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DMSP-SSM/I retrieval of proper surface winds during monsoon depression

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सार - हिन्द महासागर की पवनों का आकलन करने के लिए डी.एम.एस.पी. - एस.एस.एम./आई. उपग्रह आँकड़ों के लिए हाल ही में विकसित किए गए विभिन्न भूमंडलीय सूक्ष्म तरंग एल्गोरिथ्मों का उपयोग किया गया है। इन एल्गोरिथ्मों से प्राप्त हुई समुद्र सतह गतियों की तुलना अरब सागर में स्थित मिनिकॉय द्वीप (निम्नतम ऊँचाई 2 m a.s.l.) से प्राप्त हुई इसी प्रकार की समुद्री पवनों की गतियों के साथ की गई है। इन एल्गोरिथ्मों की साँख्यिकी तुलना rms त्रुटि, सहसंबद्ध गुणांक एकांगी और मानक विचलन के रूप में की गई है। इस तुलना से पैटी एल्गोरिथ्म के सर्वोत्तम परिणामों का पता चला है। इस एल्गोरिथ्म के आधार पर एक विशिष्ट प्रकार की उल्लेखनीय विशेषता, जैसे कि खाड़ी के ऊपरी छोर पर मानसून द्रोणीं के दक्षिणाभिमुखी होने से तेज समुद्री पवनों (12-15ms^{-1}) के क्षेत्र का विस्तार होने और फिर आगे, निम्न और अवदाब (22-27 जुलाई 1992) में इनके विकसित होने के समय इन पवनों का रूख चारों ओर पाया गया है। डी.एम.एस.पी.-एस.एस.एम./आई. उपग्रह आँकड़ों के आधार पर सतह पवनों के संबंध में मानसून अवदाब के जीवन चक्र का मानीटरन मूल्यांकन, हिन्दमहासागरीय क्षेत्र में विभिन्न मौसम तंत्रों के और विवरण सामने लाने के लिए विभिन्न आवृत्तियों पर हमारे आई.आर.एस.-पी. 4 (ओशयन सैट - 1) उपग्रह आँकड़ों के उपयोग के लिए प्रोत्साहित करता है।

ABSTRACT. Recently developed various global microwave algorithms for DMSP-SSM/I satellite data are used for the estimation of surface winds over the Indian ocean. Sea surface wind speeds from these algorithms are compared with sea surface wind speeds reported by coincidental Minicoy island (lowest height 2 m a.s.l.) station over the Arabian sea. A statistical comparison of these algorithms is made in terms of rms error, correlation coefficient, bias and standard deviation. Algorithm of Petty showed best results in the comparison. On the basis of this algorithm a notable characteristic feature such as acquiring of large area of strong surface winds (12-15 ms^{-1}) to the south of dipping of monsoon trough in head Bay and then encircling of these winds during further development of low and depression (22-27 July 1992) is observed. This complete life cycle monitoring assessment of monsoon depression in respect of surface winds based on DMSP-SSM/I satellite data encourages to utilise our IRS-P4 (Oceansat-1) satellite data at different frequencies to emerge more details of various weather systems over the Indian region.

Key words – DMSP-SSM/I, Surface wind speed, IRS-P4 (Oceansat-1)

1. Introduction

The oceans are recognised as the most energetic, dynamic and undulating bodies of the earth-atmosphere system. Various random motions that occur in the ocean vary both spatially and temporally. Frictional forcing between atmospheric motion and ocean surface is related to the kinematics of the atmospheric boundary and the resulting transfer of energy emerges as wind stress. Generation of waves, surface currents and ocean circulations are mainly caused by active driving force created by strong surface winds over the oceans. These winds also exercise a vital role in many atmospheric processes such as air-sea interaction, upwelling and biogeochemical transport over different parts of the ocean. They are also useful for detecting storm surges over the ocean near the coast. These storm surges are recognised as dangerous over the coastal areas.

It is well established fact that over the oceanic Indian region during monsoon period, sea surface winds exhibit an important role in realising the reversal of winds, inter-hemispheric moisture transport, cross equatorial flow *etc*. This information is necessary for highlighting low-level flow, input to NWP (Numerical Weather Prediction) model and also for the verification of model forecast. It is well known fact that the oceanic regions surrounding India are almost data sparse in three directions except north. Hence, in order to get reliable surface winds over the vast oceanic regions one has to depend upon non-conventional observations from satellites. It is not possible to get a large number of conventional observations from

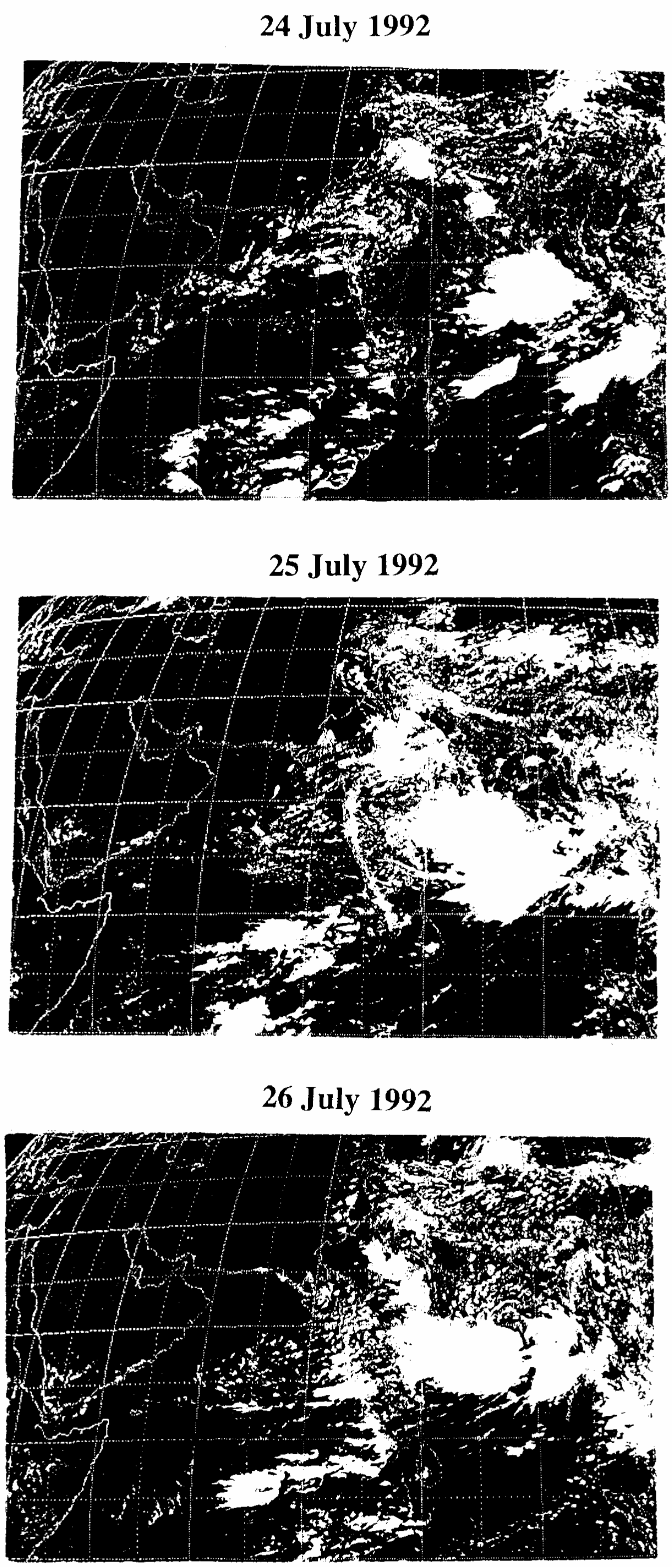

Fig. 1. INSAT-1D visible imagery at 0600 UTC on 24, 25 and 26 July 1992

TABLE 1

Meteorological Indian island stations with their heights above sea level

Station	Location		Station height (m a.s.l.)
	Lat .(°N)	Long. (°E)	
Amini Devi	11.07	72.44	04
Minicoy	08.18	73.09	02
Sandheads	20.51	88.15	10
Long Island	12.25	92.56	25
Port Blair	11.40	92.43	79
Hut Bay	10.35	92.33	05
Car Nicobar	09.10	92.50	10
Nancowry	07.59	93.32	26

ships, buoys and island stations surrounding India. Keeping in view of these limitations, some researchers (Mahajan and Nagar, 1987; Bhatia and Krishnan, 1998) have tried to estimate surface winds from low-level cloud motion vectors from GOES(IO) and INSAT satellites over the Indian oceanic regions.

It is well recognised fact that cloud motion winds from geostationary meteorological satellite can be derived only when specific types of cloud tracers are available over that region. Similarly, there is restriction of derivation of water vapour winds below 500 hPa level (Velden *et al*. 1997). Hence, direct derivation of sea-surface winds from satellite is everytime desirable. Microwave sensors onboard various satellites are archiving sea-surface winds on routine basis even under cloudy condition during more than two decades. DMSP-SSM/I (Defence Meteorological Satellite Program - Special Sensor Microwave/Imager) satellite of USA derives sea surface winds over the global oceanic regions from June-1987 onwards (Hollinger *et al*., 1987; Wentz, 1992). It is seen from the earlier research works (Chiu *et al*., 1993; Hong and Lim, 1994; Basu *et al*., 1995; Ramesh Kumar *et al*., 1999) that SSM/I data was mostly used for studying the large-scale aspects of monsoon circulation. The data have not been exploited so far, in detail for studying monsoon systems over the Indian region. In this study, globally used wind speed algorithms are examined with conventional surface winds speed reported by Minicoy island station. The algorithm which highlighted best relationship is used for the derivation of surface winds during the complete life cycle of monsoon depression over the Indian region. Characteristic features of surface wind speed associated with different stages of monsoon depression are brought out.

2. Data

DMSP-SSM/I brightness temperature measurements at four frequencies *viz*. 19.35, 22.235, 37 and 85.5 GHz are used in vertical and horizontal polarisation for the derivation of geophysical parameters over the Indian seas. Making use of recently developed algorithms by global community, wind speeds were generated at the location of Minicoy island station for match-ups that were coincidental with SSM/I overpasses. This island station has got the lowest height (2 m a.s.l.) among all other meteorological island stations over the Indian seas and hence it is considered as ideal for comparison of its surface wind speed with SSM/I wind speed. Microwave brightness temperature measurements from DMSP-SSM/I are used for monitoring areal coverage of monsoon systems, particularly depressions over the Indian seas during 1991-95. Daily weather summaries obtained from India Meteorological Department are used for selecting the synoptic situation over the Indian region for the complete life cycle of monsoon depressions. INSAT satellite imagery are used to locate and mark the advancement of monsoon depressions which were formed over the Indian region. Two cases of monsoon depressions which were formed over the open ocean *i.e*., over the Bay of Bengal are considered in this study. Visible satellite imagery obtained from INSAT-1D is depicted in Fig. 1 for a case of monsoon depression that formed during July 1992.

3. Methodology

3.1. *In situ Minicoy wind speed measurements*

The quality of surface wind speed measurements by the Minicoy island station over the Arabian sea is considered to be the amongst the highest of all oceanic surface wind speed measurements by other Indian island stations. This is due to the fact that height of Minicoy island station is lowest (2m a.s.l.) than all other meteorological island stations and it can be considered closest wind to the surface winds over the Indian seas (Table 1).

The exposure of the anemometer is crucial in wind speed measurements at sea. In case of ship, its super structure may cause flow distortion effects that will severely bias wind speed readings. The anemometer of Minicoy station is fixed in such a way that it does not have any disturbing effect on wind speed measurements. Hence, anemometer situation on Minicoy island station is thought to be appropriate for comparison with sea surface wind speeds derived by DMSP-SSM/I.

Geographically fixed position of Minicoy island station in the Arabian sea has two advantages in a wind speed comparison. First, the data will show reduced biases due to errors in the removal of ships speed from the measurement of 'apparent' wind. The biases in wind speed derivations of 'true' wind reduce the utility of wind speed measurements from voluntary sources (Kent *et al*., 1991). Second, there is absence of 'fair-weather' biases in the data. It is observed

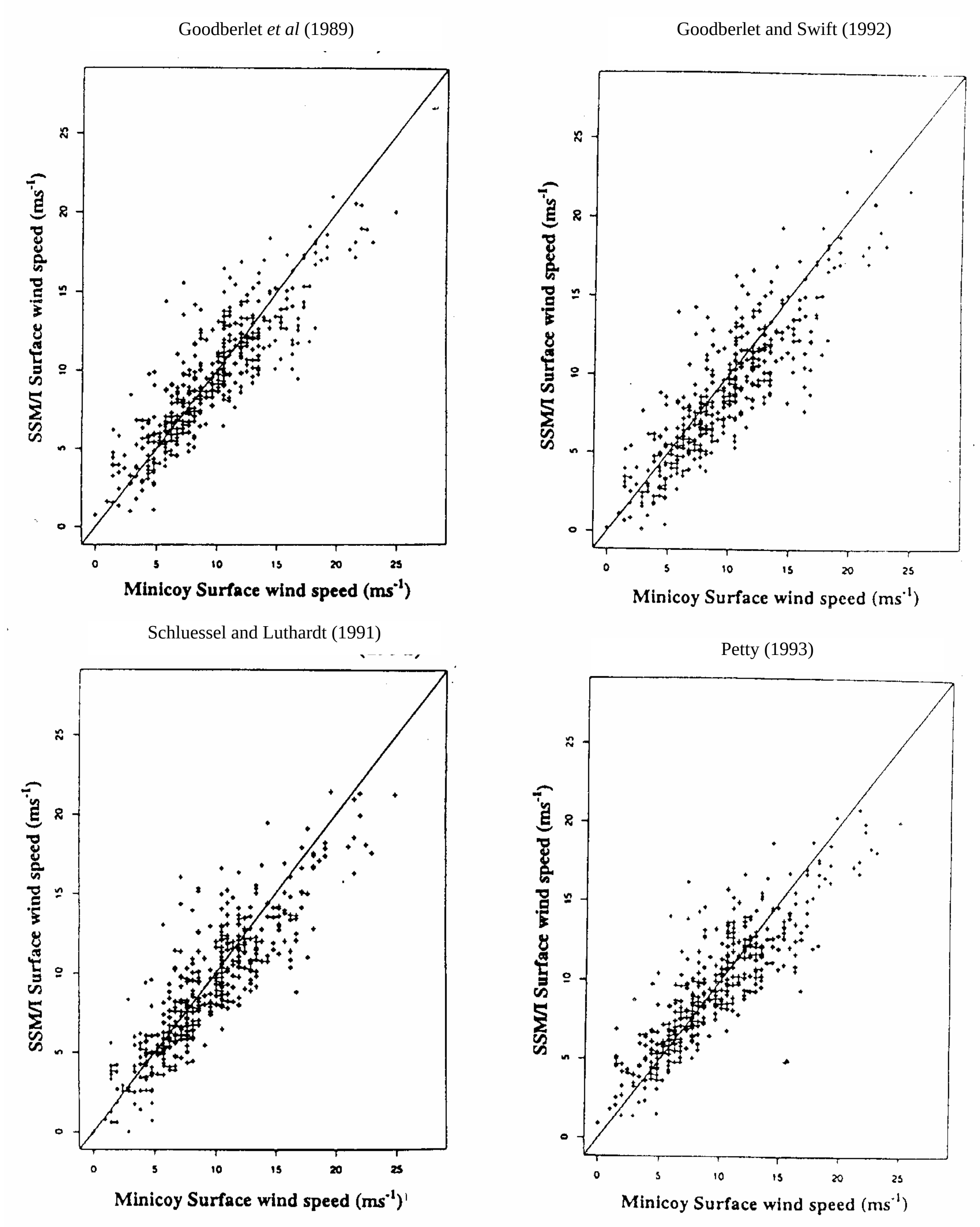

Fig. 2. Scatter diagrams of surface wind speed from Minicoy *versus* SSM/I surface wind speed for four algorithms

that most ships avoid high speed areas due to the threat to the safety of the ship.

One kind of error in the comparison of retrieved surface winds by DMSP-SSM/I with *in situ* wind speeds is the definition of an average wind speed, *i.e.*, conventional data are averaged temporally and SSM/I data are averaged spatially. Mesoscale and microscale winds have varying spatial and temporal coverages and their influences even on conventional data may be stronger than suspected because

TABLE 2

Comparison of various algorithms for surface wind speed

Algorithm	rms error (ms^{-1})	Correlation coefficient (*r*)	Bias (ms^{-1})	Standard deviation (ms^{-1})
Goodberlet *et al*.	2.23	0.86	0.07	3.99
Schluessel and Luthardt	2.33	0.86	0.31	4.32
Goodberlet and Swift	2.78	0.87	0.83	4.36
Petty	2.21	0.88	0.03	3.52

N = 296 (Number of Minicoy surface wind speed match-ups that were coincidental with SSM/I overpasses)

averaging times for conventional measurements are relatively short (Pierson, 1983). The average conventional time of meteorological measurements is too low to develop 'perfect' surface-satellite correlations. The multispectral wind speed algorithms are produced on surface radiation from satellite footprints. The SSM/I views changes in sea-surface emissivity which are then averaged to estimate surface winds.

3.2. *Sea surface winds from SSM/I measurements*

There are various algorithms developed by number of researchers in the recent years for the estimation of geophysical parameters from SSM/I measurements. Validation of algorithms against *in situ* data has previously been difficult due to lack of good quality SSM/I and reliable conventional data. Meanwhile intercomparison of algorithms is rare for attempting to validate published algorithms or physical retrieval models. Many workers and researchers proceeded with the validation of their own algorithms and ignored the work of others. Many evaluations of competitive methods proceeded *via* the intercomparison of published error statistics. While such approaches may not be unreasonable firm conclusions are difficult to draw from them as the quality of validation data sets vary from study to study. Similarly, the strictures of algorithmic performance may vary considerably causing biases in the performance of certain retrievals. For example, the presence of moderate levels of atmospheric water and subsequent attenuation of radiation upwelling from the surface greatly alters the performance of wind speed algorithms. It is well known that different algorithms are applicable in different parts of the globe. Hence, in order to assess the performance of these algorithms, an intercomparison was made by examining their scientific aspects and also by comparing their estimates with surface conventional measurements reported by Minicoy island station. Recently developed surface wind speed algorithms examined in this study are of (*i*) Goodberlet *et al*. (1989), (*ii*) Schluessel and Luthardt (1991), (*iii*) Goodberlet and Swift (1992) and (*iv*) Petty (1993). A brief synopsis of these statistical algorithms is as follows :

Goodberlet *et al*. (1989)

$$W1 = 147.90 + (1.0969*19v) - (0.4555*22v) - (1.7600*37v) + (0.7860*37h)$$

Schluessel and Luthardt (1991)

$$W2 = 149.0 + (0.88*19v) - 0.4887* (19v19h) - (0.4642*22v) - (0.7131*37v) - 0.4668* (37v\text{-}37h)$$

Goodberlet and Swift (1992)

$$W3 = [(W1 - (18.56*a)] / (1.0\text{-}a)$$
$$a = (37.7/37v\text{-}37h)^4$$

Petty (1993)

$$W4 = W1 - 2.130 + 0.2198*WV - 0.004008*WV^2$$

$$WV = 174.1 + 0.4638 \ln (300.0 - 19v) - 61.76 \ln (300.0 - 22v) + 19.58 \ln (300.0 + 37h)$$

Where *W*1, *W*2, *W*3 and *W*4 are retrieved surface wind speeds for above four algorithms. 19*v*, 22*v* and 37*v* are atmospheric brightness temperatures in vertical polarisation at 19.35, 22.235 and 37 GHz frequencies. 19*h* and 37*h* are atmospheric brightness temperatures in horizontal polarisation at 19 and 37 GHz frequencies. *WV* is the integrated water vapour at the observation location computed from microwave readings, a is a constant based on vertical and horizontal polarisation of 37 GHz frequency.

3.3. *Validation of SSM/I wind speed retrievals*

In contrast to land surfaces, the ocean surface has relatively low microwave emissivity, together with a small dynamic range. This help the investigation of oceanographic and atmospheric retrievals by providing cold backgrounds for higher emissivities from atmospheric water. But it prohibits the detection of changes in sea surface emissivity caused by wind speed. Passive microwave remote sensing of the sea surface therefore presents not only clear opportunities but also some challenges in satellite remote sensing now-a-days (Abbott and Chelton, 1991).

There are several wind speed algorithms based on SSM/I measurements. The recent ones are shown in

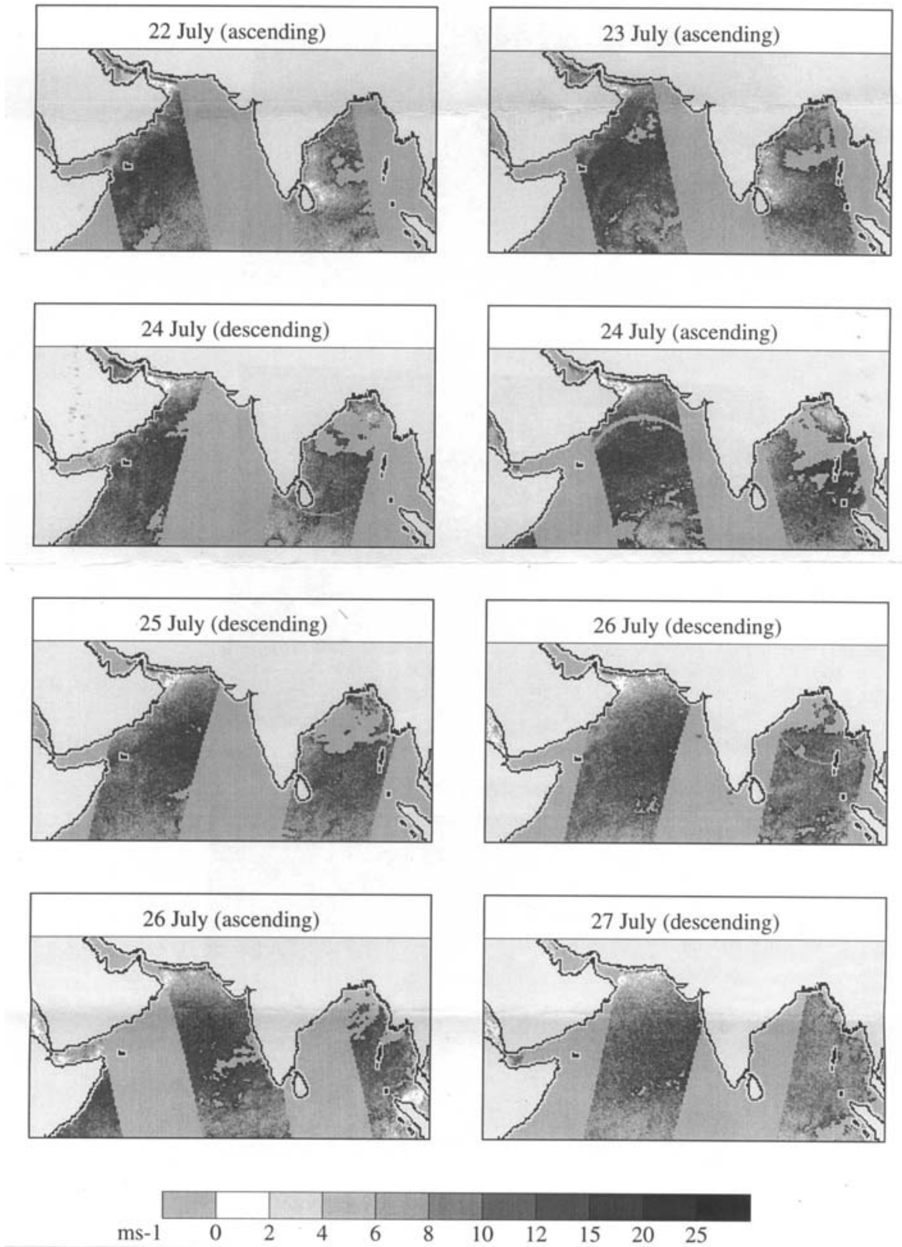

Fig. 3. SSM/I derived sea surface wind speeds distribution during 22-27 July 1992

section 3.2. Kilham *et al*. (1995) have carried out a detailed study for the validation of different algorithms. In their study they assembled a series of high quality validation data sets formed from full year's *in situ* observations at OWS LIMA, a station manned by professional meteorological observers from the UK Meteorological Office. They extracted coincidental SSM/I data on an orbit-orbit basis in the Bristol University, Centre for remote sensing. They considered six recent algorithms for comparison. Of these, the four above performed well with very small root mean square errors and biases.

Considering these four algorithms (section 3.2) an attempt is made in this study to select the best one to give better picture of surface wind speed over the Indian region. Plots of surface wind speed of Minicoy *versus* SSM/I surface wind speed for above four algorithms are shown in

Fig. 2. Error statistics of these algorithms in terms of rms error, correlation coefficient, bias and standard deviation are highlighted in Table 2. From the scatter diagrams and error statistics it is clear that best match for SSM/I wind speed is obtained from the algorithm of Petty (1993).

4. Results and discussion

Daily surface wind speed distribution obtained from the algorithms of Petty (1993) for the complete life cycle of monsoon depression that formed over the Bay of Bengal is shown in Fig. 3. Some of the important features observed in this study are as follows :

(*i*) Area of strong surface winds (12-15 ms^{-1}) is found to increase gradually around 12°N over the Bay of Bengal during 22-24 July 1992.

(*ii*) Maximum area of strong surface winds (12-15 ms^{-1}) is obtained over the south and adjoining the central Bay of Bengal when the monsoon trough dipped into the east central Bay. Wind speed also reached its maximum value (15-20 ms^{-1}) on the same day (24 July 1992) over the Central Bay.

(*iii*) The strong surface winds are found to encircle the low pressure area and depression over north Bay on 25 and 26 July 1992.

(*iv*) Intensity of surface wind speed decreased from 12-15 ms^{-1} to 6-10 ms^{-1} on 27 July 1992 over central and head Bay.

Strong surface winds (12-15 ms^{-1}) are found to be dominant over southwest, central and southeast Arabian sea stretching from 10° N to 15° N for almost all the days of the study. During 22 to 26 July 1992 a low level jet was persisting over the Arabian sea. As demonstrated by earlier investigators (Mahajan and Deshpande, 1986, Mahajan and Nagar, 1987 and Mahajan *et al*. 1992), there exist a strong relationship between the wind speed at low level jet and the wind speed at the surface over the Indian seas. In the present study, strong surface wind speed (12-15 ms^{-1}) observed in large areas over the Arabian sea seems to be due to the effect of low level jet. These features agree well with the work of earlier investigators.

Building up of the large area of strong winds over the central and south Bay prior to the formation of low pressure system, followed by gradual increase of wind speed over the head Bay after the formation and the intensification of the low pressure system are the important features observed during 22-26 July 1992. These characteristic features observed from SSM/I data also agree well with the study of earlier researchers associated with monsoon depressions (Rao, 1976; Sikka, 1977).

5. Conclusion

In this study SSM/I data retrieved from DMSP satellite is used to observe the characteristic features of surface winds during complete life cycle of monsoon depression that formed over the Bay of Bengal during 22-27 July 1992. Recent algorithms developed by various international researchers have been applied to SSM/I data and the algorithm which is found most accurate is used for estimating surface winds during different stages of monsoon depression over the Indian region. Acquiring a large area of strong surface winds to the south of dipping of monsoon trough in head Bay and then encircling of these winds during the development of low and depression are the important characteristic features observed in this study. These reliable results from DMSP-SSM/I suggest that making use of our IRS-P4 satellite data more details will emerge on Indian scenario for different weather systems.

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References

Abbott, M. R. and Chelton, D.B., 1991, "Advances in passive remote sensing of the ocean", *Rev. of Geop*., **29**, 571-589.

Basu, S., Gairola, R. M., Kishthawal, C. M. and Pandey, P. C., 1995, "Empirical orthogonal function-analysis of humidity profiles over the Indian ocean and an assessment of their retrievability using satellite microwave radiometery", *J.Geophys.Res*., **100**, D11 23009-23017.

Bhatia, R.C. and Sai Krishnan K. C., 1998, "Estimation of large scale wind fields over oceanic areas around India using INSAT derived cloud motion vectors in conjunction with ship/buoy data and scatterometer data", Proc. Fourth International Winds Workshop, Eumetsat Saanenmoser, Switzerland, October 20-23, 171-176.

Chiu, L. S., Chang A.T.C. and Janowiak, J., 1993, "Comparison of monthly rainrates derived from GPI and SSM/I using probability distribution function", *J. Appl. Met*., **32**, 323-334.

Goodberlet, M. A., Swift, C. T. and Wilkerson, J. C., 1989, "Remote sensing of the ocean surface winds with Special Sensor Microwave Imager", *J.Geophys. Res*., **94**, 14547-14555.

Goodberlet, M. A. and Swift, C. T., 1992, "Improved retrievals from the DMSP wind speed algorithm under adverse conditions", IEEE Transaction of Geoscience and Remote Sensing, **30**, 1076-1077.

Hollinger, J. P., Lo, R., Poe, G. A., Savage, R. and Pierce, A.P., 1987, "Special Sensor Microwave Imager, Users guide", Washington D.C., Naval Research Lab.

Hong, Y. and Lim, H.S., 1994, "Evidence of low frequency waves of tropical rainfall inferred from microwave brightness temperature", *Mon.Wea.Rev*., **112**, 1364-1370.

Kent, E. C., Truscott, B. S., Taylor, P. K. and Hopkins, J. S., 1991, "The accuracy of ship's meteorological observations, Results of the VSOP-NA WMO Report 26, WMO/TD-No.445, p86.

Kilham, D. A., Wilmshurst, A. D. and Barret, E. C., 1995, "SSM/I atmospheric parameter validation with OWS LIMA, Final Report Part II to the Defence Research Agency (Portland), Contract No. 2034/118, Remote Sensing Unit, University of Bristol, UK.

Mahajan, P. N. and Deshpande, V. R. 1986, "Satellite derived cloud motion vectors for monitoring lower and upper tropospheric monsoon circulation during summer MONEX 1979, *Vayu Mandal*, **16**, 6-9.

Mahajan, P. N. and Nagar, S. G., 1987, "Comparison of low level satellite winds and surface winds observed by research ships during summer Monex-1979", *Mausam*, **38**, 445-448.

Mahajan, P. N., Talwalkar, D. R., Nair, S. and Rajamani, S., 1992, "Construction of vertical wind profile from satellite derived winds for objective analysis of the wind field", *Advance in Atmos. Sci*., **9**, 237-246.

Pierson, W. J., 1983, "The measurements of synoptic scale over the ocean", *J.Geophys. Res*., **118**, 1683-1708.

Petty, G. W., 1993, "A comparison of SSM/I algorithms for estimation of surface wind", Proc. Shared Processing Network DMSP-SSM/I algorithm Symposium 8-10 June 1993, Monterey, CA.

Ramesh Kumar, M. R., Shenoi, S. S. C. and Schluessel, P., 1999, "On the role of cross equatorial flow on summer monsoon rainfall over India using NCEP/NCAR re-analysis data", *Met.Atmos.Phys*., **70**, 201-213.

Rao, Y. P., 1976, "Southwest Monsoon", India Meteorological Department Monograph, Synoptic Meteorology, No. 1/1976 Delhi, p367.

Sikka, D. R., 1977, "Some aspects of life history, structure and movement of monsoon depression", *Pure and App. Geophys. Basel*, **115**, (516), 1501-1529.

Schluesel, P. and Luthardt, H., 1991, "Surface wind speed over north sea from Special Sensor Microwave/Imager observations", *J.Geophys.Res*., **96**, 4845-4853.

Veldon, C. S., Hayden, C. M., Nieman, S. J., Menzel, W. P., Wanzong, S. and Goerss, J.S., 1997, "Upper tropospheric winds derived from geostationary satellite water vapour observations", *Bull. American Met. Soc*., **78**, 173-195.

Wentz, F., 1992, "Measurement of oceanic wind vector using satellite microwave radiometer, IEEE Transaction of Geoscience and Remote Sensing", **30**, 960-972.