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SURFACE WINDS IN THE ARABIAN SEA FROM MSMR – AN EMPIRICAL APPROACH

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ABSTRACT

Multi-channel Scanning Microwave Radiometer (MSMR) onboard IRS P4 (Oceansat I) measured Brightness Temperature data of the different bands are found sensitive to the surface and the overlying atmosphere to different degrees. A judicious combination of multi-channel data can provide such oceanic/atmospheric parameters as surface wind speed, sea surface temperature, water vapour in the marine atmosphere, etc. This paper highlights results obtained in relation to surface wind speed. Co-location and concurrence of several ocean data buoys in the Arabian Sea with MSMR observations allowed empirical construction of D-matrix coefficients for surface wind speed. With both MSMR and the Arabian Sea buoys functioning for the period of one and a half year (June, 1999 to December, 2000) without interruptions provided a large database. All channels are found to exhibit moderate sensitivity to surface wind speed. MSMR data in the immediate vicinity (within 150 km) of the buoy locations and within a time window of one hour were used. A multi-channel linear equation for surface wind speed was subsequently derived. The equation was subjected to tests with independent data set for the period January - June 2001 over the Arabian Sea and found to be moderately accurate. The empirical equation is expected to be useful for regional applications over the Arabian Sea and over regions closer to west coasts, which might have been flagged out in the operational geophysical data stream. An interesting subset of data revealed the wind signatures of the May 2001 cyclone in the Arabian Sea.

Introduction

Surface wind speed over oceans is one of the prime products of space-borne microwave radiometers, operating below 40 GHz. The satellite sensors used for this purpose are TMI (TRMM), SSMI (DMSP) and MSMR (Oceansat I). A variety of algorithms developed for this purpose are based

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on theoretical, statistical, empirical or combinations of these approaches. Each approach has its own advantages and limitations. Empirical approach based on statistically large *in-situ* database and concurrent brightness temperature of the microwave radiometer makes this approach ideal for regional applications. The present paper contains the results of an empirical algorithm developed with MSMR brightness temperatures and buoy wind speed data in the Arabian Sea for the period June 1999 – December 2000, and subsequent comparison of the results against data of the period January – June 2001.

IRS P4 MSMR

IRS P4 (also called Oceansat-I), launched by Indian launch vehicle PSLV on May 26, 1999 carrying onboard the Multi-channel Scanning Microwave Radiometer (MSMR) along with the Ocean Colour Monitor (OCM), is the first Indian satellite, dedicated for observations and predictions of Ocean State and Marine atmosphere (Sarkar, 2000). More than two years of extremely useful observations have been already collected. MSMR is basically a four frequency (6.6, 10.6, 18 and 21 GHz), dual polarisation (V & H) passive microwave radiometer observing the earth and its atmosphere from an altitude of 720 km. An overview of ground calibration methodology and expected performance of the onboard sensors is given in Misra *et al.* (2002). The orbital characteristics of the IRS-P4 satellite result in near global coverage, with a repeat cycle of two days. However, 80% of the entire globe is covered on any single day by the swath of 1360 km.

The parameters obtainable from the observations of this instrument are sea surface wind speed, columnar water vapour, sea surface temperature and cloud liquid water content. Large scale features of SST, Wind speed, water vapour and Cloud liquid water derived from MSMR have been studied in detail by Sharma *et al.* (2002). Efforts using theoretical radiative transfer simulation and statistical regression approach to retrieve the geophysical parameters were made which resulted in operational MSMR data products (Gohil *et al.*, 2000). The contemporary similar satellite instruments are the SSM/I (on DMSP satellite) and the TMI (on TRMM satellite). The 6 GHz frequency (known for its sensitivity to surface parameters) available on MSMR, has not been flown in any satellite since the SMMR on Nimbus-7 in 1987. Recently launched AMSR-E in May 2002 with six-frequency radiometer including 6GHz.

Buoy Measurements

The National Institute of Ocean Technology (NIOT) under Department of Ocean Development has installed several deep ocean buoys under National Data Buoy Program (NDBP), in the seas around India. The buoys are providing oceanic as well as the surface atmospheric parameters in the marine environment (Premkumar *et al.*, 2000). Wind speed measurements of two of the buoys (DS1 (lat/lon, 15.5/69.3) and DS2 (lat/lon, 10.7/72.5)), deployed in the Arabian Sea are available at every three hours. The winds, measured at the height of 3m above the sea surface, are averaged for the acquisition period of 10 minutes (600 samples) at every three hours. Thus eight observations in digital form are obtained everyday. Similarly, the vector mean of the 600 samples would give the wind directions. The stated accuracy of Wind speed sensor is ±1.5% FS with resolution of 0.07 m/s. For the present study, however, only the speed measurements were used.

Data used in the study

Brightness Temperature data of all the MSMR channels in different combinations were used in the study. A space–time window with dimensions of 150 × 150 km^2 and ± 1 hour was used to create the co-located and concurrent data set. The *in-situ* data consisted of 3-hourly wind speed measurements of the Arabian Sea buoys (DS 1 & DS 2), set up by the NIOT. The buoy measures the wind speed at the height of 3 m from the surface of the sea. These measurements were converted to ‘equivalent winds at 10 m height by making use of the standard logarithmic wind profile (Liu *et al.*, 1979, Rao and Premkumar, 1998), which is as follows,

$$U_{10} = U_z * (10/z)^{1/7} \tag{1}$$

Where U_z is the mean wind speed (m/s) at height z, and U_{10} is the wind speed (m/s) at 10 m height. The equivalent wind speed at 10 m can thus be obtained by multiplying the wind speed at 3 m by a factor of 1.125.

D-Matrix approach

The basic assumption in the construction of a D-matrix algorithm (Conner and Chang, 2000, Goodberlet *et al.*, 1989) is that the desired geophysical parameter (in our case, the surface wind speed), may be expressed as a linear combination of measured brightness temperatures (T_B), taking the general form expressed in equation (2),

$$U = C_0 + \Sigma C_i T_B (f, p) \tag{2}$$

where, f stands for frequency and p, for polarisation, and U is wind speed.

The bracketed T_B variables in equation (2) are the brightness temperatures associated with the channels chosen for the algorithm and the subscripted C's are the coefficients, which were determined using standard multiple linear regression analysis, fitting match up buoy wind speeds onto the MSMR brightness temperature channels. Flagged out data were rejected in the construction of the satellite-buoy match-up data set.

Results

For creating the database in the study area, two Arabian Sea buoys (DS 1 and DS 2) were selected. MSMR brightness temperature measurements within a spatial window of radius 1.5° around the buoy locations were averaged for creating the database. The temporal window for this purpose was set at ±1 hour. During the eighteen months period, covering June 1999 - December 2000, all co-located and concurrent data points were found. The multi-regression analysis (Draper and Smith, 1981) with the brightness temperature values of the eight MSMR channels yielded several equations for the surface wind speed (at 10 m height) with various channel combinations. Equation (3), involving only 6H and 10H turned out to be one of the best linear combination

$$U_{10} = C_0 + C_1 T_B(6H) + C_2 T_B(10H) \tag{3}$$

where,

U_{10} – Wind speed at 10 m height above the sea surface, and

$T_B(fp)$ – Brightness temperature at frequency 'f' and polarization 'p'.

Number of co-located points used in generation of regression is 488 and the standard deviation is 2.5 m/s. The coefficients are $C_0 = -44.7193$ m.s^{-1}, $C_1 = 0.3483$ m.s^{-1}K^{-1}, $C_2 = 0.2019$ m.s^{-1}K^{-1}. The wind speed at 10 m height were obtained by enhancing the 3m height buoy measured wind speed values by the multiplicative factor of 1.125. This follows from the assumption of logarithmic wind profiles, shown to be consistent with the flux profiles obtained through the theory of renewal of surface fluid and field measurements (Liu *et al.*, 1979).

Exercises carried out with 6, 10 and 18 GHz channels also yielded of correlation coefficient value close to the value obtained for equation (3). Since, 6 and 10 GHz channels have atmospheric transmittance better than eighty per cent, are expected to have better surface sensing capability. Hence, for the present study, only the 6 GHz - 10 GHz combinations was studied. Equation (3) was applied on the independent data set for the six months period (January-June. 2001). The derived wind speed in the proximity of the DS1 and DS2 buoys were compared with the respective buoy measurements within ± 1 hour. The comparison results are illustrated through figures 1 and 2. Figure 1 shows the scatter between wind speeds retrieved by our approach with those measured by the buoys within the specified space-time window. The coefficient of correlation between MSMR retrieved wind speeds by our empirical approach and buoy measured wind speeds is found to be 0.64 and the rms deviation is ~ 2.2 m/s. Figure 2 shows the time series of wind speed at the Arabian Sea buoy location (DS1) of both, measurements by buoy (represented by dash line with dark circle) and values retrieved by equation (3) (represented by continuous line with dark triangle). A case study of application of the empirical algorithm on a May 2001 Arabian Sea cyclonic storm shows that the wind fields reproduced by our empirical algorithm (Fig. 3) agree well with the wind estimates reported by the India Meteorological Department (IMD, 2002). It has also clearly reproduced cyclonic isotach with winds greater 24 m/s at the centre. The wind speed values lower than 2 m/s were not considered in our study, because of inapplicability of the height transformation factor of 1.125 for lower winds (Liu *et al.*, 1996), and inherent sensitivity limitation of the brightness temperatures to the roughness caused by very low winds.

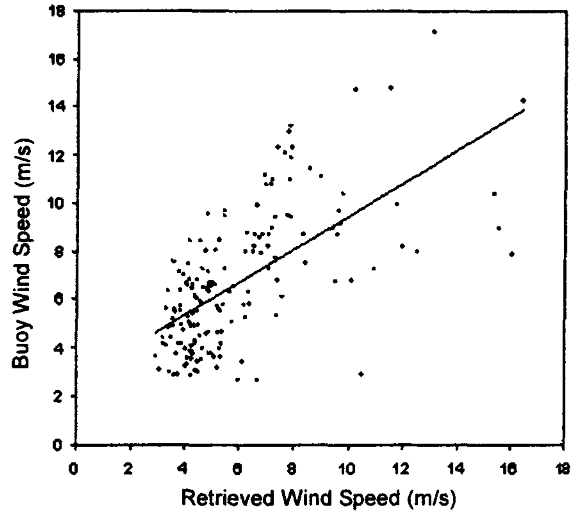

Fig. 1. Scatter plot of buoy-measured & MSMR-retrieved Wind speed.

Conclusion

The empirically developed algorithm in this work can be used for retrieval of wind speed in the Arabian sea with an expected accuracy of around 2.2 m/s. The empirically derived wind speed values (being dependent on brightness temperature data) allow construction of wind fields closer to the coast.

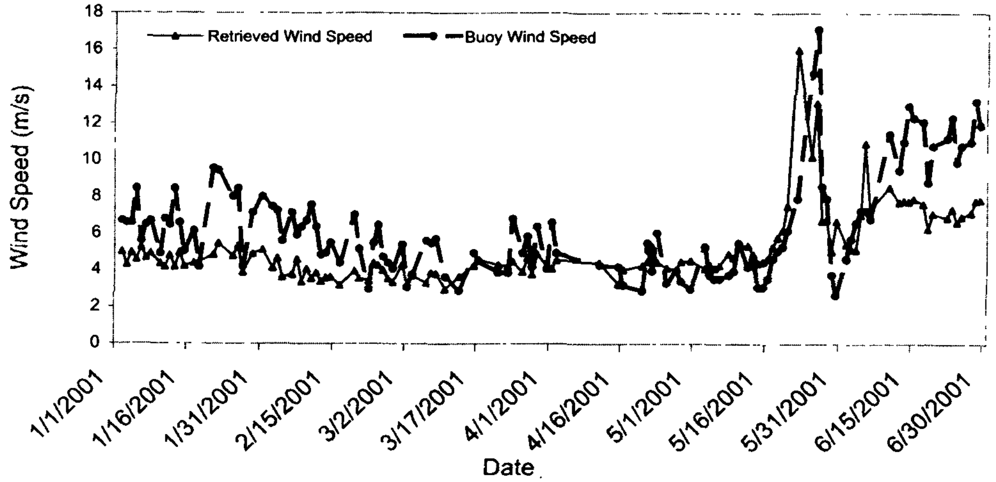

Fig. 2. Time series of Wind Speed at the Arabian Sea buoy (DS1) location.

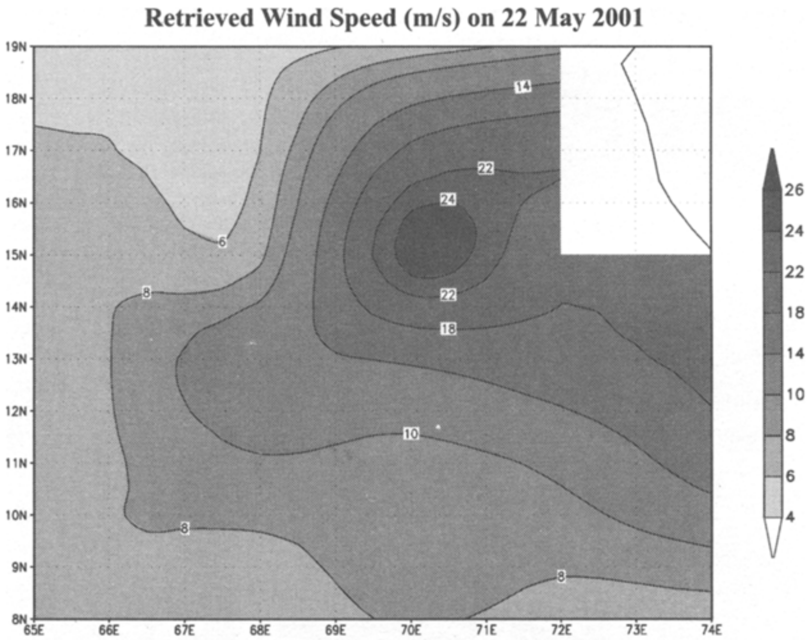
Retrieved Wind Speed (m/s) on 22 May 2001

Fig. 3. Contour plot of surface wind speed (retrieved) on 22 May 2001.

Empirical coefficients can be tuned to high or moderate wind speed regimes depending on the applications. The figures 2 and 3 show that the wind speed values thus retrieved are reproducing the high wind conditions (including the ones encountered during May, 2001 cyclone) fairly well.

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