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Parameterization of skin-bulk temperature difference in the southeastern Arabian Sea

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In this study the variation of bulk-skin temperature (ΔT) during May-June, has been studied using different methods proposed earlier. To our knowledge, this aspect has not been studied so far for the Arabian Sea or Bay of Bengal. The earlier methods failed to reproduce the variation of ΔT in this region during the period of observations. The following relations are proposed to estimate non-dimensional numerical coefficient λ and skin-bulk temperature variation (ΔT).

$\lambda = 1.37*U+9.8$ (for the wind speed, 2-8 m/sec)

$\Delta T = -0.026*Q/U + 0.089$

Where Q is the sum of latent, sensible and net long wave radiation and U is the wind speed (m/sec). The newly proposed relations are compared with the previously proposed and found that newly developed relation is suitable for Arabian Sea especially for the night time. Root mean Square (RMS) errors (0.2° C) are indicating the performance of newly proposed relations.

[**Keywords**: skin temperature, bulk temperature, total heat loss, Arabian sea, wind stress]

Introduction

It is known that skin temperature (ST) is referred to the top few mm of the sea surface while the bulk temperature is at few cm (about 50cm to 100 cm) below the sea surface. The skin-bulk temperature difference depends mainly on the winds and surface fluxes. There are several methods,[1,2,3,4,&5] to compute the bulk-skin temperature variation, from other oceanic regions. The importance of the SL in estimating the global CO_2 flux was reported by Robertson & Watson[6]. The sum of global correction (excluding south of 45° S) is 0.56 $Gt.C^{-1}$ in December and 0.69 $Gt.C^{-1}$ in June with an annual average of 0.63 $Gt.C^{-1}$ of which 00.36 $Gt.C.y^{-1}$ is from northern hemispheric oceans. If a 10% correction is added, for the southern ocean south of 45° S, the global total correction would be 0.7 $Gt.C^{-1}$. Though it is 0.7% of the total air-sea flux, it is a large fraction (30%) of the net uptake calculated from models. Hence, the measurement of ocean ST and it's deviation from bulk temperature is very important to estimate net carbon exchange accurately from our region. This is also useful to correct the air-sea fluxes and to improve the algorithms for the retrieval of SST from satellites. To our knowledge, no information is available on this aspect from the north Indian Ocean. Here, we have examined the variability of skin-bulk temperature during pre-monsoon season (May-June) using the data collected by the research vessel, ORV Sagar kanya under Arabian Sea Monsoon Experiment (ARMEX-II) program.

Materials and Methods

ARMEX-II program has been conducted over Arabian Sea to observe the variations in SST during the pre-monsoon season (Period I: 15 March - 9 Aril 2000 and Period II: 17 May–18 June 2002). SST measured using the traditional method and also by using IR Pyrometer. The Sea Surface Skin Temperature was recorded with IR Pyrometer, with in the spectral response is 9.6 to 11.5 μm with accuracy of ± 0.5°C (± 0.5°C plus 0.7% of the difference between target temperature and housing temperature). The radiation will be converted in to the temperature of the Sea surface. The IR Pyrometer is mounted perpendicularly to see the sea at the boom extended forward at the port side of the ship. The data collected for every 5 min interval and then hourly averages has

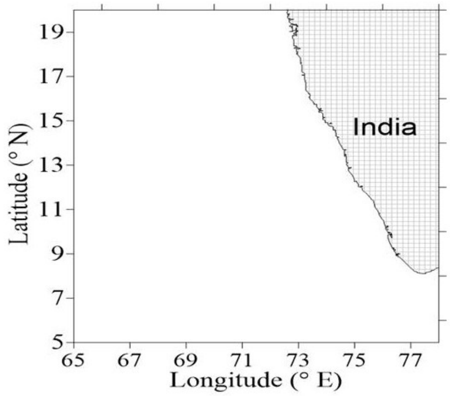

Fig. 1 — Area of Study

been computed for the analysis. We have chosen the night time bulk SST and SSST to find out the variations of bulk-skin temperature (ΔT) during May-June.

We have chosen five different methods to test the variations with the above mentions data sets.

Here five different methods are tested with the above data sets

Saunders[4] proposed the following theoretical relationship to find out the Skin-bulk temperature deviation (ΔT)

$$\Delta T = \frac{\lambda q \nu}{\kappa \left(\frac{\tau}{\rho_w} \right)^{\frac{1}{2}}} \quad \ldots (1)$$

λ is numerical coefficient (dimension less), Q is the sum of latent , sensible and net long wave radiation, ν is kinematic viscosity, K is thermal conductivity of seawater , $\left(\frac{\tau}{\rho_w} \right)^{\frac{1}{2}}$ is kinematic stress . The crux of the problem is λ, which depends on wind speed.

The wind stress, latent and sensible heat fluxes are computed using bulk aerodynamic methods. The bulk transfer coefficients have been estimated following Kondo[7]. The net long wave radiation is computed from the formula suggested by

Method 1. (H71)

Hasse[1] proposed the following relationship,

$$\Delta T = C1.S/U + C2.Q/U \quad \ldots (2)$$

Since we have tested for nighttime observations, C2 value at 2.5 m is used

$$\Delta T = -0.014 * Q/U \quad \ldots (3)$$

Method. 2 (PS81)

Paulson and Simpson[8] proposed a constant value of 6.5 for λ. Using this value ΔT has been estimated from eq.1

Method.3 (Wu85)

Wu[2] suggested the following equation,

$$\lambda = \begin{cases} 2.0+(5/7)*U, & U \le 7.5 \text{ m/sec} \\ 7, & U > 7.0 \text{ m/sec} \end{cases} \quad \ldots (4)$$

Method 4 (F99)

Fairall et al [3] suggested the following equation using the sophisticated data collected in the Pacific Ocean.

$$\lambda = 6\left[1 + \left(\frac{16 Q_b q \alpha \rho_w c_w \nu^3}{U_*^{\,4} k^2} \right)^{\frac{3}{4}} \right]^{\frac{-1}{3}} \quad \ldots (5)$$

$$Q_b = Q_n + \left(\frac{S \beta c_w}{\alpha L_v} \right) Q_e$$

A is the coefficient of thermal expansion of sea water, ρ_w is the density of sea water C_w specific heat capacity of sea water at constant pressure, Q_b virtual surface cooling flux, S is salinity, β Salinity expansion coefficient , L_v latent heat of vaporization of seawater , Q_n net heat flux and Q_e latent heat flux

Method 5 (A02)

Chia-young Tu& Tsua[5] compared four different methods [2,3,8&9] and inferred that the Artale et al [9] method, yielded better results for Tropical Ocean Global Atmosphere (TOGA) site in West Pacific Ocean.

$$\lambda = \frac{U_* K C}{\gamma \rho_w C_w h \nu} \quad \ldots (6)$$

here C is 86400

$$\gamma = \begin{cases} 0.2\,U+0.5, & U \le 7.5 \text{ m/sec} \\ 1.6\,U-10, & 7.5 \text{ m/sec} < U < 10 \text{ m/sec} \\ 6, & U \ge 10 \text{ m/sec} \end{cases}$$

The reference depth (h) of 10m is found to be suitable for Mediterranean Sea and TOGA site in west Pacific Ocean and they mentioned that it has to be tested for other oceanic regions.

Below three methods have been computed from the above methods by replacing wind and reference depths. The criteria of modified methods and new methods proposed are given below.

Method.6 (A02-modified)

By replacing the reference depth of 10m with 3m, the variation of ΔT could be reproduced reasonably. Then these values of λ are correlated with the wind speed which is in the range of 2 to 8 m/sec. High (>8 m/sec and low < 2 m/sec) are excluded from the analysis. The observations are missing on few occasions. Hourly data of skin temperature and surface meteorological data collected during May-June are used in the computations.

Method.7 (present)

The following equation was developed with the May data (period I, N=145). Very high correlation of 0.92 has been observed between U and λ. (Fig. 2a)

$$\lambda = 1.37*U+9.8 \quad \dots (7)$$

Using the values of λ from eq.7, skin-bulk temperature variations are computed from eq.1

Method.8 (present)

The net long wave radiation (Qnlw) varied from 30 to 63 W/m ^{2}. Latent heat flux (Qe) was between 61 and 266 W/m ^{2} while the sensible heat flux (Qs) was -3 to 24 W/m ^{2}. The total heat flux, Q (= Qnlw+Qe+Qs) varied from 103 to 337 W/m ^{2} during the observational period, 18 May- 13 June 2003. Then Q/U is correlated with the observed ΔT values for the period 18 -31 May and tested for the period, 1 -13 June. An inverse relationship had been observed (correlation (r) = -0.66, significant at > 99% level) between Q/U and the observed variation of ΔT (Figure 2b).

$$\Delta T = -0.026*Q/U +0.089 \quad \dots (8)$$

The above five previous methods and 3 newly proposed methods are compared and the results are presented in Fig. 3 and Table.1

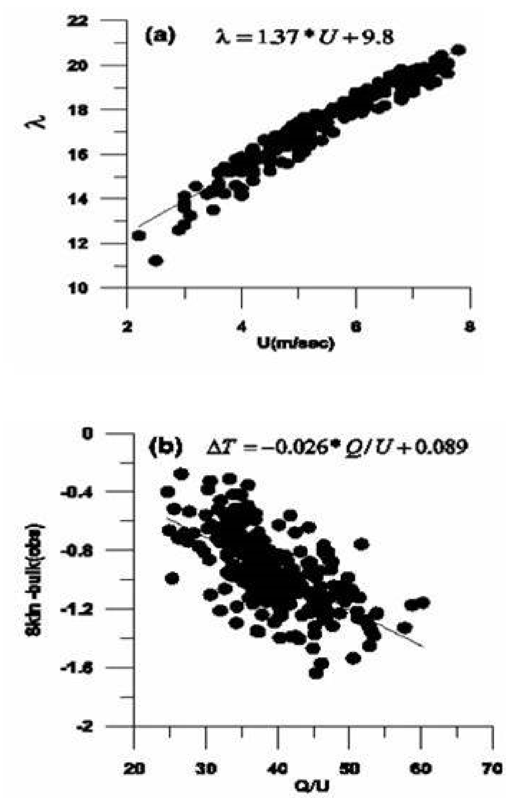

Fig. 2 — Scatter plot between (a) λ and wind speed (U) and (b) Q/U vs. skin-bulk temp (obs)

Results and Discussion

Using the estimated values of Q and wind stress at hourly interval during the night time, Saunders[4] formula was used to estimate ΔT using the λ values proposed by different methods (1-5). All the earlier five methods (1-5), could not reproduce the variation of ΔT. The values are very much underestimated (Figs. 3a-e). One could see a reasonably good agreement between the observed and estimated values of skin-bulk from the present three methods (6-8). Method 8 appears to be the best to reproduce the variation of ΔT. Methods 4& 5 showed almost similar results. Following the analysis of Chia-young Tu & Tsua[5], the mean values, correlations (r), rms errors are computed for all the methods and the results are shown in Table.1 Period I is training and period II is the testing period. The proposed methods in this study (6-8) are showing lowest RMS (Root Mean Square) errors and high correlations and the mean values are close the observed. Though the other methods are showing good correlations, the RMS errors are quite high as they very much underestimated the actual variation of ΔT (Table.1). This could not be done for day time data due to lack of measurements on insolation. From this study it is inferred that the earlier methods (1-5) appear to be not suitable to reproduce the variation of skin-bulk temperature in the southeastern Arabian Sea during May-June.

From this study, it is inferred that the reference depth of 3 m may be suitable for the Arabian Sea to estimate ΔT using Artale[9] method with Saunders[4] formula (method.6). This reference depth was 10m for the TOGA site in west Pacific Ocean and Mediterranean Sea. Mehod.7 with the relation, λ = 1.37*U+9.8 and the direct relation, ΔT = -0.026*Q/U+0.089 (method. 8) appears to be best.

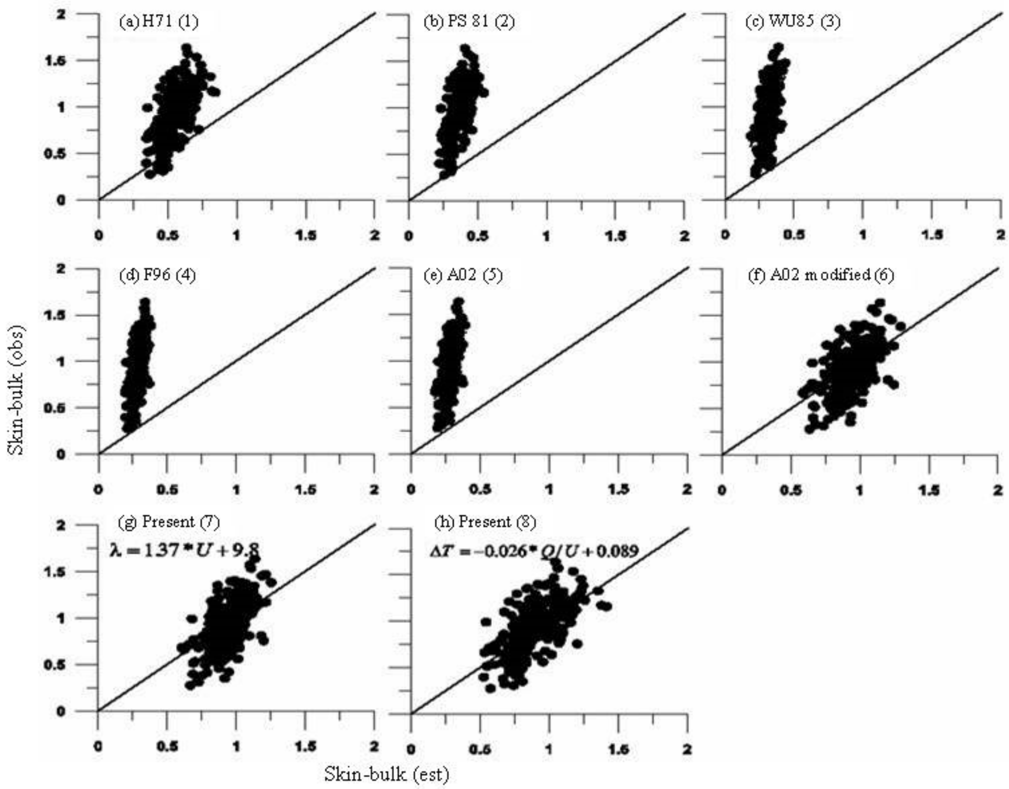

Fig. 3 — Scatter plots between skin-bulk (obs) vs. estimated from (a) H71 (b) PS81 (c) Wu85 (D)F99 (E) A02 (F) present –modified A02 (G) present (from eqs 1&7) and (H) present (from eq.8) (please note that the sign is reversed for plotting purpose)

Table 1 — Statistical analysis of the Δ**T** estimated from different methods. Best methods are indicated in bold. Period I: 18-31 May 2003 (training period) (N=145); Period II: 1- 13 June 2003 (testing period) (N=96)

method	Mean			Correlation (r)			RMS error		
	I	II	I+II	I	II	I+II	I	II	I+II
Obs	-0.93	-0.96	-0.94	-	--	---	---	---	---
1 H71	-0.56	-0.54	-0.55	0.63	0.66	0.63	0.42	0.47	0.44
2 ps81	-0.36	-0.35	-0.36	0.63	0.67	0.63	0.61	0.64	0.62
3 wu85	-0.31	-0.30	-0.31	0.50	0.46	0.47	0.65	0.70	0.67
4 F96	-0.29	-0.28	-0.28	0.65	0.65	0.63	0.68	0.72	0.69
5 A02	-0.29	-0.27	-0.28	0.62	0.58	0.58	0.68	0.52	0.70
6 A02-modified	**-0.95**	**-0.91**	**-0.94**	**0.62**	**0.58**	**0.58**	**0.20**	**0.21**	**0.21**
7 present	**-0.95**	**-0.91**	**-0.94**	**0.64**	**0.62**	**0.61**	**0.20**	**0.21**	**0.20**
8 present	**-0.95**	**-0.95**	**-0.94**	**0.66**	**0.63**	**0.63**	**0.20**	**0.20**	**0.20**

(Correlations are significant at > 99% level).

However, further work will be concentrated on the daytime and in other seasons with desirable observations of ST. After the onset of summer monsoon, rainfall and wave interaction complicates the process. However, the present three methods (6-8) could reasonably reproduce the observed variability of ΔT (Table.1).

Conclusion

To our knowledge, this aspect has not been studied over the north Indian Ocean. This is a preliminary study with a small data set. The proposed three methods (6-8) are illustrating lowest RMS errors with higher correlation and the mean values are closer to observed. An inverse relationship had been observed (r=-0.66) between Q/U and the observed variation of ΔT. The present three methods could reasonably reproduce the observed variability for the night time variation of ΔT. Detailed study with intensive measurements over north Indian Ocean is very much desirable to understand this problem.

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