

Ocean surface wind from ERS-1 scatterometer and its use in inferring cyclone parameters for storm surge modelling

B.S. Gohil & P.C. Pandey

Oceanic Sciences Division, Meteorology and Oceanography Group, Space Applications Centre (ISRO),
Ahmedabad 380 053, India

and

T.C. Panda

Department of Mathematics, Berhampur University, Berhampur 760 007, Orissa, India

Received 23 May 1997, revised 3 November 1997

The present paper deals with the use of satellite scatterometer derived ocean surface wind vectors in inferring cyclone parameters useful for the storm surge modelling. The high density of satellite surface wind data of a cyclone formed over ocean has been utilised in determining the cyclone parameters like location of cyclone centre and the radius and intensity of maximum winds. These parameters are necessary for obtaining the distribution of wind field under the influence of a cyclone which is an essential input for the storm surge modelling and prediction. Due to certain reasons like coarser spatial resolution of scatterometer compared to the size of cyclone core and the saturation of radar backscatter with increasing wind speed and the inadequacies of the model functions used for retrieval of winds, the high intensity winds in the core region of the cyclone are underestimated by the scatterometer. The method proposed here makes use of the high spatial density of wind data from scatterometer and the axially symmetric distribution of cyclonic winds around its centre to infer the cyclone parameters like the location of cyclone centre, radius and intensity of maximum winds. Results of analyses of ERS-1 scatterometer wind data for few cyclones formed over Indian oceanic region in inferring the cyclone parameters have been presented here. Comparison of cyclone parameters inferred from ERS-1 scatterometer derived winds with those available from India Meteorological Department (IMD) has been performed which indicate the usefulness of the satellite data for the purpose.

The strong ocean surface winds under the influence of cyclonic storms are devastating and disastrous when the storms hit the coasts. The large amplitude ocean waves (surges) generated by the action of strong winds inundate the coastal land. Information of these winds over oceanic region is essential in forecasting and numerical modelling of storm surge. Measurements of these winds using ships are limited. Satellite microwave scatterometers are powerful means of observing cyclonic surface winds under the dense cloud cover. Despite the limitation of continuous monitoring of cyclonic storms by polar orbiting satellite scatterometers, they provide a wide coverage of about 500 to 1300 km at a resolution of about 25 to 50 km. High spatial density of wind data provided by scatterometer has a great potential in studying the cyclonic wind structure and associated storm surge¹.

ERS-1 satellite scatterometer provides such observations at every 25 km over a swath width of about 400 km. The high density surface wind data has been utilized to infer various cyclone parameters. The wind measurements from scatterometer are underestimated due to the limited range of wind speeds of the available empirical model functions for estimating the wind vector. This problem has been tackled to an extent by utilizing the axially symmetric cyclone model of surface wind distribution and the high density surface wind speed data. The determination of cyclone parameters from ERS-1 scatterometer winds has been earlier attempted^{2,3}. Attempt has been made here to estimate the cyclone parameters on the basis of ERS-1 scatterometer derived winds alone. Analyses of ERS-1 scatterometer derived winds for three tropical cyclones of November 19, 1992;

November 14, 1993 and May 1, 1994, formed over Indian oceanic region (Fig. 1) has been made to estimate the cyclone parameters like intensity and radius of maximum winds and the cyclone centre location. Comparison of these parameters with those provided by IMD has also been made.

Materials and Methods

ERS-1 scatterometer

The ERS-1 scatterometer which operates at C-band (5.3 GHz) provides radar backscatter from ocean surface measured in three different directions by its three vertically polarized antennae azimuthally separated from each other by 45° with the middle antenna pointing normal to the satellite track. Radar backscatter triplets are provided for 19 nodes (cells) of 50×50 km with separation of about 25 km along and across the sub-satellite track. The data swath is 500 km. The incidence angles for the fore/aft and the mid beams across the data swath are in the ranges of 27° to 58° and 18° to 45° respectively. The data of incidence and azimuthal angles of radar beams at each grid are also provided along with σ° triplets required for the retrieval of the wind vectors at each grid.

Retrieval of winds from ERS-1 scatterometer

The radar backscatter data of ERS-1 scatterometer has been utilized to derive surface wind vector field using the retrieval algorithm^{4,5} and the C-band model function CMOD4⁶. The above algorithms have been utilized in the analysis of one

year of ERS-1 scatterometer data over Indian region and the comparison of derived winds have also been made with the *in situ* data⁷. The derived wind fields for three cyclone cases have been used to determine the centre of the cyclone and the radius and intensity of maximum winds and the exponent of wind distribution as given below.

Methodology for cyclone parameters

The ERS-1 scatterometer provides wind speed and direction data at a spatial resolution of about 25×25 km over a satellite data swath of about 400 km. The wind speed data has been used with an axially symmetric cyclone wind field model for the purpose as described below.

The centre of the cyclone has been estimated using the isotachs obtained from the wind speed data. For this purpose, the closed isotachs have been considered and the assumption made is that all the points with coordinates (x_i, y_i) on a closed circular isotach of radius R must satisfy the equation of a circle in (R, θ) coordinates as given below

$$x_i - x_c = R \cos \theta \quad \dots (1a)$$

$$y_i - y_c = R \sin \theta \quad \dots (1b)$$

where (x_c, y_c) are the coordinates of the centre. Taking summation over a number of points N on a given isotach using Eqs. (1a and 1b) yields

$$\sum x_i - N x_c = R \sum \cos \theta \quad \dots (2a)$$

$$\sum y_i - N y_c = R \sum \sin \theta \quad \dots (2b)$$

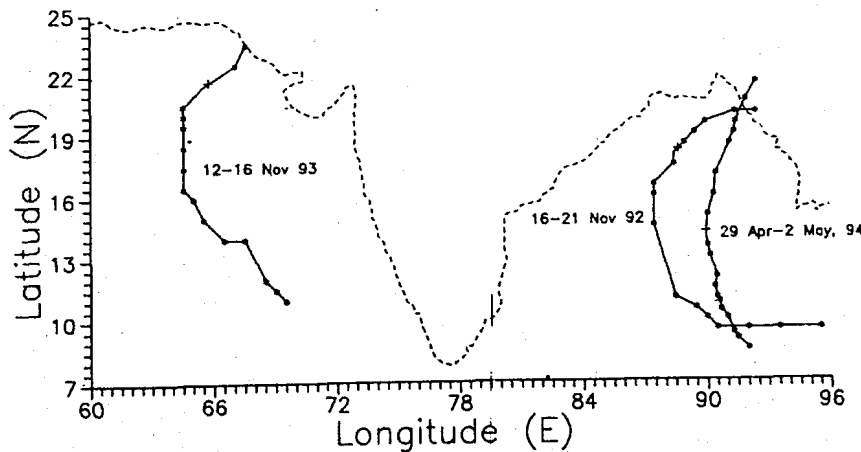


Fig. 1—Tracks of cyclone cases used in the analysis

Since the summations $\sum \sin \theta$ and $\sum \cos \theta$ over 2π are zero, the coordinates of the centre can be obtained as given below

$$x_c = \sum x_i / N \quad \dots (3a)$$

$$y_c = \sum y_i / N \quad \dots (3b)$$

Since the isotachs are neither perfect circles nor concentric, the centre location can be obtained more accurately by averaging the centre locations derived from different isotachs. The standard deviation of location is treated as the error of centre location determination. This error has also been considered for inferring the mean radius and mean intensity of maximum winds as mentioned below.

In order to obtain the radius and intensity of maximum wind, an axially symmetric cyclone model has been considered which is

$$V(r) = V_0 (r/r_0)^X \text{ for } (r \geq r_0 \text{ } X=0.5) \quad \dots (4a)$$

$$= V_0 (r/r_0)^X \text{ for } (r < r_0 \text{ } X=1.5) \quad \dots (4b)$$

where V is the wind speed at a distance r from the cyclone centre and V_0 and r_0 are the intensity and radius of maximum wind, respectively. The values of exponent X are empirical ones as found by earlier investigators. However, small variation may exist in different cyclone cases. Thus, the inference of exponent X has also been attempted from the satellite wind data.

The V_0 and r_0 values have been inferred from the wind data and the derived centre location. For this, the arbitrary values of V_0 , r_0 and X have been assumed in their respective wide range of values and an rms difference between calculated and observed winds has been obtained. The values of V_0 and r_0 corresponding to the minimum rms difference has been treated as the anticipated values. Estimation of V_0 and r_0 has been performed for all the cases of centre location shifted in all the direction by an amount equal to its standard deviation which was obtained while determining the centre. The final V_0 , r_0 and X have been obtained by averaging all the V_0 and r_0 data obtained for all the cases of centre location change. The standard deviations are treated as errors in estimation. The final V_0 , r_0 and X and the centre location have been used to obtain the new wind speed field at the satellite data locations.

Results and Discussion

Analyses of ERS-1 scatterometer derived ocean surface winds corresponding to three cyclones of November 19, 1992, (16 GMT); November 14, 1993 (18 GMT) and May 1, 1994, (4 GMT) have been presented here. The tracks of these cyclones have been depicted in Fig. 1 where '+' symbol indicates the position at which the cyclone parameters provided by India Meteorological Department⁸⁻¹⁰ (IMD) have been used for comparison with satellite derived values. The IMD supplied data as depicted

Table 1—Comparison of ERS-1 satellite inferred cyclone parameters with IMD supplied data

Date, time (GMT) IMD/ ERS-1	IMD supplied values ^{8,9,10}						ERS-1 satellite inferred values				
	Centre		Intensity				Centre location		Maximum wind		Exponent
	Location		Pressure		Max	T-	Long.	Lat.	Radius	Speed	
	Long	Lat	Val	Diff	wind	No.					
	(°E)	(°N)	(mb)	(mb)	(m/s)	No.	± SD (°E)	± SD (°N)	± SD (km)	±SD (m/s)	Mean ±SD
19 Nov 1992, 1800/ 1600	88.5	18.0	954	102	51.0	5.5	88.59± 0.11	17.74± 0.12	12±2	33.3±2.8	0.42±0.01
14 Nov 1993, 1800/ 1800	65.5	21.5	988	22	32.5	4.0	64.92± 0.11	22.53±0.18	17±7	36.0± 4.8	0.41± 0.02
1 May 1994, 0300/ 0400	90.0	14.0	986	18	30.0	3.5	90.58± 0.15	15.39± 0.13	17± 3	31.6± 2.6	0.40± 0.0

in Table 1 includes positions of storm centre, maximum sustained winds, central pressure and its difference from the surrounding area and the T-Numbers corresponding to these cyclones.

ERS-1 scatterometer radar backscatter data corresponding to these cyclones has been used to

derive the wind vector fields using the algorithms^{4,7}. The derived wind vector fields of these cyclones are depicted in Figs. 2-4, respectively. The directional ambiguities have been removed^{5,7} using the median

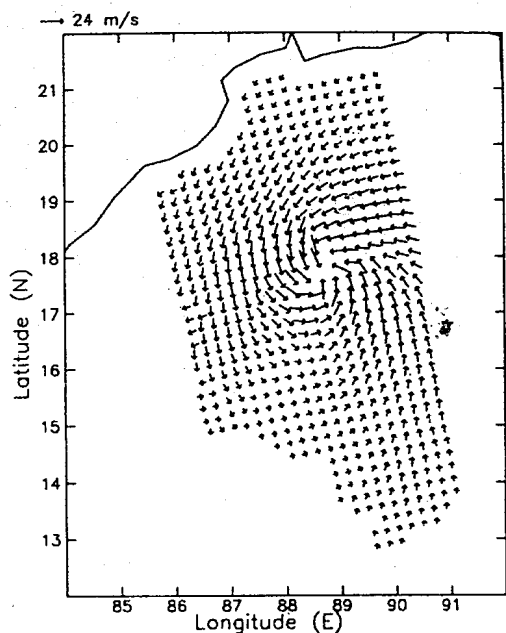


Fig. 2—ERS-1 scatterometer derived wind vector field for the cyclone on 19 November, 1992 (1600 GMT)

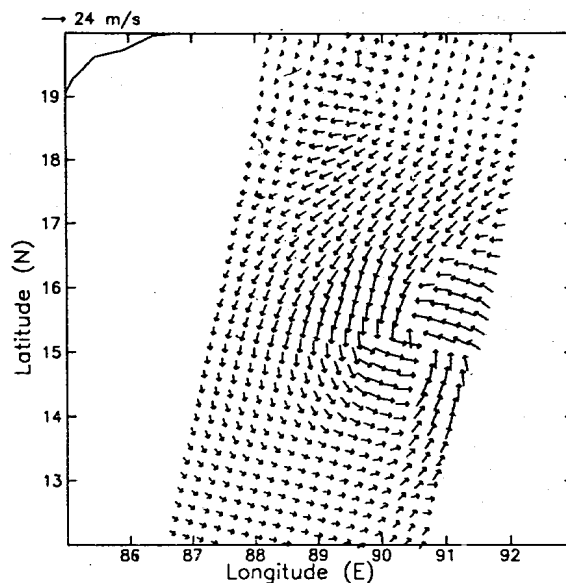


Fig. 4—ERS-1 scatterometer derived wind vector field for the cyclone on 1 May, 1994 (400 GMT)

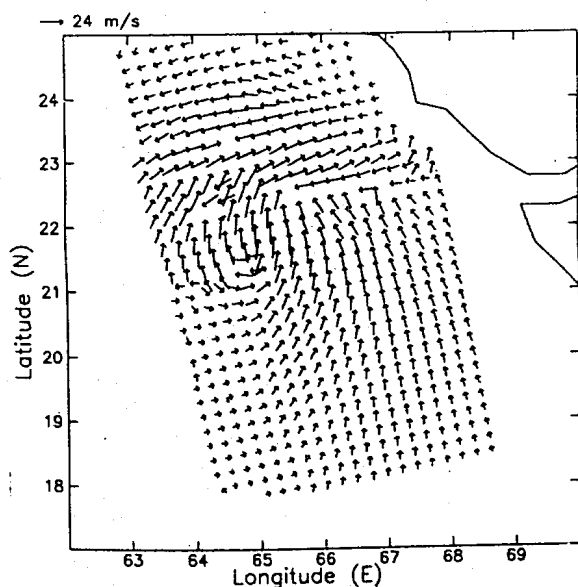


Fig. 3—ERS-1 scatterometer derived wind vector field for the cyclone on 14 November, 1993 (1800 GMT)

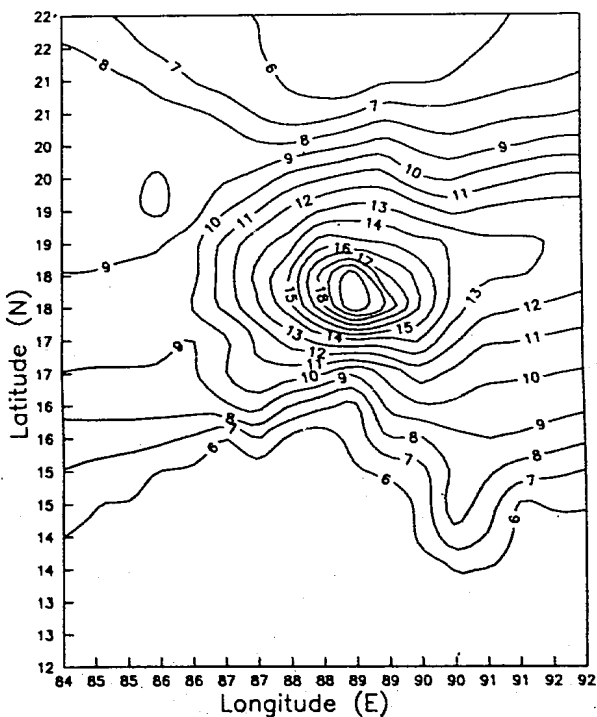


Fig. 5—Contours of wind speed of cyclone on 19 November, 1992

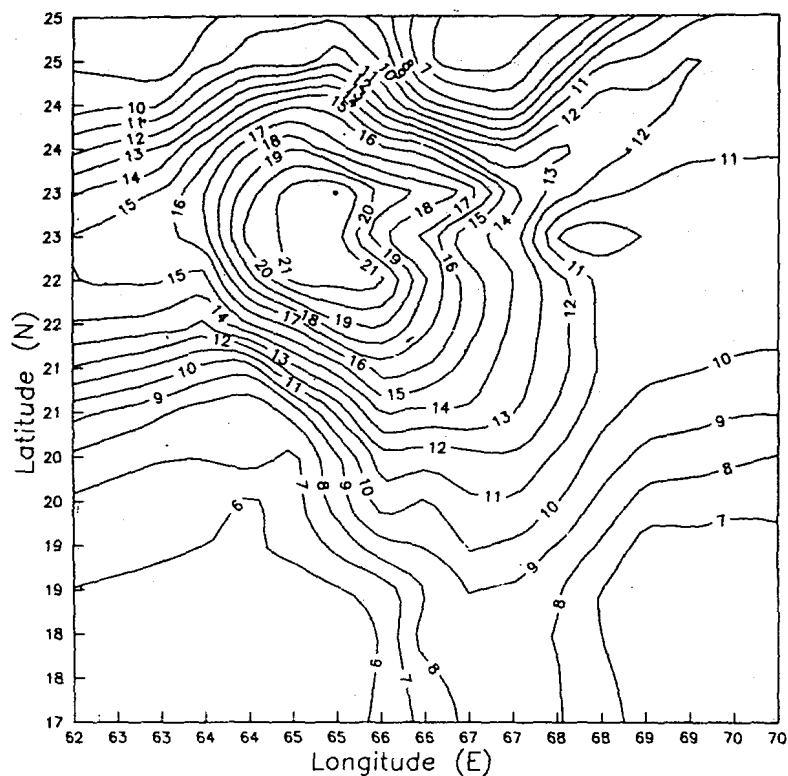


Fig. 6—Contours of wind speed of cyclone on 14 November, 1993

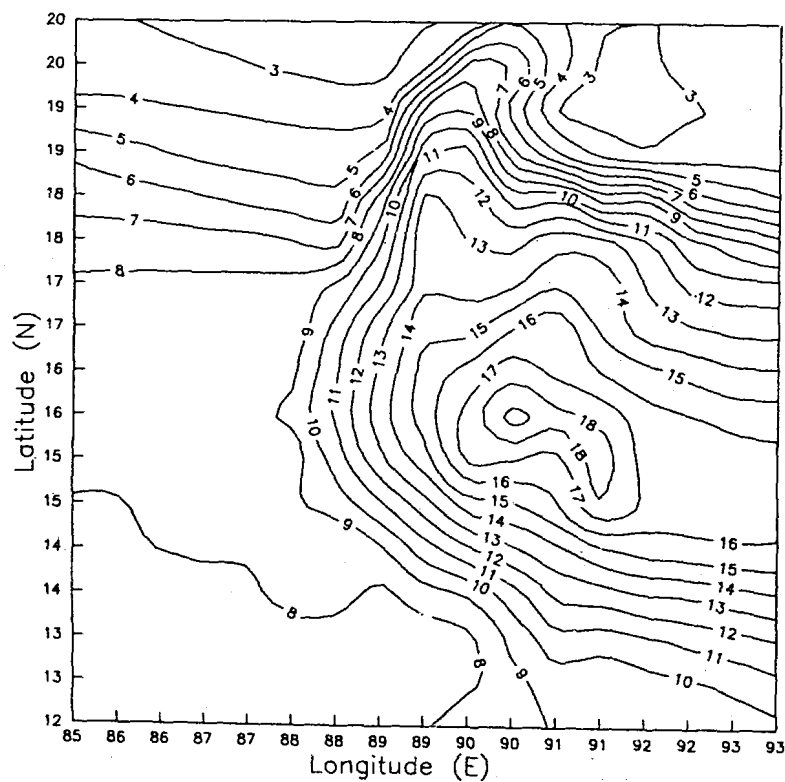


Fig. 7—Contours of wind speed of cyclone on 1 May, 1994

filter, however, a few remaining ambiguities have been corrected using the centre location and known cyclonic wind directional flow by selecting the nearest wind vector from the vector solutions available in the retrieval process.

The wind speeds derived from ERS-1 scatterometer data for each cyclone have been used to obtain the contours of wind speed (isotachs) which have been depicted in Figs.5-7. It is observed that the high wind speed isotachs are more concentric and closed in the central region compared to the low winds in periphery. Data points of the closed isotachs with wind speeds above 13 m/s have been used to estimate the centre locations. The radius and intensity of maximum wind have been obtained as mentioned above. The wind data within the radius of 2.5° from the estimated centre location have been considered. The derived cyclone parameters and their standard deviations using the ERS-1 satellite derived winds have also been presented in Table 1. The ERS-1 derived locations of centres have been found in good agreement within 1° radius with those issued by IMD which are based on satellite imagery. The inferred maximum wind speeds have also been found close to those of IMD values which are based on T-Numbers¹¹. However, in the case of 1992 cyclone, it is lower than the IMD value. One of the possible reasons could be the underestimation of high winds by scatterometer due to inadequacy of the empirical model at high wind speeds and the other due to atmospheric attenuation by high precipitation. Attenuation due to other factors like clouds and water vapour is negligible at C-band. In the case of 1993 cyclone, the maximum wind speed is slightly higher as the maximum wind speed in the data itself

is slightly higher compared to two other cases. Moreover, there is slightly higher difference in the centre location in 1993 case compared to others. The wind directional flow also indicates the mismatch between the maximum wind speed isotach and the central cyclonic wind directional flow. Efforts are continued to make use of vorticity for the purpose. Despite the limitation of satellite scatterometer observations, it has been found quite useful in providing this information. Higher resolution and better estimation of higher winds from scatterometer shall be more useful for the purpose.

References

- 1 Gohil B S, Basu S K, Pandey P C & Panda T C, *Int Seminar on mathematical modelling of atm and oceanic processes*, Berhampur University, Orissa, (1995), 34 (Abstract).
- 2 Gohil B S & Gautam N, in *Advances in tropical meteorology, monsoon variability and satellite applications and modelling*, edited by R N Keshavamurty and P C Joshi, (Tata McGraw-Hill, New Delhi), 1992, 314.
- 3 Rao B M, Kishtwal C M, Pal P K, & Narayanan M S, *Int J Rem Sen*, 2 (1995) 351.
- 4 Gohil B S & Pandey P C, *J Geophys Res*, 90 (1985) 7307.
- 5 Gohil B S, *Int J Rem Sen*, 17 (1992) 3311.
- 6 ESA, *CMOD4 Model Description*, ER-TN-ESA-GP-1120, 1.2, 25 March (1993).
- 7 Gohil B S & Pandey P C, *An atlas of surface wind vectors in the seas around India during August 1992 - July 1993 from ERS-1 scatterometer*, ISRO Report No. SP-76-95, (Indian Space Research Organisation, Bangalore), 1995.
- 8 IDWR, *Indian Daily Weather Report*, 19 November, (India Meteorological Department, New Delhi), 1992.
- 9 IMD, *Report on cyclonic disturbances over north Indian Ocean during 1993*, (India Meteorological Department, New Delhi), January 1994.
- 10 IMD, *Report on cyclonic disturbances over north Indian Ocean during 1994*, (India Meteorological Department, New Delhi), January 1995.
- 11 Dvorak V, *Mon Weath Rev*, 103 (1975) 420.