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Sathe, P.V.

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Retrieval of Sea Surface Air Temperature from Satellite Data over Indian Ocean: An Empirical Approach

P. V. Sathe and P. M. Muraleedharan

**National Institute of Oceanography
Dona Paula, Goa, India**

Abstract

The sea surface air temperature is an important parameter required for computation of air-sea fluxes over oceans which at present cannot be directly measured from remote sensing. In the present article, we have proposed an empirical approach to determine the sea surface air temperature from satellite derived sea surface humidity in the Indian ocean. Using the insitu data on surface met parameters collected on board O.R.V. Sagar Kanya in the Indian ocean over a period of 15 years, we have analysed the relationship between the surface air temperature and surface humidity by fitting a polynomial between the two for different regions of the Indian ocean in different seasons. Taking into account the variation in surface air temperatures, the Indian ocean is split in 14 regions and polynomial relationships for each region is established. The RMS errors associated with computation of surface air temperatures for each region along with constants of polynomial equations are presented.

Key words: Remote sensing, sea surface air temperature, sea surface humidity, Columnar water vapour, Indian ocean

1. Introduction

Determination of air-sea fluxes at boundary layers of the ocean and atmosphere system holds the key to understanding major meteorological phenomena like the Asian monsoon and cyclonic storms. One requires information on various features over oceans such as wind patterns, sea surface temperatures, atmospheric pressure, humidity, etc., on a very large scale to compute air-sea fluxes. With the advent of

remote sensing technique, particularly the use of weather satellites, it was expected that direct computation of air-sea fluxes would become a routine exercise. This did not happen because two important meteorological parameters needed to compute the air-sea fluxes, namely, the sea surface air temperature (T_a) and the specific humidity at the sea surface (Q_a) cannot be still retrieved through remote sensing. Satellite sensors do not make these measurements. One needs to take recourse to insitu data to supplement these parameters which are not readily available on large scales. The present work offers an empirical approach to compute the surface air temperature (T_a) on the basis of insitu data collected in Indian ocean over the last 15 years through oceanographic cruises on board ORV Sagar Kanya organized by the National Institute of Oceanography. At present, the sea surface humidity (Q_a) is indirectly computed from the satellite derived columnar water vapor (W) using the following equation (Liu, 1986).

$$Q_a = 3.819W + 0.190W^2 + 0.189W^3 - 0.075W^4 + 0.006W^5 \quad (1)$$

where both W and Q_a are expressed in gm/kg. This method involves an error of about 2 gm/kg. Hsu and Blanchard (1989) have confirmed the suitability of this equation by comparing its results with radiosonde data collected from geographically different regions within its error estimate. Wagner et al. (1990) estimated daily surface humidity from precipitable water using vertical EOF's (Empirical Orthogonal Functions). However their method was restricted to north Atlantic ocean since their EOF's were based on those regions.

Liu et al. (1992) have noted that sensible heat flux computed using values of Q_a estimated from his method (Eq. (1)) is not adequate for studying phenomena like ESNO (El Nino Southern Oscillation) or Asian monsoon due to its inherent error. It was shown by Schulz et al. (1993) and later by Schluessel et al. (1995) that the error of 2 gm/kg in Eq. (1) can be substantially reduced when one considers only the bottom 500 m layer of columnar water vapour rather than the entire 30 km of atmospheric column. The columnar water vapour (W) can be measured from satellites using the global D matrix algorithm (Hollinger, 1988, Sathe and Muraleedharan, 1998). It follows therefore that determination of surface humidity (Q_a) from satellite derived water vapour (W) using Schluessel's correction to Eq. (1) is possible with a fair degree of accuracy.

Determination of surface air temperature (T_a), however, is not so straight forward. Konda et al. (1996) have given a new method to determine T_a from sea surface temperature, wind speed and humidity. The method is validated using monthly mean data from fixed TOGA and TAO buoys in Pacific ocean. The method is not validated for Indian ocean or when there is a temporal variation of T_a 's within a month. At present, the conventional method of determining sea surface air temperature (T_a) is based on the non-linear relationship between T_a and Q_a obtained by fitting a second or higher order polynomial between measured values of T_a and Q_a . But this method is also not very convenient because it requires a very large database for both T_a and Q_a over oceans in different seasons. Secondly, this method is not valid when there is a significant variation in surface air temperature (T_a) existing in space and time. This is usually the case all over the oceans, in particular, the Indian ocean.

2. The Indian Ocean

Indian ocean exhibits a very strong variation of surface air temperatures both spatially and temporally.

The northern Arabian Sea is subjected to heavy wind divergence due to proximity of Finlater Jet during monsoon. This results in remarkably low SST's in this zone while the central bay remains warmer. The dynamics of Bay of Bengal is even more complex as it is exposed to heavy run-off from rivers and the frequent cyclonic storms. The equatorial region in the south is exposed to intense reversal of wind four times a year which ultimately gives way to Wyrтки Jet during transition seasons (April-May and October-November). At the same time the western equatorial region is normally cooler during winter where winds are favourable for equatorial divergence. Another unique feature of the equatorial region is that the trade wind drift ceases to exist during south west monsoon and the equatorial counter current merges with the eastward monsoon drift.

We have analyzed insitu surface met parameters over the Indian ocean collected over a period of 15 years and studied the relationship between T_a and Q_a . The data used for the purpose were collected from over 10000 stations during oceanographic cruises of O.R.V. SAGAR KANYA between 1983 and 1998. The data covered the entire Indian ocean in different seasons. Initially, the entire data set was used to construct a polynomial between T_a and Q_a to arrive at a single relation for the entire Indian ocean. The RMS error in this case exceeded 1.6 which looked unrealistic (see Table 1). This is mainly due to the fact that spatial and temporal variation of T_a is of the order of 20 °C in the Indian ocean ranging from as low as 18 to as high as 38 °C. A closer look at the data over individual regions (Arabian sea, Bay of Bengal, equatorial ocean and southern ocean) revealed that maximum variation of T_a occurs over Arabian sea (18-38 °C) followed by Bay of Bengal (20-35 °C) and equatorial ocean (23-30 °C) and the least variation is in the southern ocean (23-27 °C).

In this situation, retrieval of sea surface air temperature (T_a) from sea surface humidity (Q_a) is possible only after one divides Indian ocean into several homogeneous subzones having lesser variations in surface air temperatures and then construct separate polynomials of Q_a versus T_a for each subzone.

3. Subzones for polynomial construction

We first divided Indian ocean into 4 natural regions namely, the Arabian sea, bay of Bengal, equatorial ocean and southern ocean and constructed separate polynomials for each of the regions. The corresponding RMS errors for the above regions were 2.7 for Arabian sea, 1.4 for bay of Bengal, 1.2 for equatorial ocean and 0.77 for southern ocean respectively. Thus, equatorial ocean and southern ocean were fairly homogeneous to be considered as subzones but Arabian sea and Bay of Bengal required further subdivisions by taking into consideration both spatial and seasonal variability within them. In case of Arabian sea, the RMS error was higher than that for the entire Indian ocean when considered in isolation. This is because most of the variation in T_a 's comes from Arabian sea. When Arabian sea and Bay of Bengal were subdivided into northern and central regions, the RMS errors were reduced to 1.78 and 1.35 for northern and central Arabian sea respectively. For bay of Bengal, the RMS errors were 1.29 (northern bay) and 1.2 (central bay) respectively. Table 1 shows these subzones, their locations, their mean surface air temperatures, RMS errors associated with each subzone and number of data points used for polynomial construction.

Table 1: Geographic subzones of Indian ocean

Sr No.	Subzone Description	Location	Mean Surface Air Temperature ($^{\circ}$ C)	No. of
1	Indian ocean (entire)	25N - 25S, 40E - 120E	27.48	
2	Arabian sea (entire)	25N - 5N, 40E - 80E	27.29	
3	Bay of Bengal (entire)	25N - 5N, 80E - 120E	27.71	
4	Equatorial ocean	5N - 5S, 40E - 120E	27.57	
5	Southern ocean	5S - 25S, 40E - 120E	24.35	
6	Northern Arabian sea	25N - 15N, 40E - 80E	26.83	
7	Central Arabian sea	15N - 5N, 40E - 80E	27.54	
8	Northern bay of Bengal	25N - 15N, 80E - 120E	27.24	
9	Central bay of Bengal	15N - 5N, 80E - 120E	27.89	

Higher RMS errors in Arabian sea and bay of Bengal even after subdividing them into northern and southern regions were due to the fact that a significant variation in T_a 's is seasonal rather than spatial.

Dividing the regions along geographical limits does not resolve the seasonal variation. The seasonal variation could be resolved only by a further subdivision of these regions for winter, summer and spring seasons respectively. Thus we have a total of 14 subzones for Indian ocean. Table 2 shows these subzones, their locations, their mean surface air temperatures, RMS errors associated with each subzone and number of data points used for polynomial construction.

Table 2: Geographic subzones of Indian ocean with climatic subdivision.

Sr No.	Subzone Description	Location	Mean Surface Air Temperature (°C)
1	Northern Arabian sea (winter)	25N - 15N, 40E - 80E	24.85
2	Northern Arabian sea (summer)	25N - 15N, 40E - 80E	26.58
3	Northern Arabian sea (spring)	25N - 15N, 40E - 80E	28.40
4	Central Arabian sea (winter)	15N - 5N, 40E - 80E	27.21
5	Central Arabian sea (summer)	15N - 5N, 40E - 80E	27.20
6	Central Arabian sea (spring)	15N - 5N, 40E - 80E	28.85
7	Northern bay of Bengal (winter)	25N - 15N, 80E - 120E	25.25
8	Northern bay of Bengal (summer)	25N - 15N, 80E - 120E	27.99
9	Northern bay of Bengal (spring)	25N - 15N, 80E - 120E	28.69
10	Central bay of Bengal (winter)	15N - 5N, 80E - 120E	26.87
11	Central bay of Bengal (summer)	15N - 5N, 80E - 120E	28.12
12	Central bay of Bengal (spring)	15N - 5N, 80E - 120E	29.02
13	Equatorial ocean	5N - 5S, 40E - 120E	27.58
14	Southern ocean	5S - 25S, 40E - 120E	26.35

4. Retrieval of air temperatures

The polynomial relationships between T_a and Q_a were established for each region having the following form

$$T_a = A + BQ_a + CQ_a^2 + DQ_a^3 \quad (2)$$

where A, B, C and D are constants and their values are listed in Table 3. Results for all subzones including the entire Indian ocean, Arabian sea, bay of Bengal and their further geographic and climatic subdivisions are presented in Table 3. In most cases, the polynomials are of second order requiring values only for A, B and C to compute surface air temperature. Thus, if one has values of satellite derived Q_a , obtained from Eq. (1), one can compute the sea surface air temperature T_a for any region in the Indian ocean at any time of the year by using Eq. (2) and the constants listed in Table 3. The results will be accurate within the RMS errors listed in Tables 1 and 2.

Table 3: Coefficients of polynomial equation for computation of surface air temperature for different subzones of Indian ocean

Sr no	Subzone description	A	B	C	D
1	Indian ocean (entire)	19.88	0.406	0.001	0.000
2	Arabian sea (entire)	19.96	0.349	0.003	0.000
3	Northern Arabian sea	26.22	-0.919	0.072	-0.011
4	Northern Arabian sea (winter)	34.11	-2.540	0.018	-0.004
5	Northern Arabian sea (summer)	14.03	0.946	-0.013	0.000
6	Northern Arabian sea (spring)	18.25	0.448	0.002	0.000
7	Central Arabian sea	9.95	1.690	-0.039	0.000
8	Central Arabian sea (winter)	15.29	1.080	-0.022	0.000
9	Central Arabian sea (summer)	5.60	2.040	-0.046	0.000
10	Central Arabian sea (spring)	9.26	1.100	0.036	-0.002
11	Bay of Bengal (entire)	20.28	0.443	-0.003	0.000
12	Northern bay of Bengal	39.39	-3.191	0.209	-0.004
13	Northern bay of Bengal (winter)	18.25	0.627	-0.010	0.000
14	Northern bay of Bengal (summer)	27.75	-0.276	0.014	0.000
15	Northern bay of Bengal (spring)	20.36	0.443	-0.001	0.000
16	Central bay of Bengal	17.07	0.823	-0.013	0.000
17	Central bay of Bengal (winter)	14.28	1.625	-0.030	0.000
18	Central bay of Bengal (summer)	20.45	0.042	-0.002	0.000
19	Central bay of Bengal (spring)	36.70	-1.120	0.037	0.000
20	Equatorial ocean	0.86	2.780	-0.072	0.000
21	Southern ocean	28.83	-1.133	0.057	0.000

It is seen that RMS error for Arabian sea is the highest among all the other regions. The error could not be significantly reduced even after dividing it geographically into northern and central region and further subdividing it into seasonal zones. Most of this error is located in the northern Arabian sea during winter and spring. As a result, determination of sea surface air temperature in northern Arabian sea is not advised by the method developed in the article. For the rest of the Indian ocean, Eq. (2) may be used to compute sea surface air temperature with a fair degree of reliability.

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Corresponding Author:

Mr. P. V. Sathe

National Institute of Oceanography

Dona Paula, Goa, India

E-mail: sathe@csnio.ren.nic.in
