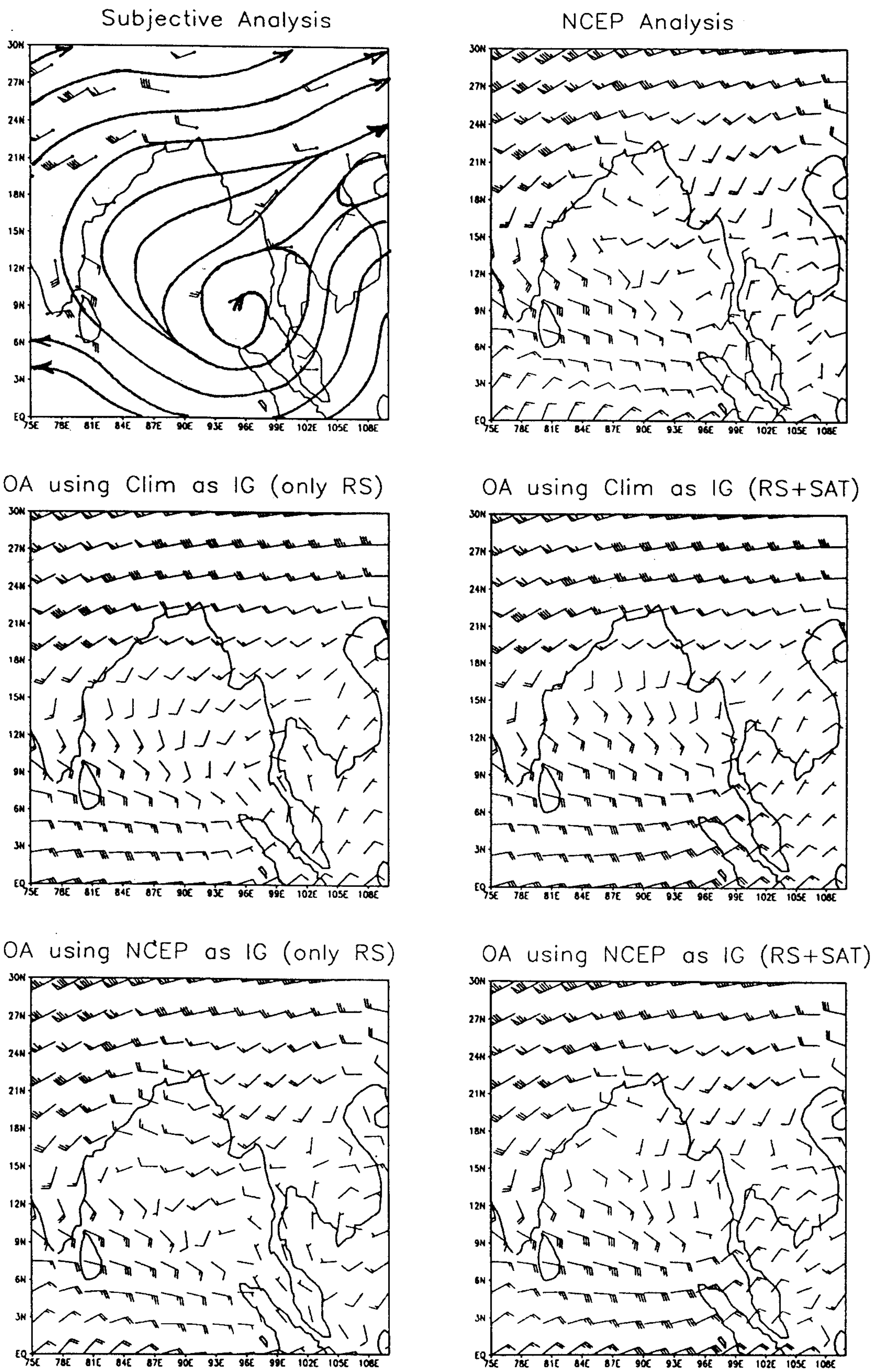

Figure 6. Analyses of 200 hPa level for 15 May 1997.

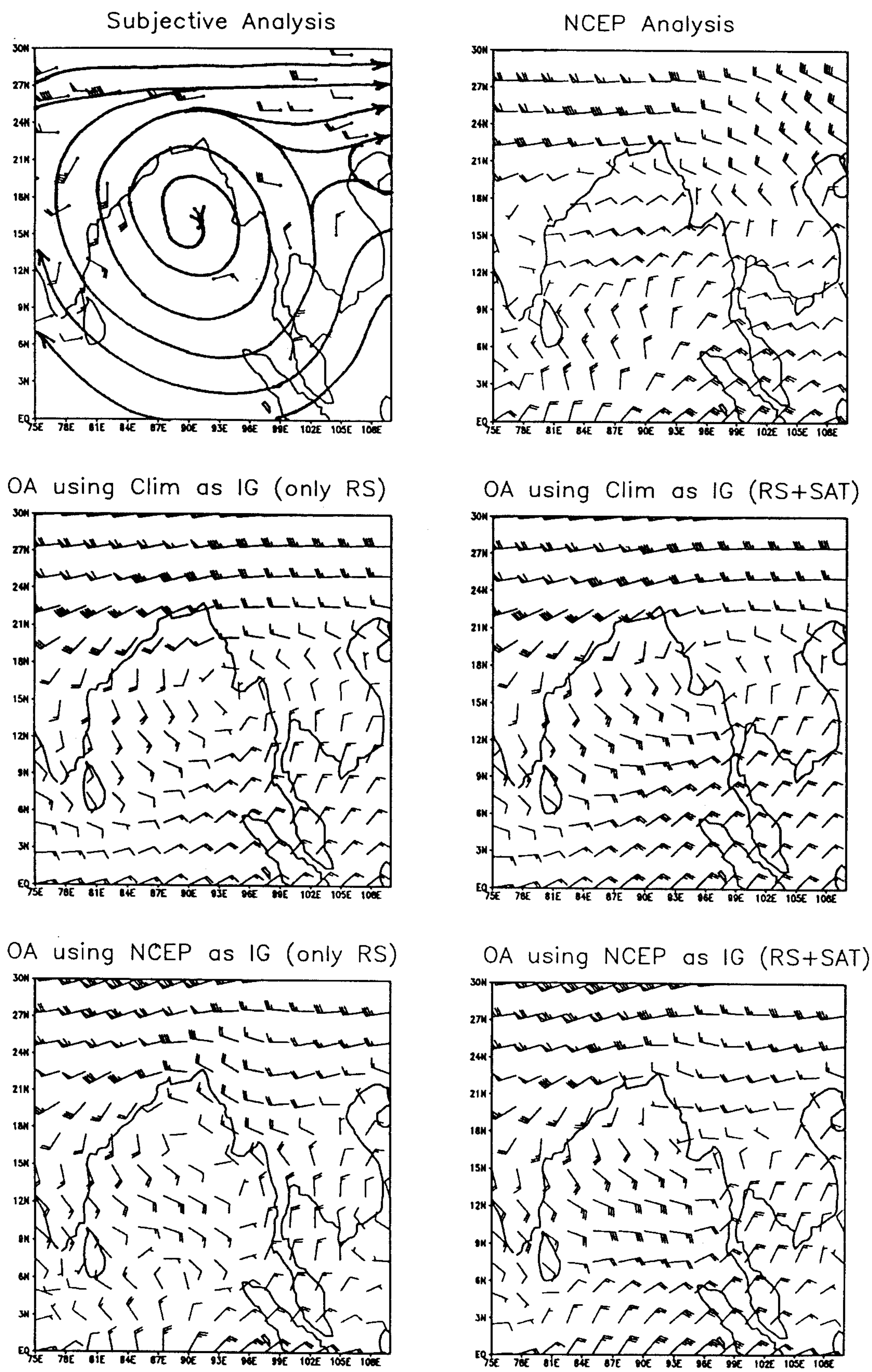

Figure 7. Same as Fig.6 but for 17 May 1997.

Table 4. RMS errors using climatology as initial guess when compared with station observations in m/s

Date (May 1997)	150 hPa				200 hPa			
	Without sat. data		With sat. data		Without sat. data		With sat. data	
	u	v	u	v	u	v	u	v
14	5.8	3.0	3.9	3.2	5.8	3.7	5.4	3.1
15	7.6	3.4	5.2	3.1	3.4	3.8	3.9	3.4
16	9.7	4.7	7.1	4.2	5.9	4.2	4.9	3.9
17	9.6	5.2	4.8	4.3	6.0	3.9	5.6	3.5
18	5.8	5.4	5.9	4.8	4.8	6.2	4.0	5.4
19	10.1	4.4	4.6	4.0	4.3	4.5	4.2	3.9
20	11.9	2.9	4.7	2.6	5.2	3.3	5.3	3.0
21	3.4	2.7	2.8	2.4	3.4	4.2	3.2	3.6

Table 5. RMS errors using climatology as initial guess when compared with station observations in m/s

Date (May 1997)	250 hPa				300 hPa			
	Without sat. data		With sat. data		Without sat. data		With sat. data	
	u	v	u	v	u	v	u	v
14	7.2	3.3	5.8	2.7	3.5	4.3	3.7	4.0
15	3.9	3.1	3.8	2.7	3.6	4.1	3.8	3.9
16	4.6	5.1	3.8	4.0	3.2	3.6	3.2	3.6
17	4.6	3.8	4.7	3.5	3.7	3.5	3.7	3.5
18	5.2	3.6	4.6	3.2	5.4	3.6	5.0	3.8
19	3.4	6.1	3.1	4.9	3.5	4.1	3.3	4.1
20	3.7	3.6	4.1	3.1	3.4	3.5	3.2	3.1
21	4.1	2.7	3.9	2.2	3.7	2.5	3.6	2.3

Table 6. RMS errors using persistancy as initial guess when compared with station observations in m/s

Date (May 1997)	150 hPa				200 hPa			
	Without sat. data		With sat. data		Without sat. data		With sat. data	
	u	v	u	v	u	v	u	v
14	4.3	3.0	3.6	3.3	4.8	3.4	4.8	3.1
15	7.6	3.0	5.6	3.0	3.2	3.2	4.1	3.2
16	9.6	5.0	7.2	4.3	5.6	4.8	5.1	4.2
17	6.8	5.5	4.7	4.7	5.4	3.9	5.4	3.8
18	5.1	5.8	5.3	4.9	4.2	6.4	3.6	5.5
19	9.2	4.5	4.3	4.0	3.9	4.5	4.1	3.9
20	8.9	3.0	5.2	3.0	5.8	4.1	5.7	3.7
21	6.5	2.7	3.3	2.6	3.6	4.5	3.3	3.8

Table 7. RMS errors using persistancy as initial guess when compared with station observations in m/s

Date (May 1997)	250 hPa				300 hPa			
	Without sat. data		With sat. data		Without sat. data		With sat. data	
	u	v	u	v	u	v	u	v
14	5.7	3.3	4.8	2.8	2.7	4.2	3.2	3.9
15	3.5	2.6	3.5	2.5	4.1	4.1	4.1	3.9
16	4.7	5.2	4.1	4.2	3.0	3.8	3.0	3.8
17	4.4	3.7	4.8	3.8	3.6	3.7	3.6	3.7
18	4.7	3.9	4.5	3.5	4.8	3.8	4.5	4.0
19	3.3	6.0	3.3	4.9	3.6	3.8	3.4	4.1
20	4.0	4.2	4.7	3.9	4.3	4.0	4.2	3.6
21	4.3	2.8	4.2	2.2	4.3	3.1	4.1	2.7

anticyclone were very well depicted in the analyses when satellite data was assimilated with the RS data using both the types of IGs. The centre of anticyclone has been slightly shifted towards north of the actual position. Similar features were also observed on 17 May, 200 hPa (Fig.7). On this day it was a severe cyclonic storm with core of hurricane winds. This intensification of the system from 15 (deep depression) to 17 was not captured by NCEP/NCAR reanalyses as well as by the objective analyses with only RS data. But this important feature, anticyclonic outflow was very well captured in the analysis when satellite data was assimilated with RS data. From this we can infer that although the analyses were carried out at upper tropospheric levels due to the lack of GMS-5 data at lower levels, the anticyclonic features have been depicted well particularly over oceanic region where RS data was not available. Due to satellite data it was possible to track the system in a more confident manner. Of course there are limitations for the analysis because in cyclonic cases even the data provided from satellites are not sufficient and accurate. For quantitative analysis, rms errors have been calculated by comparing the observed values with the analysed values at the observation locations. The rms errors using satellite winds are comparatively less than the analyses using only RS data and are given in Table 4 to 7.

CONCLUSIONS

1. High correlations have been found between observed upper tropospheric RS winds over Port Blair island and moisture winds from satellite. RMS difference between satellite winds and RS winds were generally less than 6 mps for both u and v components.
2. Regression relation between RS and GMS-5 winds have been developed to estimate the winds at different levels.
3. Analyses with only RS wind and with RS plus satellite wind agree well with subjective analyses.
4. Inclusion of satellite wind in the analysis properly depicts upper tropospheric anticyclonic circulation and hence an enhancement in the upper tropospheric divergence is expected.

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