Vol.11 No.3 Advances in Atmospheric Sciences August 1994

Estimation of Winds at Different Isobaric Levels Based on the Observed Winds at 850 hPa Level Using Double Fourier Series

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Received August 25, 1993; revised February 14, 1994

ABSTRACT

A technique based on the double Fourier series is developed to estimate the winds at different isobaric levels for the limited area domain, 35°E to 140°E and 30°S to 40°N, using the observed winds at 850 hPa level for the month of June. For this purpose the wind field at a level under consideration is taken in the ratio form with that of 850 hPa level and the coefficients of the double Fourier series are computed. These coefficients are subsequently used to compute the winds which are compared with the actual winds. The results of the double Fourier series technique are compared with those of the polynomial surface fitting method developed by Bavadekar and Khaladkar (1992). The technique is also applied for the daily wind data of 11, June, 1979 and the validation of the technique is tested for a few radiosonde stations of India. The computed winds for these radiosonde stations are quite close to observed winds.

Key words: Double Fourier series, Objective analysis, Cloud motion vectors, Numerical weather prediction, Polynomial surface fitting

I. INTRODUCTION

The non–conventional wind data derived from cloud imageries obtained at regular time interval from geostationary satellites are very useful for wind analysis over oceanic regions. Over Indian region and surrounding oceanic areas, the cloud imageries at the time interval of 30 minutes are obtained from INSAT 2A launched on 29, August, 1992. The previous satellite INSAT 1D also still provides the cloud imageries. The cloud motion vectors (CMVs) derived at Meteorological Data Utilization Centre (MDUC), New Delhi, are made available for synoptic wind analysis on routine basis. These winds give useful information over data sparse regions and are useful for objective analysis and Numerical Weather Prediction. The non conventional wind data are incorporated in NWP model by the procedure known as four dimensional data assimilation.

The CMVs are generally available at the cloud base ($\cong$850 hPa) or at the cloud top ($\cong$ 200 hPa) level. These winds thus can be directly used for objective analysis at 850 and 200 hPa levels. Attempts were also made to construct the vertical wind profiles at the location of such wind observations. (Begum 1986, Begum and Datta, 1986), Mahajan et al. (1992) used linear regression equations using satellite winds and ship winds to derive the vertical wind profile for the small area, Equator to 26°N and 48°E to 60°E. The r.m.s errors as reported by them were less than 5 mps below 500 hPa and less than 8 mps above 500 hPa level. Bavadekar and Khaladkar (1992) used the third degree polynomial surface fitting method, hereafter called Polymethod to estimate the winds at different isobaric levels based on the observed winds at 850 hPa level. The method has been tested for June winds for the domain extending from 35°E to 140°E and 30°S to 40°N. The vertical wind profile at any location within the domain can be easily constructed using the computed coefficients of the polynomial surfaces. The method, however, has got its own limitations as it provides the limited number of coefficients for computation of winds. The method is also not useful for daily winds as the accuracy of computing the winds at 500 and 600 hPa levels was not good. In the present paper, authors have used double Fourier series method, hereafter called D.F. method, to estimate the winds at different isobaric levels. Fourier analysis technique was used for the benefit of objective analysis by Ramanathan and Sikka (1971) and Ramanathan et al. (1972). The D.F. method has got the advantage over the Poly–method as it provides a large number of coefficients to represent the wind field. The method is also tested for daily winds with considerable skill. The results of the application of this method are described in this paper.

II. DOUBLE FOURIER SERIES TECHNIQUE

Two–dimensional scalar field, $f(x,y)$ bounded in the region

$$R(-l \leqslant x \leqslant l, \quad -h \leqslant y \leqslant h)$$

where l and h are half periods in x and y directions respectively, can be represented by the double Fourier series as

$$f(x,y)=\sum_{m=0}^{\infty}\sum_{n=0}^{\infty}\lambda_{mn}\Big[a_{mn}\cos\frac{\pi mx}{l}\cos\frac{\pi ny}{h}+b_{mn}\sin\frac{\pi mx}{l}\cos\frac{\pi ny}{h}+c_{mn}\cos\frac{\pi mx}{l}\sin\frac{\pi ny}{h}+d_{mn}\sin\frac{\pi mx}{l}\sin\frac{\pi ny}{h}\Big] \tag{1}$$

where,

$$\begin{cases} a_{mn}=\dfrac{1}{lh}\displaystyle\iint_R f(x,y)\cos\frac{\pi mx}{l}\cos\frac{\pi ny}{h}\,dxdy \\ b_{mn}=\dfrac{1}{lh}\displaystyle\iint_R f(x,y)\sin\frac{\pi mx}{l}\cos\frac{\pi ny}{h}\,dxdy \\ c_{mn}=\dfrac{1}{lh}\displaystyle\iint_R f(x,y)\cos\frac{\pi mx}{l}\sin\frac{\pi ny}{h}\,dxdy \\ d_{mn}=\dfrac{1}{lh}\displaystyle\iint_R f(x,y)\sin\frac{\pi mx}{l}\sin\frac{\pi ny}{h}\,dxdy \end{cases} \tag{2}$$

and

$$\lambda_{mn}=\begin{cases} \dfrac{1}{4} & \text{for } m=n=0 \\ \dfrac{1}{2} & \text{for } m>0,\ n=0 \text{ or } m=0,\ n>0 \\ 1 & \text{for } m>0,\ n>0 \end{cases} \tag{3}$$

For repesenting the wind field, as in the present investigation, $f(x,y)$ is put in the ratio form as

$$f(x,y)=V_L\,/\,V_{850}\ , \tag{4}$$

where V_L is the grid point wind at level L above 850 hPa level and V_{850} is the corresponding grid point wind at 850 hPa level, where x,y are the latitude and longitude of the grid point respectively. The method is applied for u and v components of the wind separately.

In the present study monthly mean winds of June of IIOE (International Indian Ocean Expedition) period, as obtained from the analysed charts from Ramage and Raman (1972) are used. The winds for latitude–longitude grid of 5° in the domain extending from 35°E to 140°E and 30°S to 40°N, are obtained for 200, 300, 500, 700 and 850 hPa levels. The winds at 250, 400, 600 and 800 hPa levels are obtained by linear interpolation.

Although in Eq.(1) m and n take different values from 0 to ∞, the optimum maximum values of m and n, for evaluation of $f(x,y)$ by the numerical methods for the wind data at 5° grid interval, were found to be 10 and 7 respectively. In the first instance the coefficients a_{mn}, b_{mn}, etc. as given in Eq.(2), are evaluated by the numerical method. These coefficients are then used to compute $f(x,y)$ which represents the ratio of the winds as given by Eq.(4). The computed winds can easily be obtained by multiplying these ratios by the corresponding V_{850} wind which is assumed to be the observed wind.

III. COMPARISON FOR JUNE WINDS

The circulation features of the computed June winds for 200, 300 and 700 hPa levels, using Poly–method, were satisfactory but the application of this method to 500 hPa level wind circulation is not satisfactory as evidenced by the large absolute error of 75.2°, in the direction of the wind.

Table 1 gives the comparison of the two methods for u and v components of the winds. In column 2, the absolute values of the observed average u–component of the wind for the whole domain are given. In the columns, 3 and 4, the r.m.s. deviations for the Poly and the D.F. methods respectively are given for the u–component of the winds. The r.m.s. deviations for the Poly–method are quite small compared to $|\bar{u}_0|$ but the r.m.s. deviations for the D.F. method are considerably smaller than that of Poly method. Standard deviations for the u–component of the wind for the observed, D.F. and Poly– methods are given in columns 5, 6 and 7 respectively. It is apparent that the standard deviations as computed by D.F. method are quite close to that of the observed u–component of the wind. The results for v–component of the winds are also given in Table 1. Except for 200, 250 and 800 hPa levels, the r.m.s. deviations for v–components by Poly–method do not gain any advantage compared to $|\bar{v}_0|$. The r.m.s. values of D.F. method however, show considerable improvement for the v–component of the wind.

Table 1. Comparison of the Double Fourier Series (D.F.) and Polynomial Surface Fitting (Poly) Methods for June Winds (Unit for wind: kt)

Level	$\|\bar{u}_0\|$	R.M.S. Errors		Standard Deviation			$\|\bar{v}_0\|$	R.M.S. Errors		Standard Deviation		
hPa		Poly	D.F.	Obs.	D.F.	Poly		Poly	D.F.	Obs.	D.F.	Poly
200	26.8	9.4	2.7	31.5	30.4	24.1	7.5	5.5	2.1	7.6	7.6	5.9
250	21.9	7.7	2.2	25.8	24.8	19.7	5.7	4.2	1.8	6.0	6.0	4.5
300	17.0	6.8	2.1	20.4	19.4	15.3	4.5	4.6	2.4	5.5	5.4	3.5
400	12.0	5.1	1.5	14.6	14.0	11.2	2.8	3.2	1.4	3.5	3.3	2.0
500	8.4	4.8	1.3	9.8	9.5	7.4	2.5	3.0	1.1	3.1	2.8	1.2
600	6.7	4.2	1.0	7.0	6.8	5.2	2.2	2.6	0.9	2.7	2.5	0.9
700	5.9	4.3	1.1	5.9	5.7	3.7	2.6	3.0	1.2	3.3	3.1	1.2
800	6.1	4.6	1.1	6.9	6.6	4.9	3.3	3.2	0.8	4.1	3.9	1.8

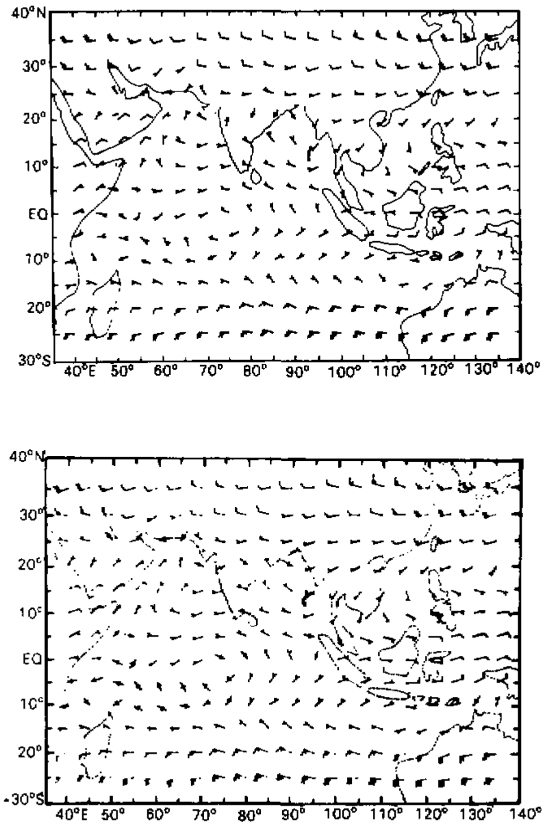

Fig. 1. Observed (Top) and computed (bottom) winds at 500 hPa level for June.

The total wind is constructed from the computed wind components. The average errors in absolute values for DD and FF are given for the two methods in Table 2. The maximum average error for the direction of the wind is 75.2° at 500 hPa level for the Poly–method whereas, the maximum average error is just 12.1° at 700 hPa level for the D.F. method. The errors in speed are also considerably smaller for the D.F. method compared to that of the Poly–method.

Table 2. Comparison of Average Errors in Absolute Values for DD and FF for June

Level hPa		200	250	300	400	500	600	700	800
Error in $\|DD\|$	Poly	30.7	29.2	33.8	27.6	75.2	71.3	49.2	35.7
(degree)	D.F.	4.8	5.5	7.3	5.8	6.9	6.4	12.1	10.3
Error in $\|FF\|$	Poly	7.3	6.0	5.3	4.0	3.0	3.1	3.0	3.4
(kt.)	D.F.	1.6	1.4	1.4	1.0	0.8	0.8	0.9	0.7

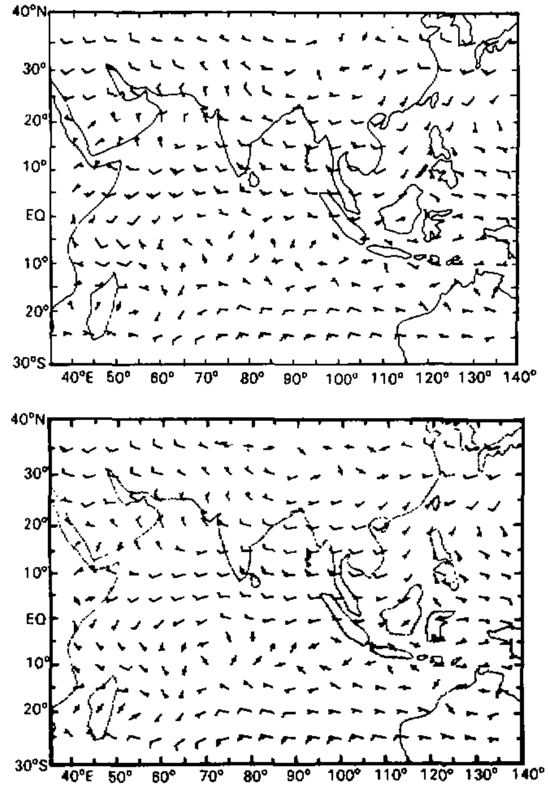

Fig. 2. Observed (Top) and computed (bottom) winds at 700 hPa level for June.

As mentioned earlier the poly–method is not suitable to resolve the circulation features over equatorial oceanic region as the winds are light in speeds and variable in directions. In order to assess the performance of D.F. method, the computed winds are shown along with observed winds in Fig. 1 and Fig. 2 for 500 and 700 hPa levels respectively. The spatial distribution of the absolute errors in direction and speed of the winds at 500 and 700 hPa level are shown in Fig. 3. Except for the isolated grid points the error in direction of the wind is less than 30° over most part of the oceanic region and the error in wind speed is less than 5 knots. The isoline of 5 kt near south Korea for 500 hPa level is shown in Fig. 3.

IV. APPLICATION OF THE D. F. METHOD TO DAILY WIND DATA

The ultimate purpose of the present study is to test the suitability of the D. F. method for daily winds so that the non–conventional satellite wind data can be conveniently incorporated in the objective analysis of wind at different isobaric levels. The D. F. method is tested for 11 June 1979 wind data for 12 GMT. The basic grid point winds at different isobaric levels are obtained from FGGE level IIIb ECMWF wind data. The technique is first tested for the regular grid point wind data and the parameters of observed and computed winds are computed. The maximum r.m.s. errors for u– and v–components of the winds for this case are 5.7 and 3.4 knots respectively and found at 250 hPa level. In Table 3, absolute errors in direction and speed are given. These errors are quite small for all the levels. The D.F. method thus appears to be quite satisfactory for application to daily wind data at various isobaric levels.

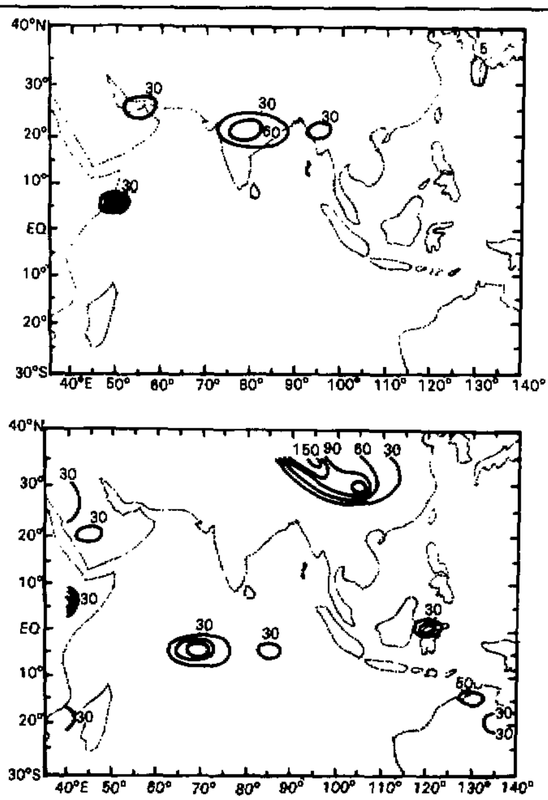

Fig. 3. The isolines showing the errors $|DD_{obs} - DD_{comp}|$ (Thick lines) and $|FF_{obs} - FF_{comp}|$ (thin lines) in wind direction and speed at 500 hPa (Top) and 700 hPa (bottom) levels respectively for June.

For validation purpose, the computed winds for a few radiosonde stations within the domain are compared with the observed winds, in Table 4. The computed winds which show the error in absolute wind speed greater than 10 knots or the error in absolute wind direction greater than 30° are star (*) marked. All the star marked winds show the errors in direction (DD) only with the criteria as mentioned above.

Table 3. Average Error in Absolute Values for DD and FF for 11. June. 79 (12GMT)

Level hPa	200	250	300	400	500	600	700	800
Error in								
5.0	7.9	7.9	7.6	10.0	8.7	9.1	11.2	$\|DD\|$
5.0	7.9	7.9	7.6	10.0	8.7	9.1	11.2	(degree)
								Error in $\|FF\|$
3.4	3.4	3.0	2.1	1.6	1.3	1.5	1.5	(kt.)

Table 4. Observed and Computed Winds for Radiosonde Stations for 11. June. 79

hPa Levels / stations	200	300	500	700
Bombay	08115	35709	04815	01905
	07814	01806	04109	02302
Madras	11732	12707	07009	04305
	09228	09409*	07105	03206
Port–Blair	08732	10111	06105	24001
	07334	08909	10501*	26805
Trivandrum	–	04511	10607	01505
	10425	10716*	08406	01604
Vishakhapatnam	07417	34509	27015	36009
	07814	29402*	31807*	34908

Computed winds are shown below the observed winds.

* : Wind differing in direction greater than 30° and / or speed difference greater than 10 knots respectively.

–: Observed winds not available

V. CONCLUDING REMARKS

The D.F. method is useful for estimation of winds at different isobaric levels based on the observed wind at 850 hPa level. The method has shown considerable improvement, in estimating the monthly winds for June, over the Poly–method as it provides large number of coefficients which can be computed easily by numerical method. The D.F. method is also useful for constructing the vertical wind profiles for daily wind data. The method has thus, important application in incorporating the satellite winds at the cloud base level over data sparse oceanic region and improving the wind analysis at different isobaric levels by using the additional estimated wind data.

Author's grateful thanks are due to Prof. R.N. Keshavamurty, Director, IITM and Dr. S. S. Singh, Head, Forecasting Research Division for encouragement and interest in the study. Thanks are also due to Dr. S. Rajamani and Mr. J. R. Kulkarni for reviewing the paper and offering valuable comments.

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