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The Accuracy of SST Retrievals from NOAA-AVHRR in the Persian Gulf

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Abstract: In the present study, sea surface temperature of the Persian Gulf was estimated using NOAA-14-AVHRR data during the period of 1996-2000. The Persian Gulf, despite being a major economic and political region has not systematic marine measurement in particular that of sea surface temperature. In order to estimate sea surface temperature in areas where no data was available, an attempt has been made to use AVHRR (Advanced Very High Resolution Radiometer) data from NOAA (National Ocean and Atmosphere Administration) satellite 14. After computing SST from AVHRR data with the use Murty, Gowda and national center of remote sensing Australia algorithms were assessed with *in situ* Boushehr buoy sea surface temperature and a linear correlation was formulated to estimate sea surface temperature with a residual mean error of ±0.43 and $R^2 = 0.994$. Finally, this modified formula was tested in 2 months (September and December 1999) of NOAA-14 AVHRR images and Sea Surface Temperature (SST) was computed in the Persian Gulf. Considering this amount of error, time series temperature can be created with this method.

Key words: Sea surface temperature, split window, AVHRR, NOAA-14, Persian Gulf

INTRODUCTION

Temperature of water surfaces is the most important oceanic parameter, that effect on climatic, atmospheric systems and aquatic life. Changes in Sea Surface Temperature (SST) play a fundamental role in the exchange of energy, momentum and moisture between the ocean and the atmosphere (Wentz *et al*., 2000). SST is a central determinant of air-sea interactions and climate variability. SST also influences the development and evolution of tropical storms and hurricanes (DeMaria and Kaplan, 1994; Emanuel, 1999) is correlated with nutrient concentration and primary productivity (Kamykowski, 1987) and impacts the distribution of fishing grounds (Shao *et al*., 2004). SST is Also, main parameter for climatic and meteorological forecasting models and important characteristic for the modeling existing spatial and temporal expansion data, that in the usual measures have to be accomplished by maritime stable stations (buoy), boats and investigation ships in certain places and spatial expansion and in some cases temporal extension of data was limited, thus data collection is necessitate much expenses.

NOAA/AVHRR data has been especially emphasized on meteorology and oceanography studies due to its low-spatial and high-temporal resolutions. Thus, to begin activity of satellite search began using its data in meteorology and oceanography studies. In some primary years Smith *et al*. (1970) extracted preciseness around ±1 centigrade degree for estimate SST via nimbus data by statistic techniques. One of the first studies was done to produce SST via NOAA satellites by Stevenson *et al*. (1972).

The SST algorithm was based on Merchant *et al*. (1999), which applies the split window technique using Bands 4 and 5 (11 and 12 µm bands, respectively) that correct atmospheric water vapour (Fig. 1).

So, In Split window method the atmospheric correction participates in the calculation. Due to the absorption ability of energy by vapor and CO_2 as well as

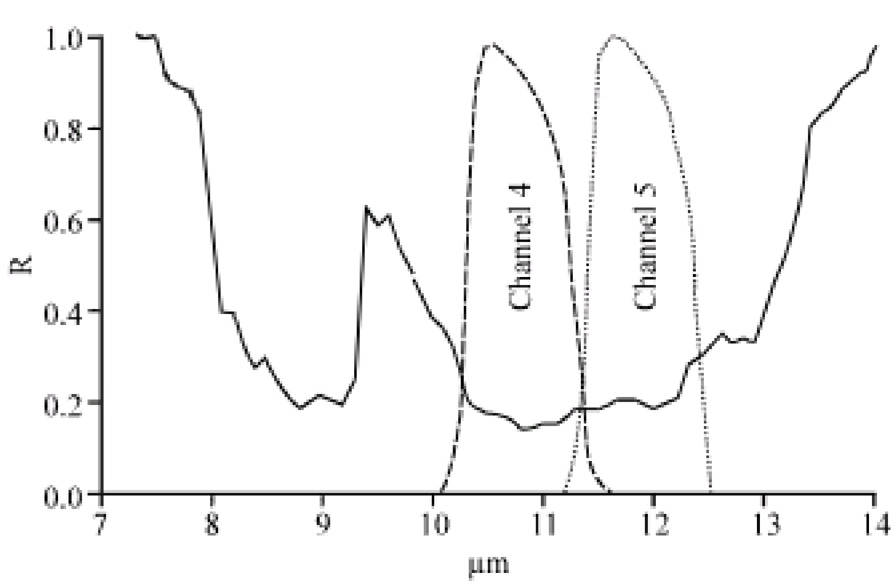

Fig. 1: Diagram of differences between absorption of radiation in 4 and 5 bands AVHRR

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ozone, the water surface temperature via satellites is forever less than estimated temperature in measured field data (Cogan and Willand, 1976).

One widely adopted linear formula is the multichannel SST (MCSST) (McClain *et al*., 1985), which applies to split-window observations, i.e., to brightness temperatures of a pair of channels within the atmospheric window between about 10 and 13 μm, the channels typically having peak sensitivity around 11 and 12 μm. In the MCSST, the retrieval equation is expressed in terms of the difference of the 11 and 12 μm BTs, a formulation which effectively imposes an additional linear constraint on the coefficients, a. In nearly linear formulations, the coefficients are weak functions of some prior information. One of such formulations is the Non-Linear SST (NLSST) algorithm, which is similar to the MCSST except the coefficient of the BT difference at 11 and 12 μm that is a function of a prior SST.

Coll *et al*. (1993), by using the split-window algorithm, determine SST in midlatitudes from NOAA-AVHRR data. The accuracy achieved for SST is 0.5°K, which is the limit accuracy that can be obtained from AVHRR measurements over midlatitudes.

The most expanded activity to accomplish via 3400 images is for a period of 8 years by Guerra *et al*. (1997) in the north-west shores of Africa.

Kearns *et al*. (2000) show that the mean difference between global Pathfinder SST products and SST recovered from a ship-mounted radiometer is 0.07±0.31°C for low and midlatitude data. Kilpatrick *et al*. (2001) state that the global Pathfinder SST product is within 0.02°C of buoy SSTs within their database, with a standard deviation of 0.53°C. Departures from these global statistics for local high resolution Pathfinder products which are used here may exist; however, the use of absolute SST values in this study is restricted to seasonal differences, significantly larger in range (>10°C) than any of the cited statistics. Other analyses focus on relative temperature patterns within scenes.

SST values, both *in situ* and satellite-derived, have been obtained from the NOAA/AVHRR for assessing rates of sea temperature increase (Strong *et al*., 2000).

The approximate root mean square error (RMSE) of the AVHRR SST retrievals is near 1.15°C (Mesias *et al*., 2007), from buoys located in the western North Atlantic and She *et al*. (2007) investigated SST in the Baltic Sea and North Sea, they concluded that the best available full-coverage SST product is generated by assimilating the SST observations to obtain a yearly mean model bias of 0.07°C and RMSE of 0.64°C.

The aim of this study is to investigate accuracy of SST retrievals algorithms in the Persian Gulf, using AVHRR data. Finally, we present a modified algorithm by using the regression analysis.

MATERIALS AND METHODS

In order to achieve the objects of the study, water (sea) surface temperature of Boushehr buoy over the Persian Gulf during 1996-2000 periods were obtained from Iranian Meteorological Organization (IRIMO) and for these periods images of AVHRR sensor of NOAA 14 satellite were obtained. The selected study area is located between 48° E to 56° E and 24° N to 30° N. This inland sea of some 251,000 km^2 is connected to the Gulf of Oman in the east by the Strait of Hormuz.

First, geometric correction was done in two ways: systematic and terrestrial point control and then, equivalent blackbody temperature computed from Eq. 1.

$$T_E^* = \frac{C_2 V_c}{\ln\left(1 + \left(\frac{C_1 V_c^3}{N_E}\right)\right)} \qquad (1)$$

where, T_E* is equivalent blackbody temperature (°K), V_c is value of central wave, where in 4 and 5 bands in turn are 929.3323 and 835.1647, C_1 and C_2 are constant coefficients, that in turn are 1.4387863 and 0.0000191062, N_E computed from Eq. 2.

$$N_E = (A * DN) + B \qquad (2)$$

where, N_E is Earth radiance value in units of mW/(m^2-sr-cm^{-1}), A and B are constant coefficients, where A in 4 and 5 bands in turn are -0.165526 and -0.18382 and B in 4 and 5 bands in turn are 160.22 and 179.598, DN = Digital Number in pixel.

Then, Brightness Temperature (BT) computed from Eq. 3. Where A and B are constant coefficients A in 4 and 5 band in turn is -0.338243 and -0.304856, B in 4 and 5 bands in turn are 1.001989 and 1.005977, T_E = BT.

$$BT = B \times T_E^* + A \qquad (3)$$

Because emissivity of water is approximately equal 1, thus BT is assumed to be equal to water surface temperature. Then, performance of the atmospheric corrections was computed from differences of absorption between 4 and 5 bands. These techniques are called split window algorithms.

In this study, SST was computed using MCSST. Several algorithms by researchers were presented for calculation of SST. In this study, the algorithms Murty *et al*. (1998), Eq. 4, Gowda *et al*. (1993) Eq. 6 and national center of remote sensing Australia Eq. 7 were used for calculation of SST (Downing and Williams, 1975):

$$SST(°C) = 1.02455T_{11} + 2.45(T_{11} - T_{12}) + 0.64(T_{11} - T_{12})(SECsza - 1) - 280.67 \quad (4)$$

where, T_{11} and T_{12} are the brightness temperatures corresponding to channel 4 and channel 5, respectively and the SECsza is the secant of satellite zenith angle. The difference between the brightness temperatures of channel 4 and channel 5 in the SST retrieval algorithm has been incorporated for correcting the effect of atmospheric water vapour absorption. Pixels are considered to be contaminated when the brightness temperature difference between the channel 4 and channel 5 is greater than the threshold value (2.5°K).

The satellite zenith angle (θ_i) is computed from:

$$\theta_i = \sin^{-1}[((R + h)/R)(\sin\phi_i)] \quad (5)$$

where R = radius of the earth (= 6378.388 km), h = height of the satellite (= 833 km), ϕ = look angle of the satellite = -55.4+(55.4i/1024) and i is the pixel number. The SST computations are performed only when the satellite zenith angle is less than 53° (Murty *et al*., 1998):

$$SST = 3.6548BT_4 - 2.6605BT_5 - 268.92 \quad (6)$$

$$SST = 1.017342BT_4 + 2.139588(BT_4 - BT_5) - 278.43 \quad (7)$$

RESULTS AND DISCUSSION

At first, we assessed Murty *et al*. (1998), Gowda *et al*. (1993) and national center of remote sensing Australia (Downing and Williams, 1975) algorithms for estimating SST of Persian Gulf. Later, by using linear regression analysis (LRA) was modified Murty *et al*. (1998) algorithm with best accuracy in Table 1 (column 6). Finally SST was computed with modified algorithm for two months in Table 1 (column 12).

Algorithms test: Accuracy assessment of algorithms for estimating SST of Persian Gulf comparison with Boushehr buoy has been shown in Table 1. According to this table Murty *et al*. (1998) algorithm has the best accuracy in rate of SST.

By using measured temperature data in Boushehr buoy and estimated temperature for 4 and 5 bands of AVHRR/2 sensor, Linear Regression Analysis (LRA) has been done to produce an equation, so that it can estimate SST via BT. In this study, the fit Linear method for production of an equation was Enter, that the temperature data in Boushehr buoy was as Dependant variable and 4 bands temperature and difference of temperature in 4 and 5 bands was as Independent variable.

Results of LRA are as follows: Correlation coefficient between variables (bands 4 and 5) was 0.977, $R^2 = 0.994$, constant was 1.331, coefficient of BT_4 was 0.987 and correlation difference between temperature in 4 and 5 bands was 0.183.

As a result the LRA produced an equation to assess the value of SST in the Persian Gulf. This equation was computed by using BT in 4 and 5 bands of AVHRR/NOAA 14 sensor. The equation is as follows:

$$SST = 0.987BT_4 + 0.183(BT_4 - BT_5) + 1.331 \quad (8)$$

In Eq. 8, the maximum of estimated error for SST in the Persian Gulf was 0.77, its minimum -0.09 and mean of error was ±0.43, it is an acceptable amount.

Finally, this equation was tested in 2 months (September and December 1999) of NOAA-14 AVHRR images and SST was computed in the Persian Gulf. For example, two images show SST in September and December 1999. Figure 2 shows the SST image in 4/09/1999 for the Persian Gulf, in this image SST differs

Table 1: Sample of images selected and results of calculation of algorithms

	Column											
Image	1	2	3	4	5	6	7	8	9	10	11	12
04/09/1999	35.05	33.59	31.91	1.68	36.65	-1.60	38.14	-3.09	37.73	-2.68	34.79	0.26
04/12/1999	22.05	20.97	19.71	1.26	23.13	-1.08	24.57	2.52	23.77	-1.72	22.26	-0.21

1: Measured temperature in Boushehr buoy, 2: Brightness temperature In 4 band, 3: Brightness temperature In 5 band, 4: Difference between 4 and 5 bands (BT4-BT5), 5: SST of calculated algorithm Murty *et al*. (1998), 6: Difference between column 1 and column 5, 7: SST of calculated algorithm Gowda *et al*. (1993), 8: Difference between column 1 and column 7, 9: SST of calculated algorithm national center of remote sensing Australia, 10: Difference between column 1 and column 9. 11: SST of produced algorithm, 12: Difference between column 11 and column 1

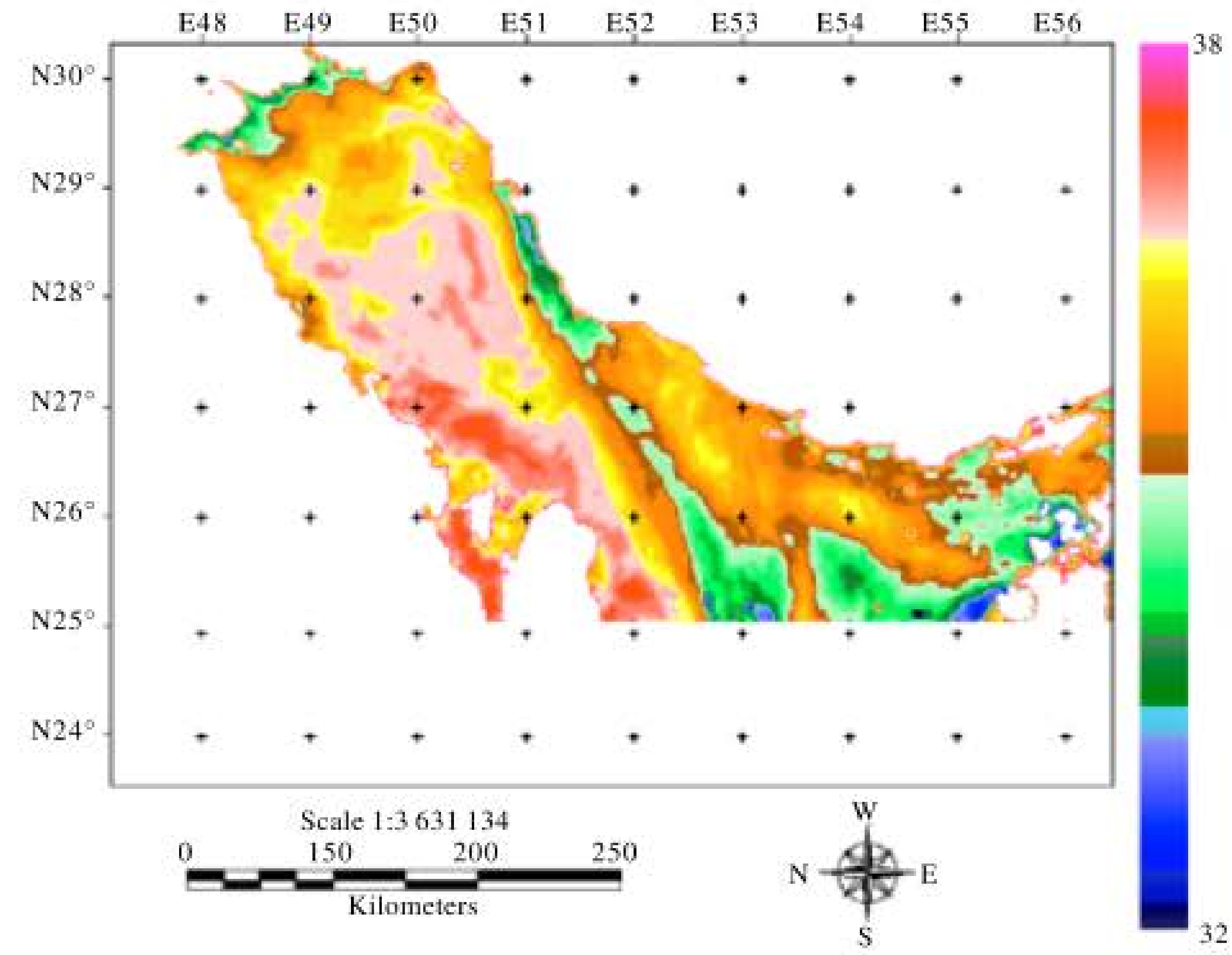

Fig. 2: Map of sea surface temperature the Persian Gulf in date 4/09/1999(°C)

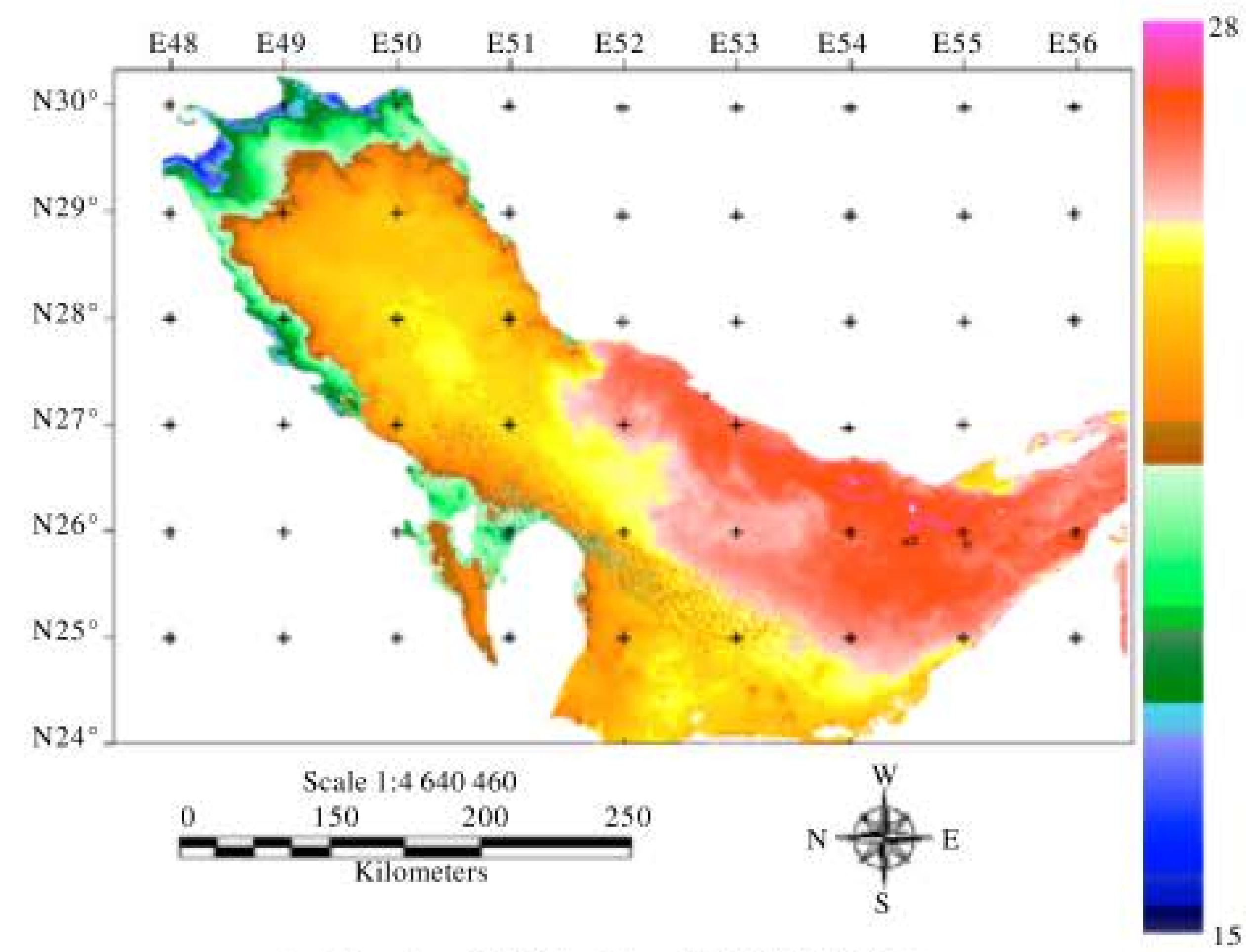

Fig. 3: Map of sea surface temperature the Persian Gulf in date 4/12/1999(°C)

from 32°C in the southern shore to 38°C in the southwestern shore. Mean of SST is 34.79°C in Table 1 (Column 11). In general the temperature is high in summer, because it is located near the tropic of cancer. So, the deserts are located around the Persian Gulf, which is high SST.

Figure 3 shows the SST image in 4/12/1999 for the Persian Gulf, in this image SST differs from 15°C in the northwestern shore to 28°C in the northern shore. Mean of SST is 22.26°C in Table 1 (Column 11). The temperature lowers in the northwestern shore because of the entrance of the water of the Shatt al-Arab (Arvand Rood) river to the Persian Gulf.

CONCLUSIONS

The presents study, firstly assessed the accuracy of SST retrievals algorithms with the NOAA-AVHRR satellite over the Persian Gulf. Secondly, SST an equation by using linear regression analysis (LRA) was produced.

Thirdly, this equation was tested on AVHRR images and SST computed in the Persian Gulf. The important findings of the study are:

- The AVHRR/ NOAA-14 images are suitable for generating the time series SST in the Persian Gulf
- Mean of error in formula was ±0.43, which is an acceptable amount
- In summer, the highest temperature was in the southwestern shore and the lowest temperature was in the southern shore and the difference between the highest and lowest was 6°C
- In the last autumn, the highest temperature was in the northern shore and the lowest temperature was in the northwestern shore and the difference between the highest and lowest was 13°C
- Different temperature in the summer was lower as compared with the last autumn, because it is located near the tropic of cancer

This study is an introductory work and we hope that it will be helpful in economical planning over the Persian Gulf and its surrounding countries.

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