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VALIDATION OF SATELLITE DERIVED LHF USING COARE_3.0 SCHEME AND TIME SERIES DATA OVER NORTH-EAST INDIAN OCEAN

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ABSTRACT

Time series measurement of surface meteorological parameters using an Autonomous Weather Station and Moored Buoy positioned at 10.5 N and 72 E from July to November 2000 are used to compute latent heat flux (LHF) using COARE_3.0 algorithm for validating Special Sensor Microwave Imager (SSM/I) derived LHF data. Mean positive and negative biases are observed between satellite and sea truth derived LHF estimates for summer (July to Sept) and inter-monsoon (Oct-Nov.) seasons respectively. Comparison during summer season exhibits very high correlation (> 75%) and is increasing progressively with longer climatologies. Satellite underestimates higher LHF values during summer while it overestimates lower LHF values in inter-monsoon season. Root Mean Square Deviation (RMSD) of LHF in summer is 12.5% of the highest value of 200 Wm^{-2} while it is 42 % of the mean lowest value of 50 Wm^{-2} during inter-monsoon season.

Key words : Validation, Autonomous Weather Station, COARE_3.0 Scheme, Latent Heat Flux, Summer Monsoon.

INTRODUCTION

Accurate heat flux computations across the boundary layer is still a challenge to the scientific community as it call for near perfect observational platforms and sensors to

withstand any adverse sea conditions. Several efforts have been made to compute energy exchange at the air-sea interface by using classical bulk computations ([Hastenrath and Lamb 1979](#), [Bunker 1976](#), [Clark et al 1974](#), [Read 1977](#), [Blanc 1985](#); and [Blanc 1987](#)). Usually, the bulk method is used to estimate latent heat fluxes from rudimentary shipboard measurements. The bulk formula parameterizes the flux mainly as a function of near-surface wind speed, air humidity and sea surface temperature. [Mcbean \(1972\)](#), [Horst \(1973\)](#) and [Francey and Sahashi \(1979\)](#) have clearly shown that the accuracy of flux measurements depends on the accuracy of the sensors. [Blanc \(1985\)](#) found that the same set of ship observation could yield bulk determination that differs by more than 100%. A detailed study leads [Blanc \(1987\)](#) to believe that the bulk scheme could roughly yield an uncertainty of 53% (66 Wm^{-2}) for LHF computations ranging from 0 to 300 Wm^{-2} . This would increase to 80 % (32 Wm^{-2}) if the LHF values were between 0 and 100 Wm^{-2} . However the uncertainty decreases to 40% (83 Wm^{-2}) if the LHF values are between 100 and 300 Wm^{-2} .

Twenty years later, with the advancements in technology, several research groups around the world are making air-sea flux measurements from ships almost routinely. As a result, in 1996, version 2.5 of the coupled ocean-atmosphere response experiment (COARE) bulk algorithm was developed using limited wind speed range (1-12 m/s) ([Fairall et al., 1996](#)). The algorithm was widely used even outside the tropics under variety of atmospheric conditions obviously doubted its applicability in mid latitudes and much higher wind speeds. Since then, efforts were put in to globalize the algorithm for accommodating wide range of meteorological and atmospheric conditions ([Bradely et al., 2000](#)). The latest of the version was released in 2003 by [Fairall et al. 2003](#) where the authors claimed to accomplish the fete of achieving an uncertainty of 5% in computing fluxes for wind speed 0-10 m/s and 10% for wind speed between 10 and 20 m/s.

The primary objective of this paper is to validate the satellite derived LHF (SSM/I and TMI) using time series surface meteorological data collected at the eastern Arabian Sea using well calibrated autonomous weather station (AWS) and moored buoy (MB) during July to November 2000 using COARE 3.0 scheme.

DATA AND METHODOLOGY

Time series measurement (30 minutes interval) of wind speed, air temperature, relative humidity, solar radiation, atmospheric pressure, etc. were collected from July to November 2000 using an autonomous weather station (AWS) installed at the coral island of Kavarathi, Lakshadweep island (10.5 N; 72 E) . The island measures 40 km^2 area situated 300 km away from the mainland in the eastern Arabian Sea. The AWS was installed at 30 m above sea level. Specifications of AWS sensors are described in [Table 1](#). The sea surface temperature data was collected every 3hrs by a moored buoy (MB) stationed at 10.6 N and 72.5 E and the data were interpolated to every half hour to match with AWS data. One of the India Meteorological Department's (IMD) observational sub division fall close to this measurement grid and is situated in the island Amini Divi (11 N & 72.4 E). Therefore, daily rainfall estimate was taken from IMD's daily weather report to supplement the surface met data collected by AWS and MB. Precise time series data of various surface met parameters required for computing latent heat flux (LHF) using the state of the art COARE_3.0 algorithm was generated. Instantaneous, 1 day, 3 day, 7 day and 30 day mean parameters were then produced from the above time series data to compute mean latent heat fluxes for comparing with satellite data.

Table 1. Autonomous Weather Station sensor specifications

Parameter	Sensor/Model	Accuracy/Error	Range
Total Solar Radiation	L1-200SA Pyranometer	5 %	0 - 3000 Wm ⁻²
Pressure	HoneyWell precision barometer	± 0.8 mBar	500 - 1200 mBar
Relative Humidity	Rotronic Hygrometer	C94 ± 1 % at 20 °C	0 - 100 %
Air temperature	Rotronic	± Pt100 RTD	0.2 °C -40 to 60 °C
Wind Speed	Young Model	± 05103 wind monitor	0.3 m/s 0 to 60 m/s

Day and night passes of SSMI (wind speed and columnar water vapor) and TMI (sea surface temperature) data for the period July to November 2000 was downloaded (<ftp.ssmi.com/ssmi> or <ftp.ssmi.com/tmi>) for computing instantaneous LHF using COARE_3.0 scheme. Efforts are being made to compute specific humidity (Qa) directly from SSMI brightness temperature to minimize uncertainty following [Schlussel et al., 1995](#). Air temperature was derived from a set of empirical relationships developed between specific humidity and air temperature from the *insitu* surface met data collected over the tropical Indian Ocean over a period of 15 years (Sathe and Muraleedharan, 1999). Since high rainfall events adversely affect the SSMI retrieval processes and retrievable SSMI rainfall estimates are yet to be properly validated, the daily rainfall estimate is approximated to zero in the COARE_3.0 scheme. An average atmospheric pressure of 1008 mb is considered at the boundary layer as the LHF computation seldom changes with atmosphere pressure perturbations. Day/night, 1 day, 3day, 7day and 30 day mean LHF was then computed from day-night passes of SSMI-TMI satellites to match with the observational data set. Satellite-seatruth comparison was then made for various combinations to understand the nature of relationship.

RESULTS AND DISCUSSION

Satellite derived LHF is compared with LHF derived from the AWS time series observation for instantaneous value, 1 day mean, 3 day mean, 7 day mean and for 30 day mean during July to November 2000. [Figure 1](#) shows the scatter plots of LHF between satellite and sea truth during the entire period (July to November). Highest correlation is obtained while comparing instantaneous LHF values and it decreases with increase from shorter to longer climatological mean. Therefore, when the LHF is averaged over 30-day period, the correlation between satellite and sea truth tend to decrease. This contradicts the conventional belief and views of [Schlussel et al. \(1995\)](#) that the accuracy of single satellite sounding is coarser than the accuracy of monthly averages. The mean bias progressively decreased from 10 to -5 Wm⁻² when compared with instantaneous to 30-day mean values ([Table.2](#)). The trend of residue (satellite-in situ) in [fig.1](#) (right panel) indicate positive and negative biases for LHF varying from 40 to 200 Wm⁻² respectively. This explains the reason for near insignificant mean bias obtained.

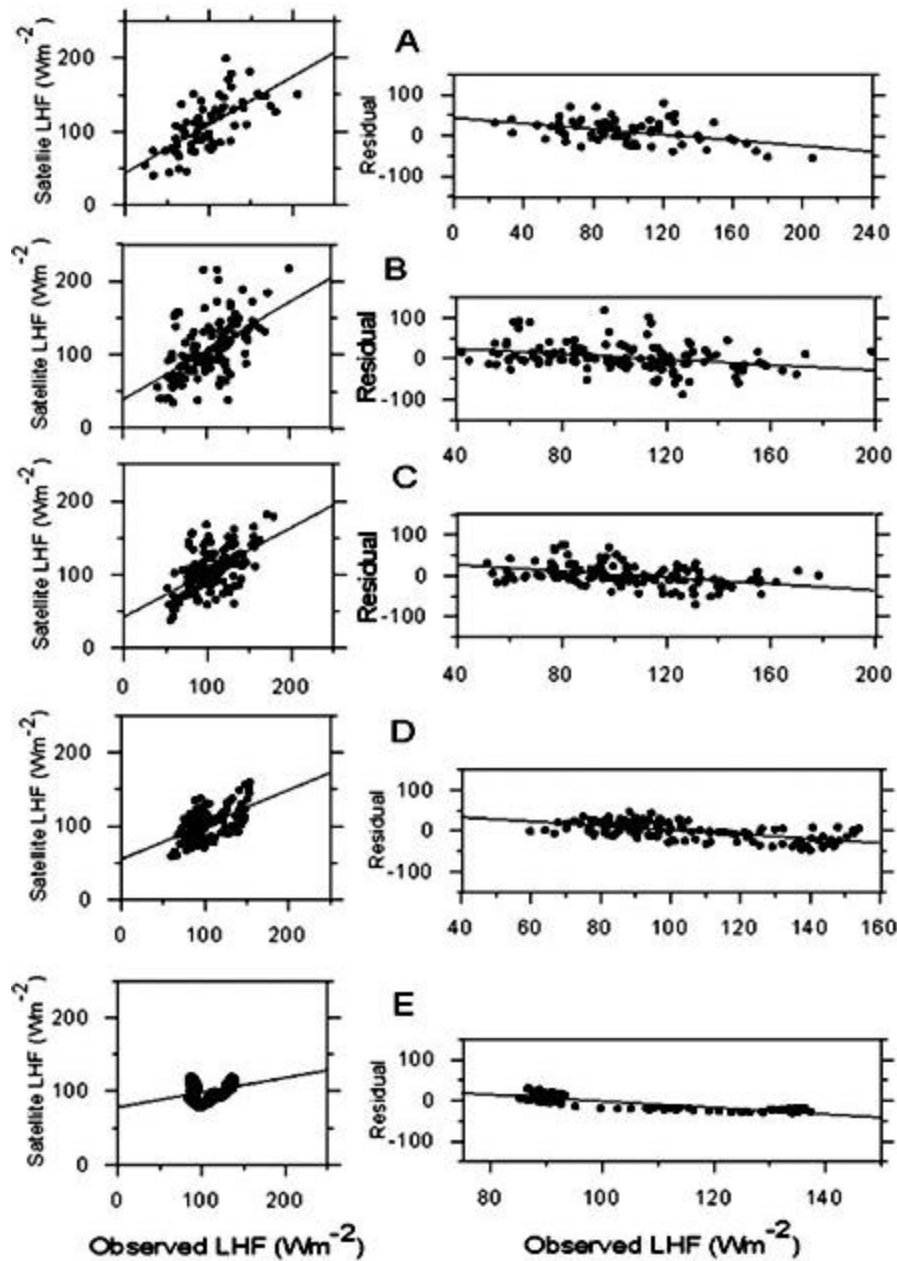


Figure 1. Scatter plots of Satellite LHF (left panel) and Residual (right panel) Vs Observed LHF during July to November 2000. (A) Instantaneous values (B) 1 day mean (C) 3 day mean (D) 7 day mean (E) 30 day mean

In short, the trend in bias (residual) reveals that the algorithm over estimate low LHF values and under estimate high LHF values. This is of great concern to the research community as it adversely affects the objectives of research using satellite data. A closer look at these results made us to believe that the abnormality may not be with the discrepancy in algorithm, but with the geographical location of the area of study and seasonal behavior of ocean and atmosphere. The unique geography of

Indian ocean induce seasonal reversal of winds (monsoon) along with meridional oscillation of thermal equator. This peculiar air-sea interaction pattern will give rise to extreme climatic conditions that prevails over a period of time. Southwest monsoon, northeast monsoon and inter monsoon are the extreme phases of the tropical Indian Ocean. Both satellite and sea truth data are, therefore, analyzed separately to highlight seasonal variability. Northeast monsoon data during 2001 is being analyzed and is excluded from the present discussion.

Trend of the residual noticed in the earlier figure is again replicated for instantaneous match-up during summer monsoon period (July-Sept.) (Fig.2a; right panel) whereas it disappeared during the inter-monsoon (Oct.-Nov) period. But the trend in bias associated with the climatology (1 day to 30 day) drastically varies with these two seasons. Mean bias is negative during summer monsoon while it is positive during inter monsoon (Table 2). It is interesting to note that high bias is associated with higher LHF values during summer monsoon whereas it is associated with lower LHF values during inter-monsoon period. However the bias is reduced drastically for lower and higher LHF values for monsoon and inter-monsoon respectively. The correlation between satellite and observed LHF values seems to be very high and progressively increasing from 1day to 30 day climatology during summer monsoon period (Fig.2; left panel & table 2). Correlation is comparatively poor and inconsistent with the climatology during the inter-monsoon season (Fig.3; left panel & Table.2). The scatter shown by the rmsd values during summer and fall inter-monsoon was grossly subdued by the variation in bias caused by the slope of the distribution. The actual measure of uncertainty (rmsd) is, therefore, obtained after removing the bias. The reduction in uncertainty with longer climatologies is, now, clearly seen in the refined rmsd values.

Table 2. Details of relationship between satellite derived LHF and observed LHF from instantaneous to 30 day climatology during various phases of monsoon. The abbreviations n, b, r and rmsd represents number of observations, bias, coefficient of correlation and root mean square deviation.

Period	Summer & Inter-monsoon				Summer				Inter-monsoon			
	n	b	rmsd	r	n	b	rmsd	r	n	b	rmsd	r
Statistics	n	b	rmsd	r	n	b	rmsd	r	n	b	rmsd	r
Day/Night	068	100	30	0.68	37	004	26	0.79	24	21	36	0.69
1 Day	135	3	33	0.54	79	-11	28	0.75	56	23	40	0.44
3 Day	131	2	27	0.56	75	-12	23	0.79	56	20	30	0.42
7 Day	123	-0.4	21	0.55	67	-15	21	0.81	56	17	21	0.52
30 Day	106	-5	18	0.36	50	-21	21	0.93	56	10	14	0.14

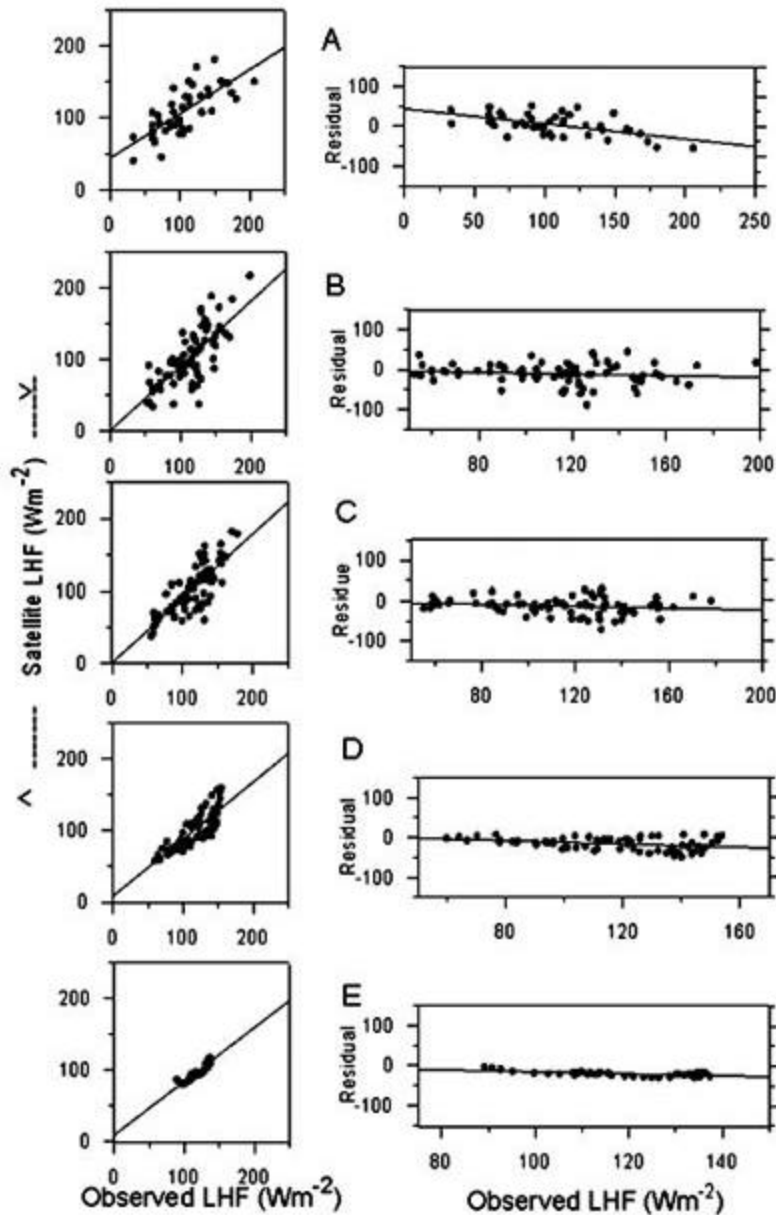


Figure 2. Scatter plots of Satellite LHF (left panel) and Residual (right panel) Vs Observed LHF during July to September 2000. (A) Instantaneous values (B) 1 day mean (C) 3 day mean (D) 7 day mean (E) 30 day mean

[Fairall et al., \(2003\)](#) claims that the improved COARE_3.0 bulk parameterization method reduces the uncertainty to a staggering 5 to 10% level when air-sea fluxes are computed from various observational platforms. The above uncertainty cannot be achieved for computing fluxes from satellite retrieved parameters as the sensors has its own inherent uncertainties in measuring various parameters such as sea surface temperature, wind speed, humidity etc. This compounds the computational uncertainty using COARE scheme. The present error analysis highlights the accuracy of this state of the art bulk scheme in handling satellite data. The effort is more complex when regions of extreme climatic conditions are included in the validation exercise. [Thadathil et al. \(1995\)](#) has shown an uncertainty of 50-90 Wm^{-2} for

satellite derived net fluxes for a variation of 0 to 300 Wm^{-2} . [Isemer and Hasse \(1987\)](#) have obtained an average standard deviation of 73 Wm^{-2} between the fluxes derived from SMMR (Scanning Multichannel Microwave Radiometer) and ship data over the north Atlantic. [Schulz et al. \(1997\)](#) has shown that standard deviation in satellite derived flux due to wind speed errors are 33 Wm^{-2} . Sea surface temperature and humidity errors contribute to the remainder. North Indian Ocean is well known for extreme variability of these parameters with space and time. RMSD is a measure of variability reflected from uncertainties. Two seasons are covered by the time series data analyzed here and the uncertainties in flux measurement for satellite and sea truth are discussed. Relatively high root mean square deviation (RMSD-bias) existed for the instantaneous and daily LHF comparisons in both the seasons and it decreases with longer climatological mean ([Table 2](#)). However the variation in RMSD between satellite and observed value is much less in summer than in inter-monsoon season. An average RMSD of 25 Wm^{-2} for both seasons amount to 12.5% of the highest LHF of 200 Wm^{-2} that falls close to the range of uncertainties achieved by COARE_3.0 scheme ([Fairall et al. 2003](#)). This argument suit well for summer monsoon as the residue (bias) increases with increase in LHF ([Fig.2](#)). During this season the mean uncertainty (rmsd) is decreased to 9% of the highest LHF of 200 Wm^{-2} . During fall inter-monsoon period, however, the argument does not hold good as the residue seem to increase when LHF decreases. This season exhibits a mean uncertainty of 21 % for LHF varying from 40 to 200 Wm^{-2} . [Blanc \(1985\)](#) attributes the uncertainty in measuring low flux magnitude to errors inherent in low wind speeds. Low wind speed during the inter-monsoon season can give rise to similar errors. But the percentage of RMSD for the lowest flux magnitude of 50 Wm^{-2} increases to about 42 % when measurements were made from satellite. The results are encouraging when compared with the observation of [Blanc \(1987\)](#) where he showed the percentage of uncertainty for 25 Wm^{-2} as approximately 100%. The above results exhibited better accuracy in computing fluxes from satellite measurements even in extreme sea condition. The computational uncertainties are still comparable with the estimates carried out using rudimentary ship measurements.

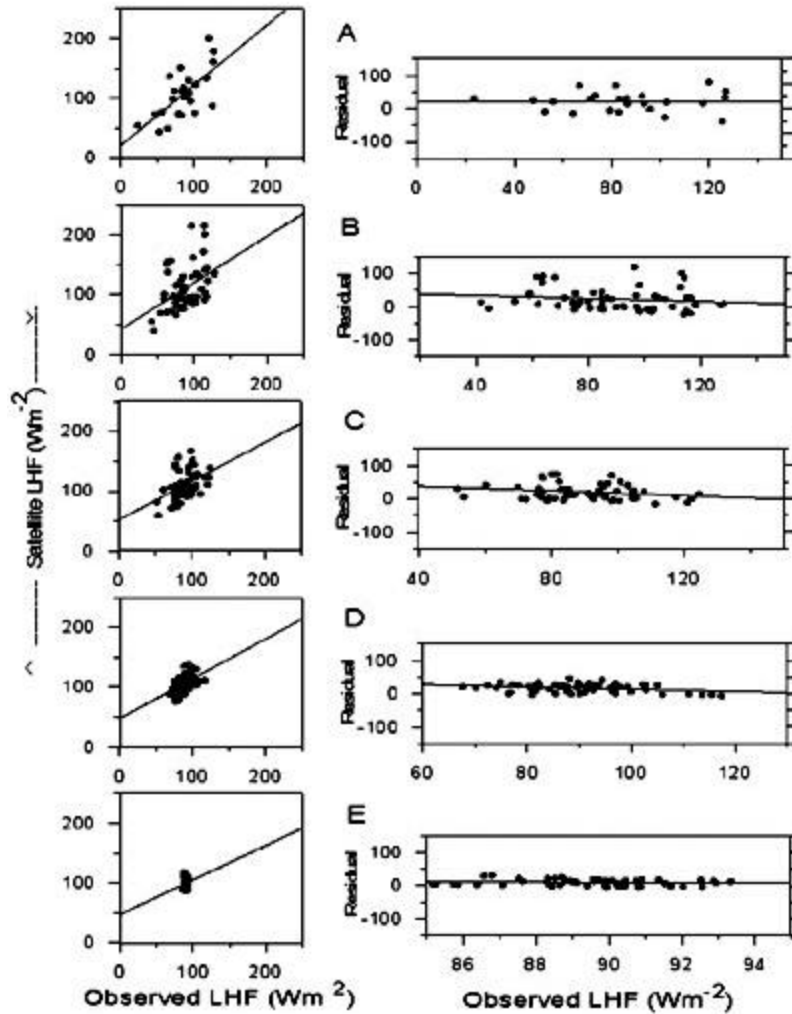


Figure 3. Scatter plots of satellite LHF (left panel) and Residual (right panel) Vs Observed LHF during October to Nov. 2000 (A) Instantaneous values (B) 1 day mean (C) 3 day mean (D) 7 day mean (E) 30 day mean

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