Retrieval of Sea Surface Temperature from AMSR-E and MODIS in the Northern Indian Ocean

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Abstract—**The sea surface temperature (SST) is an important parameter of ocean environment. The remote sensing technology is an effective method to retrieve the sea surface temperature. In this paper, we studied the retrieval of sea surface temperature by using the brightness temperature data obtained from the Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E), the infrared data from the Moderate-resolution Imaging Spectroradiometer (MODIS) and in situ SST data from the Global Ocean Data Assimilation Experiment in the Northern Indian Ocean. The original brightness temperature data of the polarization channels from AMSR-E L2A and the original MODIS L1B thermal infrared data were preprocessed firstly, and then the retrieval model of AMSR-E SST was built on the multi-parameters linear regression, which based on the correlation of the AMSR-E brightness temperature and the in situ sea surface temperature. The MODIS SST was retrieved by Multichannel algorithm. Finally, we obtained the SST from the AMSR-E brightness temperature and MODIS SST by an AMSR-E and MODIS SST retrieval model developed by the multi-parameters linear regression. This retrieval model mainly relied on the AMSR-E brightness temperature while making the MODIS surface temperature subsidiary. Compared with the in situ SST, the root mean square error of retrieved result is 0.3240 ℃.**

Keywords-sea surface temperature; MODIS; AMSR-E; the Indian Ocean; remote sensing

I. INTRODUCTION

Sea Surface Temperature (SST) is a significant parameter in the ocean environment. SST refers to the temperature of the ocean skin (skin SST) in the remote sensing technology. SST has been performed with infrared and passive microwave sensors for many years. As early as 1975, considering the different absorption characteristics of the atmosphere in two adjacent spectral windows—— AVHRR 4 band and 5 band, McMillin had proposed the “split window" algorithm to retrieve the SST [1]. Combined the GMS infrared data with NOAA/TOVS water vapor data, Li Wanbiao retrieved the North Pacific sea surface temperature [2]. Wu Yumei discussed the relationship of the brightness temperature of the 12 channels of AMSR-E and the sea surface temperature, sea surface air temperature, humidity and wind speed, and established the multi-channel parameters regression equation [3]. Wang Yu built a surface temperature retrieval algorithm by using TMI aboard TRMM satellites in non-precipitation condition [4]. Kohtaro compared and analyze common four SST inversion algorithms: MCSST, WVSST, QDSST and NLSST by using Aqua/MODIS global ocean data, which showed that WVSST model has the highest precision, but it needed to obtain synchronous water vapor parameters [5]. In those data sources used for obtaining SST, thermal infrared remote sensing has higher spatial resolution, but its disadvantage is the impact of the atmospheric conditions, especially cloud cover. Due to the penetrability, Microwave offers a method to obtain SST in all weather and all time. However, it cannot get exactly retrieved result near the coast, because the microwave signal received by antenna side lobe is polluted by land [6]. In this paper, using the AMSR-E (Advanced Microwave Scanning Radiometer-Earth Observing System) brightness temperature data and the MODIS (moderate-resolution imaging spectroradiometer) infrared data on Aqua satellite, we studied the retrieval algorithm of SST and then compared the results with the in situ SST. The study area is the Northern Indian Ocean (Fig.1).

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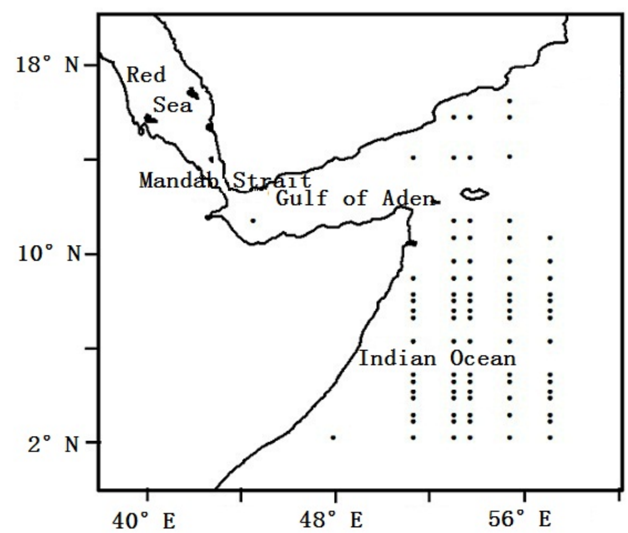

Figure1. Study area and distribution of in situ data points(• matching point)

II. DATA AND METHOD

In this paper, remote sensing data is MODIS L1B data and AMSR-E L2A brightness temperature data on Aqua satellite on January 7, 2010. The data is downloaded from the NASA website. We choose 31 and 32 far-infrared bands for MODIS SST retrieval. The selection of the AMSR-E bands is decided by the temperature sensitivity and spatial resolution of each band according to the correlation analysis. The in situ data is from the SFCOBS-GHRSST published by the Global Ocean Data Assimilation Laboratory. The in situ data points are shown in Fig.1 (85 points). The Fig.2 is the Technology flow chart.

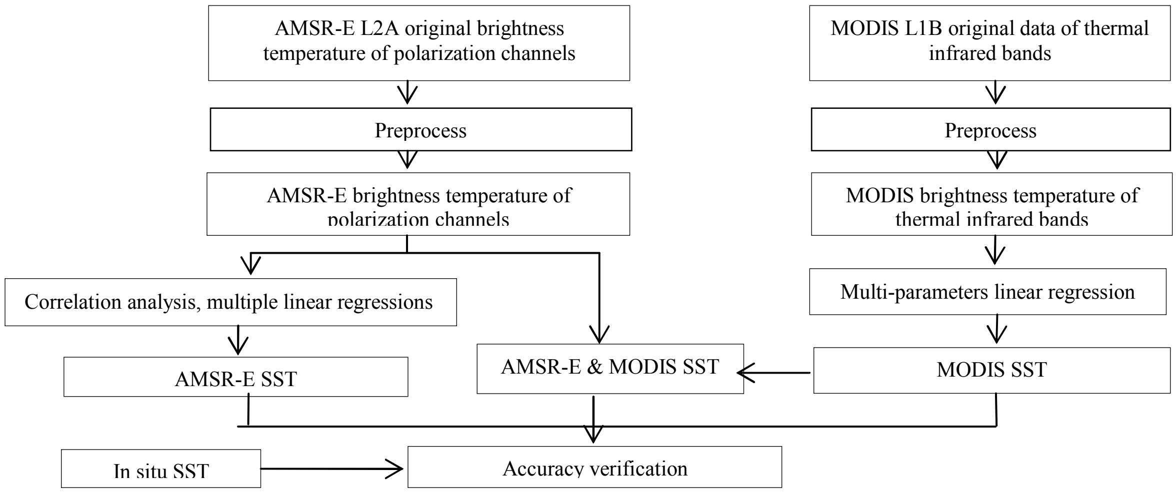

Figure2. Technology flow chart

III. RETRIEVAL OF SST

A. AMSR-E SST

Before establishing AMSR-E SST inversion model, the pretreatment of AMSR-E L2A data includes geographical calibration, brightness temperature calibration and land mask. We compute the correlation coefficients of SST and AMSR-E remote sensing parameters (Tab. I). 18.7GHz and 23.8GHz bands are chosen for AMSR-E SST retrieval. 18.7GHz and 23.8GHz dual-polarized channel brightness temperature and in situ SST are served as input parameters for Multi-element linear regression. Regression coefficients of equation and the confidence interval of the parameters are shown in Table II. The formula (1) is the inversion model of AMSR-E SST.

TABLE I. CORRELATION COEFFICIENTS OF SST AND AMSR-E REMOTE SENSING PARAMETERS

	In situ SST
T_{89V}	0.8685
T_{89H}	0.8675
$T_{36.5V}$	0.8756
$T_{36.5H}$	0.8667
$T_{23.8V}$	0.8987
$T_{23.8H}$	0.8987
$T_{18.7V}$	0.8953
$T_{18.7H}$	0.8926
$T_{10.65V}$	0.8281
$T_{10.65H}$	0.8100

TABLE II. MULTIPLE LINEAR REGRESSION COEFFICIENT FOR AMSR-E SST RETRIEVAL

Regression coefficient		Confidence interval
A_1	257.7965	[209.4171,306.1758]
A_2	0.0023	[-0.1794,0.1839]
A_3	-0.0439	[-0.3457,0.2580]
A_4	-0.1319	[-0.3549,0.0911]
A_5	0.3248	[-0.0443,0.6939]

$$SST = 257.7965 + 0.0023 \times T_{18.7H} - 0.0439 \times T_{18.7V} - 0.1319 \times T_{23.8H} + 0.3248 \times T_{23.8V} \quad (1)$$

Where $T_{18.7H}$, $T_{18.7V}$, $T_{23.8H}$, $T_{23.8V}$ represent horizontal and vertical polarization brightness temperature of 18.7GHz and 23.8GHz, respectively.

Fig. 3 is the remote sensing quantitative result of AMSR-E SST in the northern Indian Ocean using formula (1).

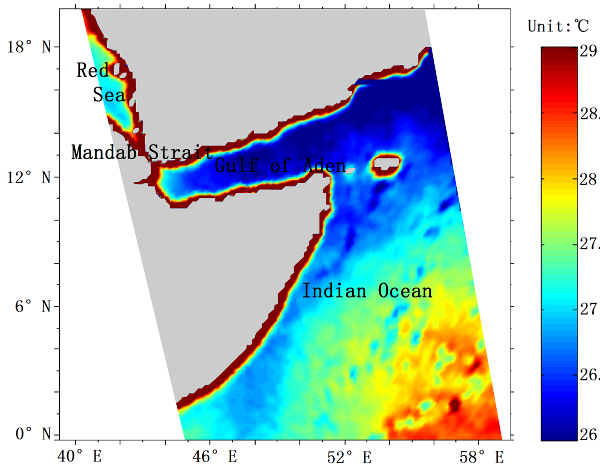

Figure3. AMSR-E SST in the northern Indian Ocean

According to Fig. 3, we find that all-weather SST products can be obtained by microwave remote sensing. But it cannot offer exactly retrieved SST result near the coast, because the microwave signal received by antenna side lobe is polluted by land. We calculate the average width of the polluted part by land in AMSR-E microwave image is about 75Km. So we need to make use of MODIS data to retrieve SST in the offshore area.

B. MODIS SST

Pretreatment of MODIS L1B data includes geographic calibration, eliminating the "bow" effect, radiometric calibration, land mask and cloud detection.

The linear multi-channel algorithm MCSST (Multi-Channel Sea Surface Temperature) is a routine SST statistical regression model, which can be expressed as follows [7]:

$$SST = C_1 + C_2 \times T_i + C_3 \times (T_i - T_j) \qquad (2)$$

Where, T_i and T_j is the brightness temperature of two thermal infrared bands, C_1, C_2 and C_3 are the regression coefficients of the model.

According to formula (2) and the features of MODIS thermal infrared bands, we select thermal infrared band 31 and 32 as the main inversion bands. T32, (T32-T31) and the in situ SST are served as input parameters, then adopt multiple linear regression to determine the coefficients of the model, the coefficients and the coefficients' confidence intervals are shown in Table III.

TABLE III. MULTIPLE LINEAR REGRESSION COEFFICIENTS FOR MODIS SST RETRIEVAL

	C_1	C_2	C_3
regression coefficient	318.4948	-0.0465	-0.8126
confidence interval	[306.6544,330.335]	[-0.0917, -0.0013]	[0.3763, 1.2489]

Applying the regression coefficients in Table III to formula (2), we get the inversion model of MODIS SST as follows:

$$SST = 318.4948 - 0.0465 \times T_{32} - 0.8126 \times (T_{32} - T_{31}) \qquad (3)$$

Fig. 4 is the remote sensing quantitative result of MODIS SST in the northern Indian Ocean using formula (3), in which the white areas are the pixels obscured by clouds.

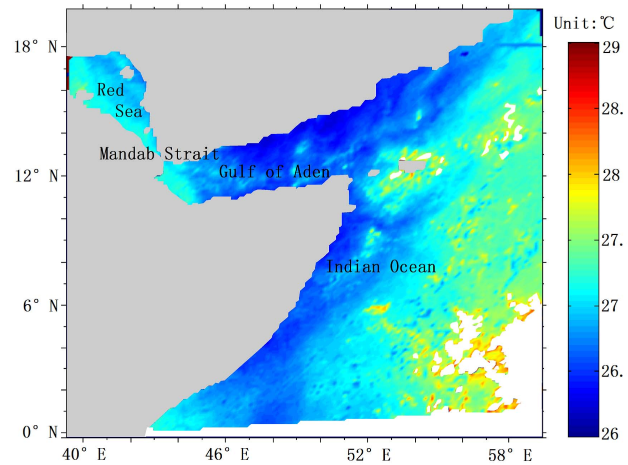

Figure4. MODIS SST in the northern Indian Ocean

From Fig. 4, we find that the eastern region generally suffers from the impact of cloud cover, especially at low latitudes, the impact is stronger.

C. Improved SST Retrieval Algorithm

In order to obtain all-weather sea surface temperature of the study area, we choose MODIS SST as the initial temperature field, the MODIS SST, 18.7GHz and 23.8GHz dual-polarized channels brightness temperature as remote sensing parameters to establish the SST inversion model (formula 4):

$$SST = C_0 sst_0 + C_1 T_{18.7H} + C_2 T_{18.7V} + C_3 T_{23.8H} + C_4 T_{23.8V} + C \qquad (4)$$

Where SST_0 is MODIS SST, $T_{18.7H}$, $T_{18.7V}$, $T_{23.8H}$ and $T_{23.8V}$ are horizontal and vertical polarization brightness temperature of 18.7GHz and 23.8GHz, respectively. C_0, C_1, C_2, C_3, C_4 and C are regression coefficients of the model.

Making multiple linear regressions with in situ SST, the regression coefficients and Confidence intervals are shown in Table IV:

TABLE IV. MULTIPLE LINEAR REGRESSIONS COEFFICIENTS FOR SST RETRIEVAL

Regression coefficient		**Confidence Interval**
C_0	0.2357	[-0.0121, 0.4836]
C_1	0.0673	[-0.1241, 0.2587]
C_2	-0.1333	[-0.4450, 0.1783]
C_3	-0.2061	[-0.4391, 0.0268]
C_4	0.4401	[0.0571, 0.8231]
C	183.4761	[91.9660, 273.9863]

For the offshore area (75km from the coast), we still use the MODIS SST inversion model. Applying the regression coefficients in Table IV to formula (4), we can get all-weather SST inversion model of whole area as follows,

$$SST=\begin{cases}318.4948-0.0465\times T_{12}+0.8126\times(T_{11}-T_{12}) & (L\le 75Km)\\ 0.2357\times sst_{0}+0.0673\times T_{18.7H}-0.1333\times T_{18.7V}-0.2061\times T_{23.8H} & \\ \quad +0.4401\times T_{23.8V}+183.4761 & (L>75Km)\end{cases} \tag{5}$$

Where L is the distance from the coast, other parameters are same as formula (3) and formula (4).

Fig. 5 is the remote sensing quantitative result of AMSR-E and MODIS data in the northern Indian Ocean using formula (5).

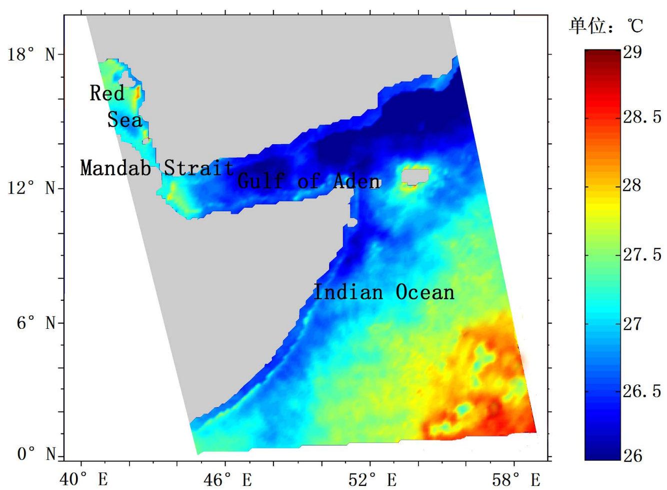

Figure5. SST in the northern Indian Ocean from AMSR-E and MODIS data

Compared with Fig. 3, Fig. 4 and Fig. 5, we find Fig. 3 can't obtain a higher accurate SST map in the area closed to land because the water signal that microwave antenna side lobes receiving is polluted by land signal. In Fig. 4, SST can't be obtained in some area because of cloud cover. But in Fig. 5, we can get all-weather SST products regardless of weather conditions. It is the combination of respective advantages of thermal infrared and microwave remote sensing technology.

D. *Accuracy verification*

The inversion results and the in situ SST are compared to verify the accuracy of AMSR-E SST, MODIS SST, and MODIS & AMSR-E SST (retrieved from both AMSR-E data and MODIS data). The in situ data is from SFCOBS-GHRSST published by Global Ocean Data Assimilation Experiment. Maximum absolute error, minimum absolute error, mean absolute error and root mean square error (RMSE) are shown in Table V. From the Table V, we can find that the largest absolute error appears in MODIS SST, the mean absolute error of AMSR-E SST is less than the MODIS SST, and the mean absolute error of MODIS & AMSR-E SST is the least. The root mean square error of MODIS & AMSR-E is 0.32397 that also less than the AMSR-E SST and MODIS SST. This indicates that the accuracy of MODIS & AMSR-E SST retrieval model is better than AMSR-E SST and MODIS SST.

TABLE V. SST RETRIEVAL ACCURACY VERIFICATION (UNIT: ℃)

Error	Maximum Absolute Error	Minimum Absolute Error	Mean Absolute Error	RMSE
MODIS SST	1.1041	0.0007	0.4307	0.50513
AMSR-E SST	0.7378	0.0023	0.2821	0.33124
MODIS&AMSR-E SST	0.7486	0.0065	0.2708	0.32397

IV. CONCLUSIONS

In this paper, we study the retrieval of sea surface temperature in the Northern Indian Ocean by using the remote sensing data obtained from two sensors - AMSR-E and MODIS aboard AQUA satellite. To obtain the brightness temperature of the AMSR-E polarization bands and MODIS thermal infrared bands, the original brightness temperature data of the polarization channels from AMSR-E L2A and the original MODIS L1B thermal infrared data are preprocessed firstly, and then the retrieval model of AMSR-E SST is built by multi-parameters linear regression, which base on the correlation among the AMSR-E brightness temperature and the in situ sea surface temperature. The MODIS SST is retrieved by Multichannel algorithm. In order to gain the all-weather sea surface temperature of the target area, we retrieve the SST from the AMSR-E brightness temperature and MODIS SST by an AMSR-E and MODIS SST retrieval model developed by the multi-parameters linear regression. This retrieval model mainly relies on the AMSR-E brightness temperature while making the MODIS surface temperature subsidiary. Compared with the in situ SST, the root mean square error of MODIS & AMSR-E SST is 0.32397℃ that is better than MODIS SST and the AMSR-E SST. The experiment shows it is an effective method to improve the accuracy of the sea surface temperature by giving priority to microwave remote sensing data and Optical remote sensing data as supplementary.

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