INSITU VALIDATIONS OF SEA SURFACE TEMPERATURES DERIVED FROM SATELLITE MICROWAVE AND INFRARED SENSORS: A CASE STUDY OF TRMM/TMI AND TERRA/MODIS

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ABSTRACT

Intense sea surface skin temperature (SSST) measurements were taken using infrared radiation pyrometer onboard research vessel SagarKanya during ARabian sea Monsoon EXperiment (ARMEX) period over Arabian Sea in 2002 and 2003. Daily mean daytime and nighttime skin temperatures were compared with near simultaneous SST fields derived from MODIS mid and far infrared channels. Data comparison shows a root mean square deviation (RMSD) of 0.65 K and 0.58 K after bias correction for MODIS far infrared SST during daytime and nighttime respectively. Nighttime SST derived from MODIS mid infrared channels show an RMSD of 0.57 K after bias correction. Similar validation exercise was carried out for TRMM/TMI derived SST using bulk sea surface temperature measurements taken during ARMEX cruises. TMI derived SST showed RMSD of 0.51 K and 0.53 K during daytime and nighttime respectively when compared with near coincident insitu observations.

INTRODUCTION

With the launch of technologically advanced and innovatively designed satellite instruments like Advanced Along Track Scanning Radiometer (AATSR) onboard ERS-2 and ENVISAT, the Tropical rainfall measuring mission (TRMM) Microwave Imager and Moderate resolution Imaging Spectroradiometer (MODIS) onboard TERRA and AQUA satellites, need to validate SST products derived from such instruments with high precision and consistency has now become more demanding and challenging. Need to validate satellite derived SST products with the best possible insitu observation have been a long pending requirement. But in the last 5-7 years, efforts have gained momentum in this direction[1] and satellite derived SST products are being routinely validated with ship borne IR radiometers (M-AERI, SISTER etc.) observations which represent the temperature of approximately the same layer of the sea surface as sensed by the satellite radiometer. The existence of cool skin at the top of the oceans has been explained by many experts [2],[3],[1] and it was observed that the desirable approach to validate satellite derived skin SST observation using bulk SST observation by buoys is to use only those observations which are collected in high wind speed (greater than 6 m/s) conditions. In these cases the wind-induced turbulence at the air-sea interface dominates the heat exchange between the ocean and atmosphere and turbulent heat transfer domination is negligible and hence SST is directly comparable to satellite observations. On the other hand bulk SST as measured by buoys at around one meter depth can be warmer by a few tenths of degrees than the skin for wind speeds less than ~ 6 m/s. So ideally, measurements from ship based IR radiometer or interferometer (e.g. M-AERI) which has internal calibration targets and can measure the spectrum of infrared radiation in the range from 3-18 ?m with a spectral resolution of ~0.5 cm^{-1}, should be used to validate satellite derived SST. Further, Arabian Sea is the region where wind speeds are generally found to be less than 6 m/s throughout the year indicating the necessity of direct radiometer measurements for satellite derived skin SST validations [1].

The present paper is an effort in the same direction and describes the accuracies of SST retrieved using MODIS and TMI channels on comparison with ship based infrared pyrometer and bulk SST measurements respectively made over Arabian Sea during four cruises in 2002 and 2003.

VALIDATION OF TERRA/MODIS SST

The Infrared Radiation Pyrometer

The IR-Pyrometer KT-19.85 (designed and manufactured by Heitronics Infrarot Messtechnik, GmbH) was installed on research vessel Sagar Kanya to measure ocean surface skin temperature. It measures the emitted radiation in the spectral range of 9.6-11.5 ?m with the effective central wavelength of 10.5 ?m and consists of S 925AR lens made of ZnSe with aperture diameter of 39 mm. The response time of the instrument was fixed at one minute leading to NE?T of 0.01K. The instrument also houses the blackbody target for regular calibration. Onboard Sagar Kanya, the pyrometer was fixed with a boom at the same height (19 meters) as the anemometer for wind measurements from the ocean surface. Surface skin temperature data was recorded every minute during all the four cruises. Emissivity corrections in the measurements were made according to model developed by [4].

Data And Methodology

MODerate resolution Infrared Spectroradiometer (MODIS) onboard TERRA satellite launched in December 1999 has many thermal bands in mid and far infrared region for SST determination. Because of its narrower split thermal window channels and better NE?T (compared to NOAA-AVHRR), MODIS is expected to improve the retrieval accuracy as far as SST retrieval over Indian ocean region is concerned [5]. For the present study, level-3 daily SST product data at 4 km resolution derived from MODIS mid infrared and far infrared channels have been downloaded from http://poet.jpl.nasa.gov site. The data was extracted for Arabian Sea region corresponding to the four cruises during Arabian Sea Monsoon Experiment period (Table-1). MODIS daytime and nighttime data was compared with observed skin temperature by IR pyrometer(PSST). Collocated data of MODIS and IR pyrometer was extracted with spatial and temporal thresholds of 0.1??and 1 hour respectively. Only cloud free data points of MODIS level-3 SST product were considered for collocation.

Results

Table 2 shows that collocated PSST and daytime SST derived from far infrared channels of MODIS($MSST_{df}$) have a correlation of 0.70 with rms error and bias of 0.79K and 0.44K respectively. After bias removal the rms improves to 0.65K. The scatter plot (Fig. 1:left panel) also shows that when observed skin temperature is around 28K, $MSST_{df}$ tends to underestimate while at warmer temperatures (around 30K) there is no trend.

Nighttime comparisons of PSST and $MSST_{nf}$ through scatter plot (Fig. 1:right panel) shows a better accuracy of $MSST_{nf}$ than that in daytime. The plot shows a correlation of 0.67 with rms deviation and bias of 0.58K and 0.05K respectively and the accuracy marginally improves to 0.57K after bias correction(Table 2).

Similar to the above analysis, scatter plot (Fig. 2: left panel) was drawn between observed PSST and SST derived from MODIS mid infrared channels(MSSTm) and it was seen that MSSTm has rms deviation of 0.63K and it reduces to 0.57K after bias correction of –0.26K(Table 2).

Table 1. Details of IR pyrometer measurements during ARMEX cruise in Arabian Sea

Cruise	Duration of Cruise	Central area of observations
SK178	July 4-14,2002	16N 72E
SK179	July 7 – August 14, 2002	15N 72E
SK190	March 15 – April 9, 2003	10N 74E
SK193	May 17 – June 18, 2003	12N 73E

Table 2. Statistics of the comparisons between pyrometer skin temperature(PSST) and SST derived from MODIS far ($MSST_{nf}$ and $MSST_{df}$) and mid ($MSST_m$) infrared channels.

Daytime		
	PSST-$MSST_{df}$	
RMS Deviation (K)	0.79	
Bias(K)	0.44	
RMS after bias (K)	0.65	
Correlation	0.80	
Number of observations	32	
Nighttime		
	PSST-$MSST_{nf}$	**PSST-$MSST_m$**
RMS Deviation (K)	0.58	0.63
Bias(K)	0.05	-0.26
RMS after bias (K)	0.57	0.57
Correlation	0.67	0.69
Number of observations	24	29

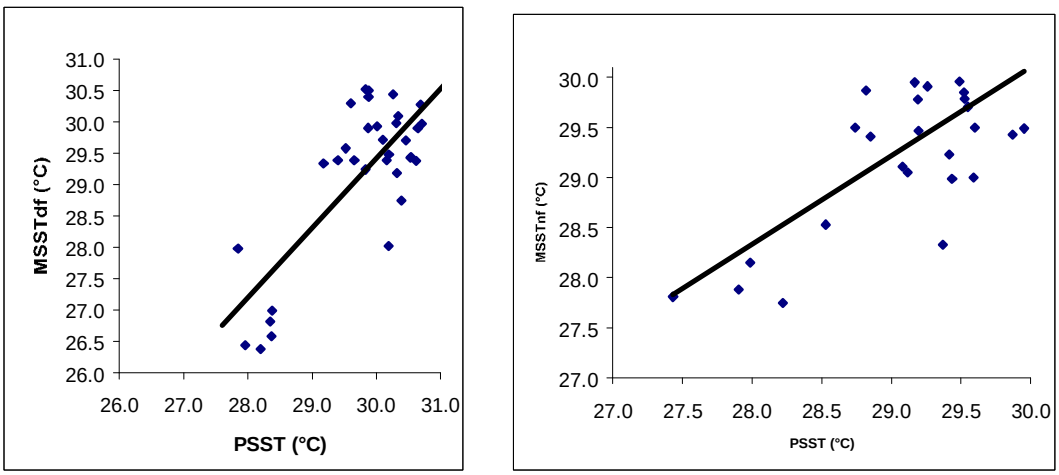

Fig. 1. Left panel: Scatter plot of observed IR pyrometer measurements (PSST) and SST derived from MODIS far infrared channels during daytime ($MSST_{df}$). Right panel: Same as left panel except for MODIS nighttime data.

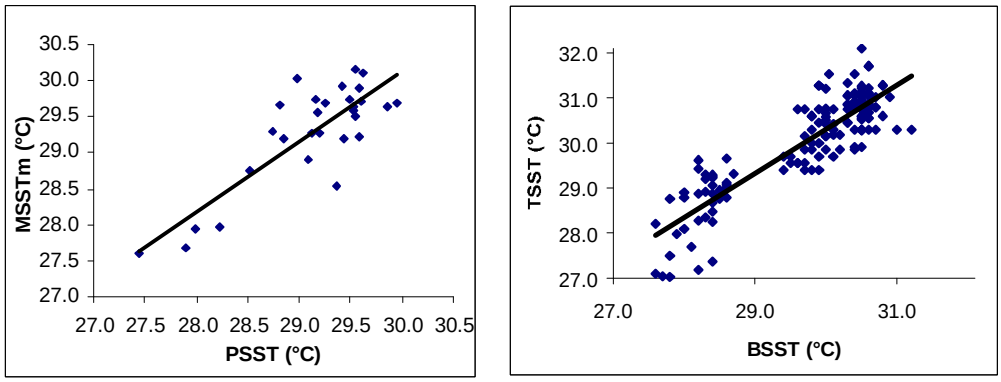

Fig. 2. Left panel: Same as Fig. 1 except for MODIS mid infrared channels during nighttime ($MSST_m$). Right panel: Scatter plot of SST measured from bucket (BSST) and SST derived from TRMM microwave radiometer (TSST).

VALIDATION OF TRMM/TMI SST

TRMM/TMI derived SST(TSST) was obtained from [6] and was validated with near simultaneous (with the same conditions as MODIS SST) skin temperature measured by IR pyrometer as described above. The comparisons were also carried out with near simultaneous bucket temperatures measurements(BSST). In the present study results about the bucket temperatures are discussed. During daytime rms deviation of the difference between TSST and BSST is 0.54K with a bias of -0.18K. This rms is improved to 0.51K after bias correction. Similarly in nighttime the rms deviation after bias correction is 0.53K. Unlike MODIS SST, TMI derived SST have almost slightly more error during nighttime. Fig. 2 (right panel) shows a scatter plot for all the points (day and night combined) for BSST and TSST comparison.

CONCLUSIONS

A validation study between observed skin temperature by IR pyrometer and MODIS daytime and nighttime SST have been carried out for a limited region over Arabian Sea. It was found that daytime and nighttime MODIS SST derived from far infrared channels has rms deviation of 0.65K and 0.57K respectively while nighttime MODIS SST derived from mid infrared channels has rms deviation 0.57K when compared with IR pyrometer observed skin temperature. Similarly validation of TRMM/TMI derived SST with bucket temperature yields an rms deviation of 0.51K and 0.53K in daytime and nighttime respectively. Considering the heavy water vapor loading in tropical atmospheres, MODIS and TMI algorithms for SST retrievals are generating high quality SST products and the accuracies show much better performance than the similar validation results for earlier satellites viz. NOAA-AVHRR and ERS-1/ATSR [7] and [8]as far as Indian ocean is concerned. As suggested by [1] the present study would not only enhance the quality performance of the SST retrieval algorithms for MODIS channels but also provide a practical low cost solution to the validation of skin temperature derived from satellites. In view of the sparse skin temperature data availability over Indian oceans for satellite data (MODIS) validation, the present study would be useful for oceanographers and modelers to use MODIS skin temperature products. Further, with the availability of accurate satellite derived SST from microwave radiometers (for example TRMM/TMI) even in cloudy conditions, it should be possible to blend SST measurements from microwave and infrared sensors to provide oceanographers and numerical modelers all weather SST fields for better weather and ocean state forecast.

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