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SSM/I derived sea surface winds *vis-à-vis* NWP model initial wind analysis and forecast

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ABSTRACT
The Special Sensor Microwave Imagers (SSM/I) aboard the DMSP satellites provides the sea surface wind speeds over the global oceans with high resolution and good coverage. A study is carried out to compare the SSM/I derived sea surface winds with those of numerical weather prediction (NWP) model initial wind analysis and 24 hour model forecast over the oceanic regions surrounding India. The model adopted is the operational global spectral model. Various aspects like the winds over Arabian Sea and Bay of Bengal, embedded circulation patterns, the cross equatorial flow etc. are examined during the onset phase of Indian summer monsoon season-1996. This study reveals that, in general, the model analysis and forecast winds differ from the SSM/I winds by about 4 mps. However; in some pockets the difference is 6-8 mps.

INTRODUCTION

The sea surface wind data of high quality and resolution are required for many applications like understanding of large scale air-sea interaction processes, input to atmospheric and oceanic models, computation of various fluxes and delineating certain low level circulations on the daily weather charts. However, most of the oceanic areas of the monsoon region are data sparse as the conventional observations provided by the ships, buoys and some island stations are very scanty. Apart from the model specifications, the accuracy of the NWP model forecast depends upon the quality of the initial input data. Therefore, the initial model analysis over the data sparse areas are based on the first guess or background information, which in turn, affects the accuracy of the final forecast. In view of above points, world-wide efforts are being made during last two decades to retrieve the sea surface winds directly from the satellites through active and passive microwave remote sensing techniques. Advantage of microwaves remote sensing is that the sea surface can be observed even under cloudy conditions.

Active remote sensing by radar backscatter makes it possible to estimate sea surface wind vectors from the scatterometers aboard the polar orbiting satellites like European remote sensing satellites (ERS-1 and ERS-2) or QuikSCAT. The ERS data are available from 1991 while the QuikSCAT was launched by National aeronautics and space administration (NASA) in 1999. Over the Indian sub-continent, the ERS sea surface winds have been used in some applications e.g. for improving the analysis of synoptic scale weather systems (Bhatia & Sai Krishnan 1998), their potential use in forecasting the onset of summer monsoon (Rao et al. 1998), preparation of an atlas of the sea surface winds around India (Gohil & Pande 1995) etc. Although, the ERS scatterometer provides very useful data, its daily coverage of global oceans is limited due to its smaller swath of about 500 km.

On the other hand, the passive remote sensing techniques of retrieving the geophysical parameters is based on sea surface response to microwave emissivity in different channels of the satellite sensor. In this category, Indian remote sensing satellite (IRS-P4) launched in the recent past has the capability to retrieve sea surface wind speeds along with other geophysical parameters by its sensor multifrequency scanning microwave radiometer (MSMR). Different organisations in India are involved in validation and application of these data for various studies (Ali 2000).

One of the longest series of several atmospheric and oceanic parameters is provided by the SSM/I aboard the polar orbiting satellites of defence meteorology satellites program (DMSP) of USA. First SSM/I was flown on *F8* DMSP satellite in 1987. The SSM/I provides microwave brightness temperatures at 19.35 (V/H), 21.235 (V), 37.0 (V/H) and 85.5 (V/H) GHz channels, where V or H denotes vertical or horizontal polarisation respectively. Its swath is about 1400 km. Other details of the SSM/I are available in a paper by Hollinger et al. (1987). There are at least two DMSP satellites operating simultaneously from 1990. Therefore, they provide daily data of the global oceans with good coverage. Utility of the SSM/I derived integrated water vapour during the passage of monsoon depression over the Bay of Bengal is demonstrated by Mahajan (2001).

The SSM/I derived sea surface winds have high quality, good coverage and the resolution. These data on monthly scales for the period 1988-90 have been used by Ramesh Kumar et al. (1999) to assess the role of cross equatorial flow during summer monsoon period in comparison with the re-analysis data produced at National Centre for Environmental Prediction (NCEP). The present study is carried out to understand what is the extent to which the SSM/I derived sea surface winds compare with the NWP model analysis and forecast on day-to-day basis over different oceanic regions of the Indian summer monsoon area.

DATA

An algorithm by Wentz (1994) retrieves the sea surface wind speeds using 22 and 37 GHz channels brightness temperatures of the SSM/I. The data from 19 GHz channel are employed for quality control. The wind speeds produced over the global oceans by this algorithm have an effective accuracy of 2 mps over the range of 3-25 mps. Atlas et al. (1996) developed a scheme based on variational analysis method (VAM) to assign directions to the SSM/I derived wind speeds by combining them with all the conventional data from the ships, buoys and the 10-m analysis of European centre for medium range weather forecasting (ECMWF) model. Several quality control tests, appropriate weights, dynamical and smoothness constraints have been incorporated in VAM while producing the global data set of sea surface wind vectors. The validation of these data against both analysed ship and buoy observations and independent tropical buoy data shows high accuracy for both the SSM/I speeds and directions. Data impact studies indicate its potential to improve surface wind analyses, weather forecasts and ocean model simulations etc. Comparison with climatological fields and other analysis indicate reasonableness of the data. Overall annual average of the SSM/I winds clearly shows the typical manifestation of the atmospheric general circulation over the global scale. The details of the data, VAM, validation studies, accuracy and the applications are described by Atlas et al. (1996). These daily wind vectors categorised as Level 2.5 with the resolution of 75 km at 00 and 06 hours UTC are used in this study during the period June 1-8, 1996. The data corresponds to DMSP *F12* and *F13* satellites, which were operational during the period of study.

NWP MODEL

NWP model adopted in this work is the version of NCEP global spectral model installed at Space Applications Centre (SAC), Ahmedabad. This model is operational at the National centre for medium range weather forecasting (NCMRWF), New Delhi from June 1, 1994. The horizontal resolution of model is 80 waves represented in triangular truncation with 18 vertical levels (T80 L18). The resolution roughly corresponds to about. 1.4° latitude / longitude grid. The spectral statistical interpolation (SSI) scheme is used for the data assimilation. The details of the model and its capability in representing/predicting various characteristic features of monsoon and the cyclogenesis cases is well documented in many studies. (E.g. Singh 1996, Gupta et al. 1998). The SSM/I data are not incorporated in the initial model analysis considered here.

The domain of study is Indian summer monsoon region: Long. 40° E to 110° E and Lat. 25° S to 25° N. The model initial analysis data was provided by the NCMRWF.

METHODOLOGY

The SSM/I winds, model analysis and forecast winds at 1000 hPa level are plotted on the maps for qualitative and quantitative comparisons. The differences viz. (SSM/I – model) for the initial wind analysis and its 24 hour forecast are also depicted to bring out the locations and the magnitude of wind speed differences. For these charts, the positive (negative) sign indicates that the SSM/I derived winds are stronger (weaker) than the model analysis or forecast winds. During the period of study, the SSM/I wind data at 00 UTC are available almost on each day over the region except on 4-th and 6-th. For these two days, the SSM/I winds of 6 UTC are considered. The maps/charts are plotted using the GrADS software designed by COLA/IGES, University of Maryland.

Statistical comparison of the SSM/I and the model winds is also carried out computing the statistical parameters.

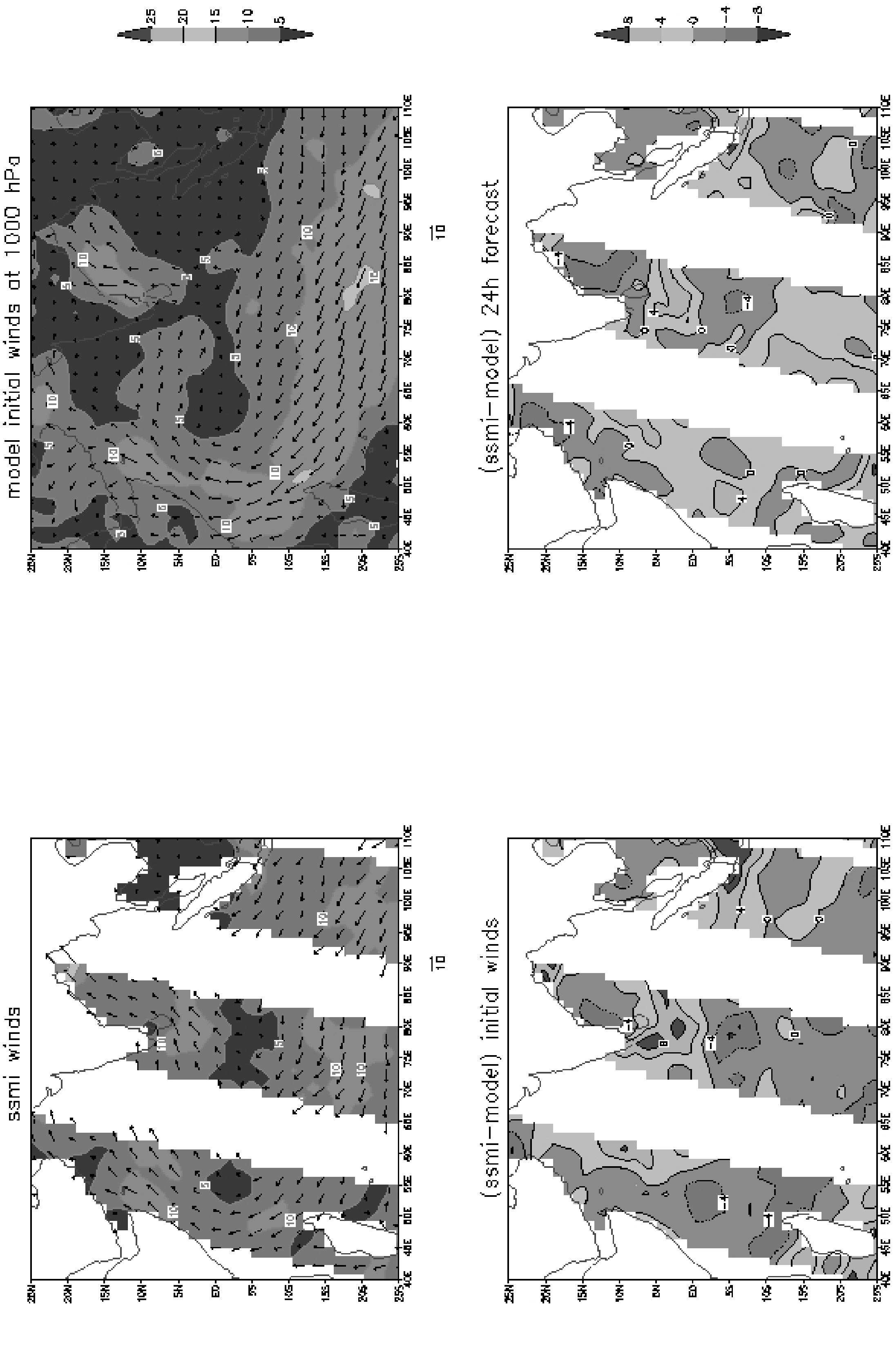

Figure 1. Comparison of SSMI and NWP model sea surface winds
Date : 3 June 1996 at oo UTC

DISCUSSION

a) Qualitative and quantitative comparison

The maps as mentioned earlier are prepared for all the days of the study. However, only the charts for 3 June 1996 are shown in Fig. 1 for brevity. This is the day of monsoon onset over Kerala coast as per India Meteorological Department. The salient features of qualitative and quantitative comparisons are given below. Although certain features are not seen in Fig.1 but they are noticed on majority of the cases where the data are available.

Wind speeds

The low level wind flow from the southern hemisphere to the northern hemisphere typical of the Indian summer monsoon with the strong winds of about 13-16 mps along the Somalia coast are seen. As we approach the equator from the southern hemisphere (SH), the winds which are of the order of 10-12 mps become weak i.e. of the order of 2-8 mps and after crossing the equator, they are strengthened again in the northern hemisphere (NH). These features are noticed in all three data sets viz. the SSM/I, model analysis and model forecast winds.

Near Somalia coast, both the SSM/I and model analysis winds have almost the same magnitude with the difference about 0-2 mps. Over the equator, between Longitude 45° E to 55° E, the model analysis winds are stronger by 2-4 mps. On the other hand, between 55° E to 85° E, in general, the SSM/I winds are stronger than the model winds by about 2-8 mps. This feature is broadly noticed on 2, 3, 4 and 7 June 1996. It indicates that in general, the cross equatorial flow is stronger in the SSM/I data over this region as compared to the NWP model analysis. The cross equatorial flow over this region may be stronger as per the SSM/I data. This positive difference may also be due to overestimation of winds by the SSM/I or underestimation of winds by the model analysis owing to lack of observations.

Over the Bay of Bengal, model analysis and forecast winds are stronger than the SSM/I winds by about 4-6 mps over the east coast of India. On the contrary, over the Arabian Sea near the west coast, the case is reverse.

So far as model forecast is concerned, in general, the SSM/I wind speeds differ from 24-hour model forecast by about 4 mps. However, in the certain pockets the difference is 8-10 mps on some days.

Circulation features

Although, the SSM/I sea surface wind data are available only for the certain strips corresponding to the track of the DMSP satellite, one or two cyclonic circulations are noticed in this data set over near-equatorial region located east of the Longitude 50° E. The circulations are better depicted on 1, 2, 3, 5 and 7 June. On 7 June there are two circulation patterns observed in the SSM/I wind field - one is at 62° E and the other at 94° E. Some times these circulations are also noticed in INSAT imageries as convective cloud cells. On certain occasions, these features are also observed in the model analysis and 24 hour forecasts as weak circulations occupying broader area. These circulations may be associated with the inter tropical convergence zone (ITCZ) or the activity of the southern hemispheric equatorial trough (SHET) observed as one of the important characteristics of the tropics. Some times, the high wind differences between the SSM/I and the model winds noticed over near-equatorial region in certain pockets are seen to be located in the vicinity of such cyclonic circulations.

Table 1: Comparison of the SSM/I winds with the model initial wind analysis (winds in mps)

Date	N	ssbar	anbar	SDss	SDan	RMSD	CC
1-6-96	0347	5.80	4.51	2.98	2.68	2.81	0.61
2-6-96	1116	6.97	7.39	3.09	4.31	3.18	0.68
3-6-96	1089	7.57	7.84	2.89	3.82	3.61	0.45
4-6-96	0332	6.14	8.36	2.57	3.84	4.30	0.40
5-6-96	0416	7.42	6.62	2.74	2.75	3.39	0.28
6-6-96	0180	6.99	9.67	2.06	2.95	3.80	0.46
7-6-96	0932	7.30	7.05	3.11	3.76	3.16	0.59

Note: N is the number of wind observations, ssbar and anbar indicate mean of the SSMI and model analysis wind speeds, SDss and SDan are the Standard deviations of SSM/I and the model analysis winds respectively, RMSD denote the RMS deviations and CC is the correlation coefficient between the series.

(b) Statistical comparison

For statistical comparison of the data sets, the series of the available SSM/I and corresponding model analysis wind speeds are constructed for each day and the statistical parameters viz. the number of SSM/I wind observations and corresponding model winds

(N), mean wind speeds, standard deviation (SD), RMS deviations (RMSD) and the correlation coefficients (CCs) between these two series are worked out. The same procedure is adopted for model forecast winds. To assess whether the statistical relationships between the SSM/I derived sea surface winds and the model analysis winds are similar in both the hemispheres, separate series of the wind speeds for NH and SH are constructed and above parameters are computed. The results of the comparative study are discussed below.

Table 2: Comparison of the SSM/I and model forecast winds for 24 hours

Date	N	ssbar **(mps)**	fcbar **(mps)**	SDss **(mps)**	SDfc **(mps)**	RMSD **(mps)**	CC
2-6-96	1116	6.97	6.12	3.09	2.77	2.98	0.53
3-6-96	1089	7.57	7.18	2.89	3.10	2.97	0.52
4-6-96	0332	6.14	6.51	2.57	2.81	3.03	0.37
5-6-96	0416	7.42	7.70	2.74	2.86	3.55	0.20
6-6-96	0180	6.99	8.34	2.06	2.28	2.80	0.37
7-6-96	0932	7.30	6.47	3.11	2.96	3.12	0.51
8-6-96	1166	7.04	6.41	3.23	3.38	2.75	0.67

Note : fc stands for the model forecast winds. Other symbols have the same meanings as per Table 1

i) Comparison with the model analysis

Comparative Statistics for the SSM/I and model analysis winds is provided in Table 1. As seen from the Table, the number of SSM/I wind observations over the region during 1-7 June varies from 180 to 1116. The mean SSM/I wind speeds are in the range 5.8 to 7.6 mps, whereas the model analysis winds range from 4.5 to 9.7 mps indicating more day-to-day variation in the model analysis mean wind speeds as compared to the SSM/I winds. The SDs are between 2.1 to 3.1 mps for the SSM/I winds whereas they are between 2.7 to 4.3 mps for model analysis winds. The RMSDs between two series vary from 2.8 to 4.3 mps. The CCs range from 0.28 to 0.68 during the period of study. They are all significant at 1 % level showing that both the wind sets are well correlated.

ii) Comparison with the model forecast

Comparative statistics for the SSM/I and 24 hour model forecast wind speeds is presented in Table 2. The variation in the means of the SSM/I winds during 2 to 8 June is very small i.e. from 6.1 to 7.6 mps and for the forecast the range is from 6.1 to 8.3 mps. The SDs are between 2.1 to 3.2 mps for the SSM/I winds. For the model forecast winds, SDs are of the same magnitudes. The RMSDs range from 2.8 to 3.6. The CCs are in the range from 0.20 to 0.67 which are significant at 1 % level. However, they are less in the magnitude as compared to the analysis except on 3 June. (Table 1).

It is also noticed that during the time of the onset of the monsoon, CCs between the SSM/I winds and model initial analysis fall on 3, 4 and 5 and increase on 6 and 7 June (Table 1). Similarly, on 4-th, 5-th and the 6-th the CCs fall with the magnitude less than 0.40 and again increase to 0.51 and 0.67 on 7-th and 8-th respectively for the model forecast winds(Table 2). This could be due to the fact that the rapid changes in the winds at the time of onset might not be represented in the model analysis due to sparsity of the data and the same is reflected in 24 hour forecast.

iii) Comparison for NH and SH separately

The comparison of the SSM/I and the model analysis winds for NH and SH separately shows following features.

It is noticed that mean wind speeds of the model analysis are in the range 2.8 to 10.0 mps whereas for the SSM/I winds the range is from 3.1 to 8.7. (Table is not shown). On certain occasions, the means of the SSM/I and the initial winds are very close to each other e.g. in the SH on 7-th they are 8.71 and 8.68 mps respectively. The RMSDs are of the order of 3 mps with the magnitudes more than 4 mps on 4-th and 6-th. The CCs between the series are quite significant in both the hemispheres for 3 days out of 7 viz. on 2,3 and 7 June. But, on 1, 4, 5 and 6 June, the correlations are quite significant in one hemisphere with the CCs : 0.54, 0.66, 0.38 and 0.77 while the relationship is very poor with the corresponding CCs : 0.11, 0.03, 0.14 and 0.04 in the other. This shows that in one hemisphere two wind sets are well correlated while in the other they are poorly correlated on some days. The results indicate that the difference between the SSM/I winds and the model analysis is not uniform in both the hemispheres. If the SSM/I wind estimates are within their specified accuracy then the variation of CCs from one hemisphere to the other on certain occasions could be attributed to lack of observational data over these regions for the model analysis or failure of some such observations to model quality control procedures.

CONCLUSIONS

The comparative study between the SSM/I derived sea surface winds and the NWP model analysis and 24 hour forecast is carried out during 1-8 June 1996. This study shows following features:

During the period of onset phase of Indian summer monsoon 1996, the low level wind flow from southern hemisphere to north Indian ocean, Arabian sea and Bay of Bengal are depicted in all three data sets viz. the SSM/I, the model analysis and the forecast. Near Somalia coast, the SSM/I and the model winds are of the same order i.e. 13-16 mps. Over the equatorial region between Long. 45°E to 55° E, the model analysis winds are stronger as compared to SSM/I winds. The SSM/I winds show stronger cross equatorial flow as compared to the model analysis between Long. 55° E to 85° E. In general, there is the difference of 4 mps between the SSM/I winds and the model analysis as well as its 24 hour forecast. In some pockets, the difference is around 6-8 mps. Some cyclonic circulation are noticed over the equatorial belt in the SSM/I winds. Occasionally, they are also seen in the model analysis and the forecast, but they are weak and occupy larger area. The SSM/I winds are stronger near the west coast of India whereas near the east coast they are weaker as compared to the model analysis.

Statistical comparison shows that both the wind sets do not differ significantly so far as the means and standard deviations are concerned. For the model analysis, the means range from 2.1 to 3.1 mps whereas for the SSM/I winds the range is from 2.6 to 4.3. The RMS deviations are in the range 2.8 to 4.3 for the model analysis. The correlation coefficients vary from 0.28 to 0.68 for different dates and are significant at 1 % level. However, for each hemisphere considered separately, they are quite significant in one hemisphere while in the other the SSM/I and the NWP model winds are poorly correlated for some days.

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