Indian Journal of Radio & Space Physics
Vol. 31, August 2002, pp. 210-215

Validation of IRS P4 MSMR data over the central Bay of Bengal during July-August 1999

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Received 16 July 2001; revised 18 December 2001; accepted 3 April 2002

Validations of satellite-derived sea surface temperature (SST) and wind speed (WS) were carried out with sea-truth measurements obtained from moored data buoy and ship during July-August 1999. The SST sensed by multi-frequency scanning microwave radiometer (MSMR) showed significant departures from sea-truth measurements. The difference in SST (sea-truth – MSMR) was negative and large during daytime and vice versa during nighttime. Sea-truth measurements of wind speed indicated that they were always lower (2-5 ms $^{-1}$) than the MSMR winds. The derived correction factors reduced the biases of satellite data.

1 Introduction

The IRS P4 is the first Indian remote sensing satellite launched to collect the ocean environmental data over the seas. It is a sun-synchronous polar orbiting satellite launched in May 1999 with orbital height of 720 km and period of 99.31 min. The ground repetivity of this satellite is 2 days. The payloads consist of a multi-frequency scanning microwave radiometer (MSMR) and ocean colour monitor (OCM). The MSMR onboard IRS P4 satellite gives valuable information on atmospheric and oceanic parameters over the remote Indian seas[1]. Different parameters sensed by the satellite are estimated based on different principles. For instance, wind speed (WS) and sea surface temperature (SST) are estimated from the emissivity of the sea surface. The principle behind the estimation of water vapour and cloud liquid water is based on absorption in the spectral band. The technical specifications of MSMR, parameters sensed and their accuracies are given in Tables 1 and 2.

The SST and WS are the two important parameters required for ocean environmental predictions, navigation, deployment of underwater systems, etc. The *in situ* measurements of these parameters at sea are normally carried out by research ships, moored/drift buoys and ships of opportunity. These platforms are not adequate to cover the spatial and temporal variability of parameters fully. Because of this, large data gaps exist especially for Indian seas. The recently launched IRS P4 is extremely useful to provide adequate spatial coverage of data over the Indian seas.

However, satellite-derived ocean environmental parameters need to be validated with sea-truth observations to ascertain their reliability/accuracy. Bay of Bengal Monsoon Experiment (BOBMEX-99) conducted during July-August 1999 onboard INS Sagardhwani provided useful inputs for IRS P4 evaluation. In fact, sea-truth data collection for IRS P4 validation was taken care of, while planning this experiment. The data buoys deployed in the central Bay of Bengal by the National Institute of Ocean Technology (NIOT) have also provided valuable time series (60 days @ 3 hourly sampling interval) data on SST and WS for the validation purpose. The instruments used onboard INS Sagardhwani and ORV Sagarkanya were compared to check the reliability of various sensors[2] before the BOBMEX programme. This exercise proved that the measurements made on these platforms are in good agreement. Subsequently, data collected during this programme are checked for quality before analysis. Rigorous validations of satellite data products are required before their use in research activities or operational models. In this paper, MSMR

Table 1—MSMR specifications

Frequency (GHz) :	66	10.65	18	21
Polarization :	Vertical and horizontal			
Antenna diameter :	862×800 mm			
Spatial resolution (km):	120	75	45	40
Swath (km) :	1360			
Environmental parameters:	Integrated water vapour, cloud liquid water, WS and SST			

Table 2—MSMR parameters

Parameter	Channels	Rationale	Accuracy	Resolution (km×km)	Range
WS	10.65 with 6.6, 18 and 21 GHz (H and V)	Emissivity	2.50 m/s	150×150	0-24 m/s
SST	6.6 with 10.65, 18 and 21 GHz (H and V)	Emissivity	1.2 K	150×150	273-303 K
Water vapour	21 with 18 GHz (H and V)	Absorption	0.3 g cm^{-2}	50×50	0.2-7.5 g cm^{-2}
Cloud liquid water content	21 with 18 GHz (H and V)	Absorption	0.01 g cm^{-2}	50×50	0-80 $mg.cm^{-2}$

data products are evaluated with *in situ* data collected by INS Sagardhwani and NIOT buoy.

2 Data

During the BOBMEX-99 programme, research vessel INS Sagardhwani, remained stationary at 13°N and 87°E (Fig. 1) for making time-series observations of surface marine meteorological parameters for a period of about 30 days (17 July-22 Aug. 1999) under different weather conditions.

In addition to this, surface marine meteorological observations collected from deep-sea data buoy of NIOT in the vicinity of the ship (approximately 3 km away) are also used (Fig. 1). Concurrent, remotely sensed data from IRS P4 were also utilized in this study. The *in situ* data collected by the ship and the buoy are the major data sets used for the validation of IRS P4 data. Details of data collected, instruments used and their accuracies are given in Tables 3 and 4.

The spatial and temporal variations of the parameters should be considered while comparing satellite-derived parameters with *in situ* observations. The MSMR SST and WS used in the study have a spatial resolution of 150×150 km. Hence, a search radius of 1.5° centred around *in situ* measurements has been fixed. The data that fall under this category have been considered for the validation exercise. In the present analysis all the observations falling within an interval of ±1h with respect to the *in situ* measurements are used for validation.

All the data sets were subjected to detailed quality checks to remove the outliers. As a first step, range check was performed. Secondly, the data exceeding three times the standard deviation from the mean were removed. These checks removed 12% of the data from the satellite data set.

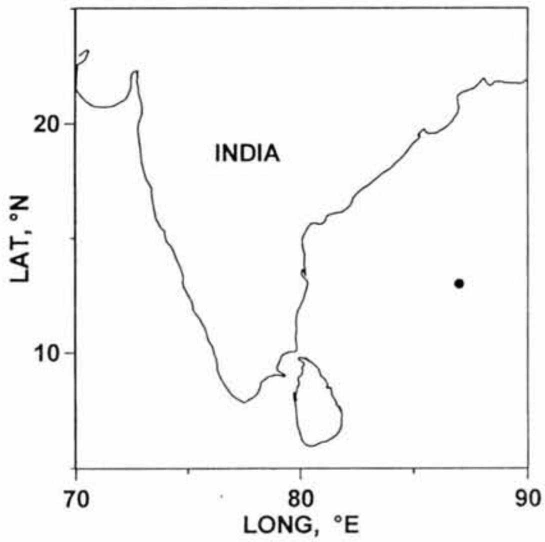

Fig. 1 — Location of INS Sagardhwani and NIOT data buoy indicated by a dot

3 Results and discussion

The sea-truth SST during this period was around 29°C (Fig. 2). The SST exhibits oscillations of diurnal periodicity. However, magnitudes of diurnal oscillations were small due to increased turbulence and vertical mixing associated with strong monsoon winds. The SST measured using infrared thermometer (skin temperature) was high (0.2°-0.3°C) and exhibited large amplitude (0.4°C) compared to data obtained from Mini CTD and NIOT buoy. These high values are attributed to large air-sea exchange at the skin/surface compared to one-meter level. Even though satellite and infrared thermometer measure the skin temperature of the sea, departures are observed. This stresses the importance of a proper validation and correction of satellite data before they are put to application.

Table 3—Details of data used for validation

Source	Period	Parameters
INS Sagardhwani	17 July-22 Aug. 1999	WS and SST
NIOT data buoy	19 July-22 Aug. 1999	WS and SST

Table 4—Instruments and their accuracies

Parameter	Instrument	Accuracy	Range
WS	Anemometer	0.25 m/s	0-30 m/s
SST	Bucket thermometer	0.2°C	5°-35 °C
	Mini-CTD	0.05°C	−2°-40°C

The number of MSMR data in this period was less, since the satellite repetivity is of two days, whereas *in situ* measurements were made at every 3 h. Satellite values of SST significantly departed from sea-truth (NIOT buoy) by as high as 2.5°C with root mean square (RMS) error of 1.25°C (Table 5). The comparison with ship data also indicted similar trend but with higher RMS errors (1.63°C).

The weak diurnal scale variability of SST during summer monsoon over the tropical Indian seas is an established fact and the same feature is evident in the data set too (Fig. 2). One of the important results observed was that the difference between satellite and *in situ* SST values showed large diurnal variations. During daytime, satellite-derived SST was more than the sea-truth [by 2.5-3°C (Fig. 3)]. However, the trend reversed during nighttime and the difference became negative (less than 2°C). The plausible reasons for the departure may be due to the well-known Faraday rotation taking place in the ionosphere. When an electromagnetic wave interacts with the charged particle and earth's magnetic field, its plane of polarization is rotated. The so-called Faraday rotation is proportional to the total electron content (TEC) of the iono-

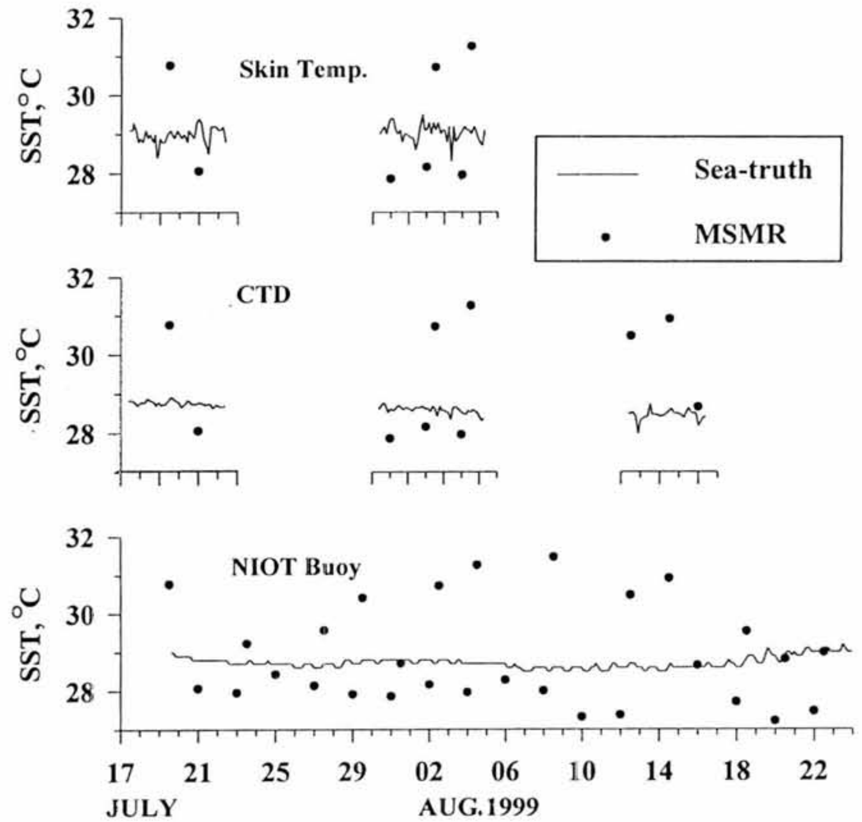

Fig. 2—Comparison of SST collected onboard INS Sagardhwani and NIOT buoy with MSMR

sphere[3] and inversely proportional to the square of the frequency. It is observed that, during daytime, TEC is higher as compared to that during nighttime. This will cause an error in the estimation of brightness temperature which is more in the lower MSMR channel (6.6 GHz), the main channel used for estimating SST.

Another explanation for day/night variability is that, the satellite measures skin temperature, which is warmer than the temperature at a depth of 1m, especially, during daytime. Moreover, the skin of sea in direct contact with the atmosphere responds more to the air-sea interaction process than the sub-surface levels leading to large diurnal variation at the skin[4]. This results in large difference between MSMR and sea-truth measurements, especially, during daytime. The radiative cooling and turbulent mixing during nighttime reduce the vertical gradient of temperature, leading to smaller difference.

Table 5—RMS errors and correction factor for the satellite data

Parameter		Corrections factor	RMS errors	
			Before corrections	After corrections
SST (°C)	Day	−1.4		
	Night	0.6	1.25 (1.63)	0.51 (0.73)
WS (m/s)		−1.8	2.47 (1.97)	0.80 (1.53)

Note: Values in parentheses are for INS Sagardhwani data.

The surface winds measured from NIOT buoy and the ship (Fig. 4) revealed strong wind (10 m s^{-1}) during experimental programme. However, winds got weakened during the break (6 ms^{-1}), indicating weak monsoon conditions. Oscillations ranging from semi-diurnal to intra-seasonal periodicities are evident in sea-truth wind[5]. The MSMR wind speed does not exhibit a strong day/night bias. It is observed that MSMR winds were always higher compared to the sea-truth. Satellite-sensed WS significantly departed from sea-truth (NIOT buoy) with RMS error of 2.47 ms^{-1} (Table 5). The comparison with ship data indicted similar trend, but with lower RMS errors (1.97 ms^{-1}).

The significant departures noticed between satellite-derived WS and SST compared to sea-truth prompted us to derive correction factors to satellite-derived data. The difference between the sea-truth (blended NIOT and ship data) and MSMR winds were computed for all observations. The mean of this departure is the correction factor (−1.76 ms^{-1}). This correction factor was applied to the satellite measure-

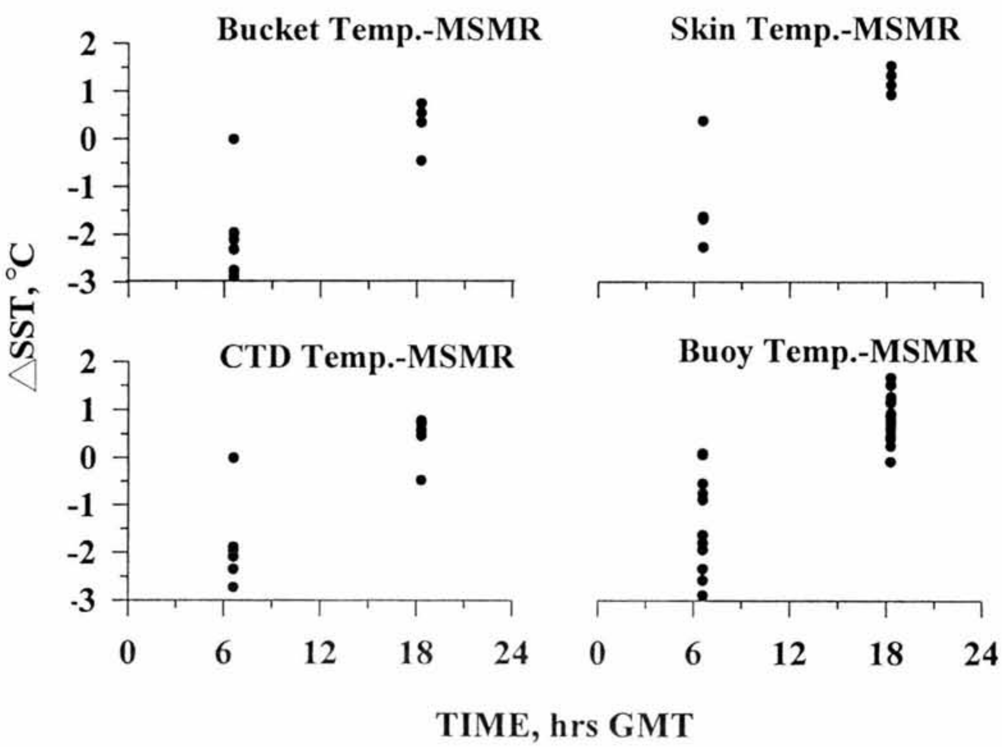

Fig. 3—Difference between sea-truth and MSMR for day and night

ments to remove the bias. After applying correction factor, differences between NIOT and ship observations were again computed. A remarkable improvement was noticed in the satellite derived WS (Fig. 5) after subjecting it to the correction, as indicated by small RMS errors (0.8 ms^{-1} and 1.53 ms^{-1} for NIOT and ship, respectively). The values are well within the accuracy of the MSMR sensor, indicating the suitability of the correction procedure adopted.

The correction factor for SST data was derived based on the day and night bias of the satellite, NIOT and ship data. To obtain the correction factor for SST, we have followed procedures similar to WS. However, correction factors were derived separately for

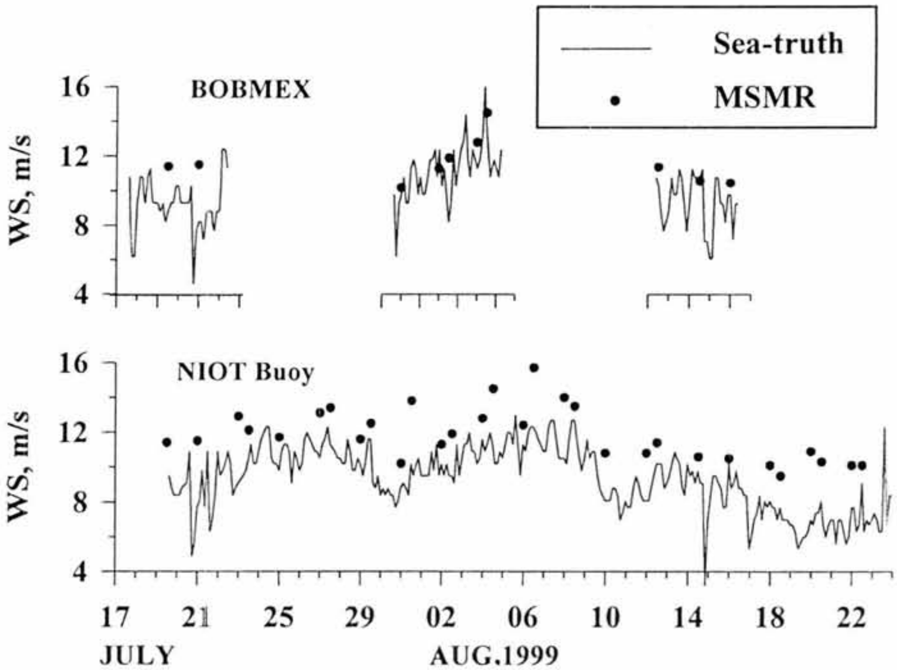

Fig. 4—Comparison of WS collected onboard INS Sagardhwani and NIOT buoy with MSMR

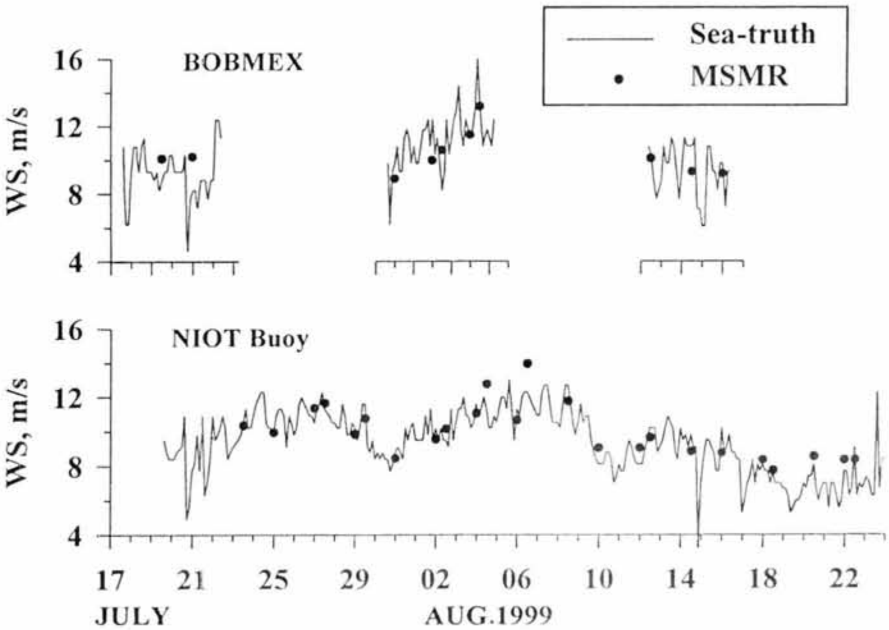

Fig. 5—Comparison of WS collected onboard INS Sagardhwani and NIOT buoy with MSMR after correction

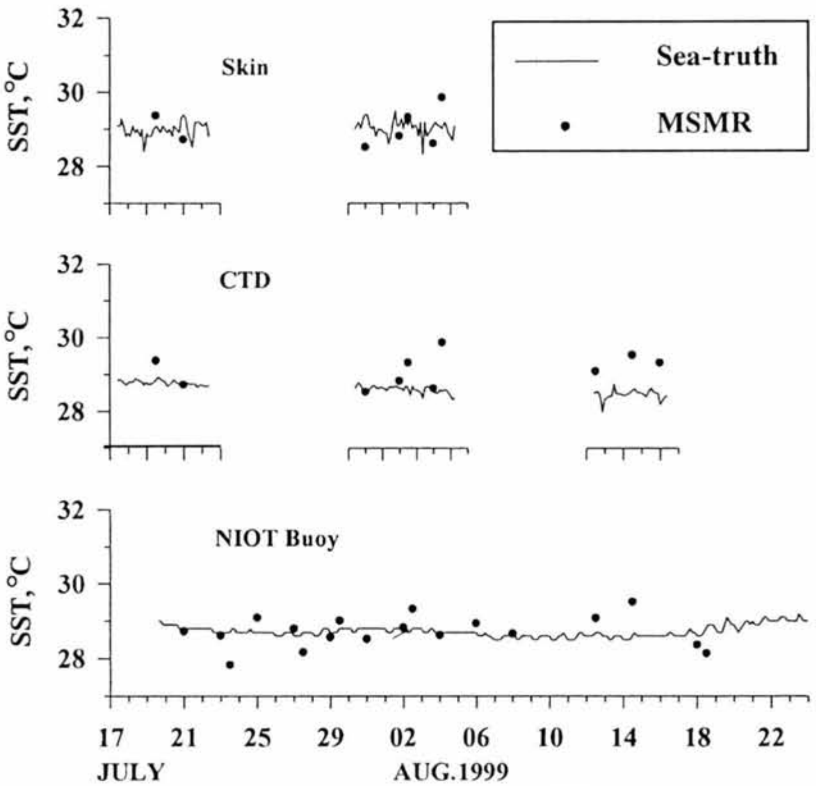

Fig. 6—Comparison of SST collected onboard INS Sagardhwani and NIOT buoy with MSMR after correction

day and nighttimes to take into account the biases observed in satellite SST. The correction factors obtained were −1.4 and 0.6°C, respectively, for day and night (Table 5). This procedure helped to obtain good agreement between the observed and satellite SST (Fig. 6). This is reflected in the reduction of RMS errors (Table 5) between sea-truth and satellite (0.51 °C for NIOT and 0.73°C for ship).

The number of observations of MSMR was less in comparison to sea-truth measurements. This posed problems to make specific conclusions. An extensive validation campaign has to be carried out to assess the performance of correction factors before they are put into use. In this connection, it is worthwhile to use the sea-truth data from the moored buoys as they give continuous data for long durations.

4 Conclusions

The results of the study shows that IRS P4 (MSMR) derived SST and WS require correction before their extensive use. Day and night biases have been observed in the satellite-derived SST. This phenomenon is attributed to intense air-sea interaction at the skin and Faraday rotation. A correction of −1.4°C for the daytime and +0.6°C during nighttime is suggested for satellite SST. A correction of $-1.8\ ms^{-1}$ is found to be appropriate for MSMR winds. The application of these correction factors improved the satellite derived SST and WS.

Acknowledgements

This work has been carried out as a part of collaborative programme between Naval Physical and Oceanographic Laboratory, Kochi and Space Applications Centre, Ahmedabad. The authors are grateful to NIOT, Chennai, for providing data of moored buoy.

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