Assessment of Landsat8 TIRS Sea Surface Temperature Retrieval algorithms

Ji-An Wei[1,2], Difeng Wang[2]

[1]*Satellite Environment Center, Ministry of Environmental Protection, Beijing, China*

[2]*State Key Laboratory of Satellite Ocean Environment Dynamics, Second Institute of Oceanography, State Oceanic Administration, Hangzhou, China*

Abstract: High resolution SST estimation with thermal infrared onboard satellites is widely used in coastal regions for environmental monitoring. Landsat 8 Thermal Infrared Sensor (TIRS) provides two thermal channels, which supplies high resolution image and has a great benefit for the SST retrieval. In this paper, we compared SST retrieval approaches between split-window (SW) algorithm and single-channel (SC) algorithm from TIRS. SST errors due to sensitive input factors including water vapor content (WVC) and sea surface emissivity (SSE) were analyzed, and in-situ buoy data were collected for the two methods' validation. Results show that SW is less susceptible to WVC comparing with SC, whereas SW is more sensitive than SC as SSE deviation increase. An order of 0.1 g/cm^2 WVC deviation would introduce an average SST errors of 0.012**K** and 0.070**K** in SW and SC, respectively. 0.005 SSE change could yield SSE errors lower than 0.4**K** for SC, depending on WVC and sensor bright temperature. However, SSE errors of SW owning to SSE relies on WVC, a 0.005 change in the value of SSE would generate SST errors range from 0.2**K** to 0.4**K**, which lies on the SSE variations of one or both two thermal channels. With obtaining precise input factors (WVC and SSE), algorithms validation result indicate that SW possess higher measurement accuracy than SC with lower standard deviation and RMSE.

SST Algorithms

1. Single Channel Algorithm

On the basis of radiative transfer equation and Planck's law, a linear relationship between radiance and temperature was found from the Taylor series expansion and approximation around a certain temperature value by Jiménez-Muñoz *et al*. The SC algorithm was proposed by Jiménez-Muñoz *et al* [1] using the following general equation:

$$T_s = \gamma\left[\frac{1}{\varepsilon}(\psi_1 L_{sen} + \psi_2) + \psi_3\right] + \delta$$

$$\gamma \approx \frac{T_{sen}^2}{b_\gamma L_{sen}} \qquad \begin{bmatrix}\psi_1\\ \psi_2\\ \psi_3\end{bmatrix} = \begin{bmatrix}C_{11} & C_{12} & C_{13}\\ C_{21} & C_{22} & C_{23}\\ C_{31} & C_{32} & C_{33}\end{bmatrix}\begin{bmatrix}w^2\\ w\\ 1\end{bmatrix}$$

$$\delta \approx T_{sen} - \frac{T_{sen}^2}{b_\gamma}$$

where T_s is the sea surface temperature; ε is the sea surface emissivity; L_{sen} and T_{sen} is the at-sensor radiance and brightness temperature, respectively; and ψ_{1-3} are the parameters which related to atmospheric vapor w.

2. Split Window Algorithm

The basis of this technique is that the radiance attenuation for atmospheric absorption is difference at two different wavelengths. The mathematical structure of SW algorithm can be expressed as[2]:

$$T_s = T_i + a1(T_i - T_j) + a2(T_i - T_j)^2 + a0 + (a3 + a4w)(1 - \overline{\varepsilon}) + (a5 + a6w)\Delta\varepsilon$$

where T_i and T_j are the at sensor brightness temperature; $\overline{\varepsilon}$ is the mean emissivity, $\overline{\varepsilon} = 0.5(\varepsilon_i + \varepsilon_j)$; $\Delta\varepsilon$ is the difference emissivity, $\Delta\varepsilon = (\varepsilon_i - \varepsilon_j)$; w is the atmospheric water vapor content; $a0 \sim a6$ are regression coefficients which are derived from atmospheric sounding data.

Most SST algorithms require the computation of certain coefficients obtained from simulations that use atmospheric profile databases. Global Atmospheric Profiles from Reanalysis Information (GAPRI) is the first compilation of an ERA-Interim atmospheric profile presenting various vertical situations in different parts of the world (ocean, lakes, or continental areas) following the cloudless sky selection criteria, which was designed for earth surface temperature retrieval (Figure 1).

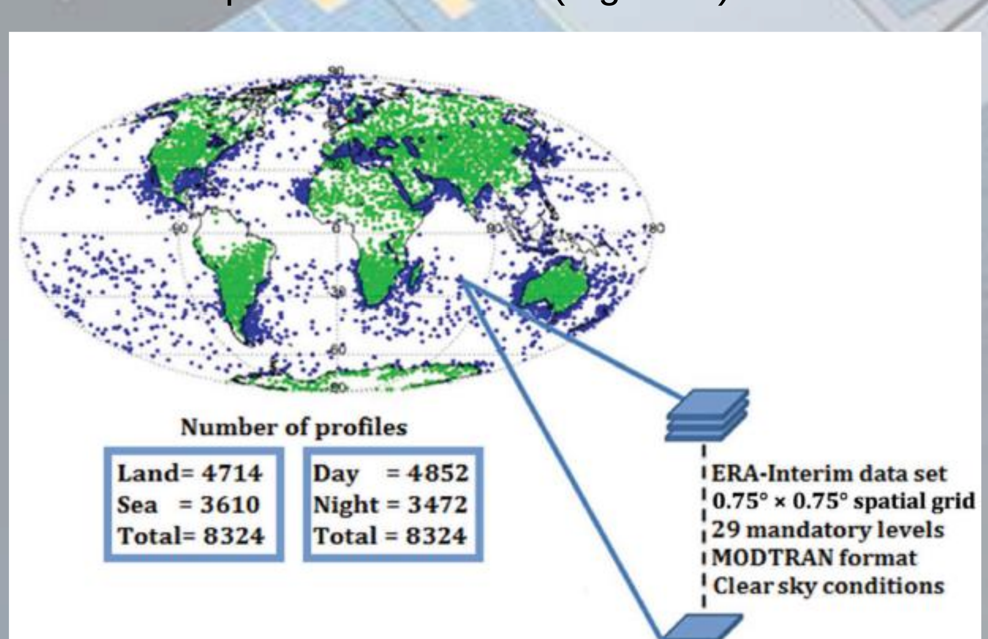

Figure 1. Location of atmospheric profiles extracted from ERA-Interim reanalysis to generate the GAPRI database. Green and blue points indicate profiles extracted over 'land' and 'sea' (*C. Matter et al. 2015*).

The Jiménez-Muñoz *et al* computed the regression coefficients of SC and SW algorithms with statistical fits performed over a simulated GAPRI database. The SC and SC Coefficients are as follows：

$$\begin{bmatrix}C_{11} & C_{12} & C_{13}\\ C_{21} & C_{22} & C_{23}\\ C_{31} & C_{32} & C_{33}\end{bmatrix} = \begin{bmatrix}0.04019 & 0.02916 & 1.01523\\ -0.38333 & -1.50294 & 0.20324\\ 0.00918 & 1.36072 & -0.27514\end{bmatrix}$$

$$\begin{bmatrix}a0 & a1 & a2 & a3\\ a4 & a5 & a6 & \end{bmatrix} = \begin{bmatrix}-0.268 & 1.378 & 0.183 & 54.30\\ -2.238 & -129.20 & 16.40 & \end{bmatrix}$$

Sensitivity Analysis

Both of the SC and SW algorithms are dependence on sea surface emissivity (SSE) and water vapor content (WVC). Therefore, it is very necessary to conduct sensitivity analysis of the algorithms in order to assess the impacts of the possible error of these critical parameters on the SST estimations. The following equation is used to evaluate the SST retrieval errors:

$$\Delta T_s = |T_s(x + \Delta x) - T_s(x)|$$

where ΔTs is the SST estimation errors as the possible error in variable Δx, which is the SSE and WVC in our case.

1. Water Vapor Content

Under controlled conditions of ε_{10} =0.991, ε_{11}=0.986 and actual WVC spanning from 0 to 5 g/cm^2, we analyzed the sensitivity of WVC.

Figure 2 depicts SST errors in SC algorithm because of deviation of WVC. The abscissas are deviation of WVC and the ordinates are the given actual input WVC. The Positive deviations of WVC produce negative SST errors, and vice versa at different brightness temperature levels. The positive

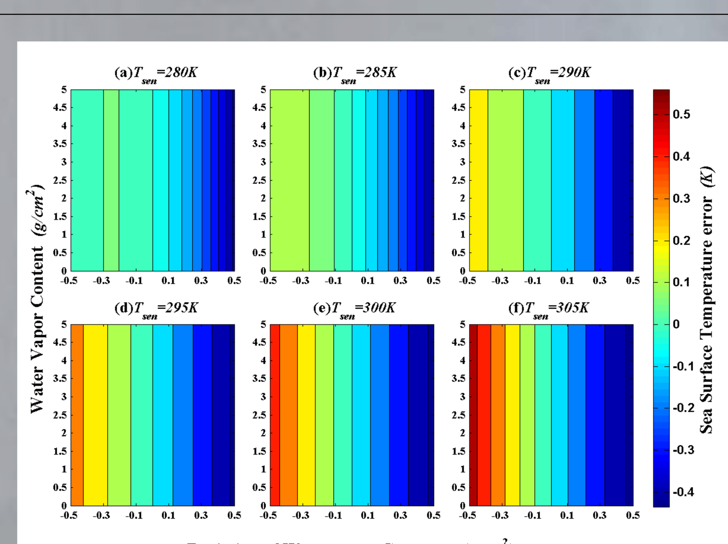

Figure 2. Plot showing the SC algorithm SST error due to deviation of WVC.

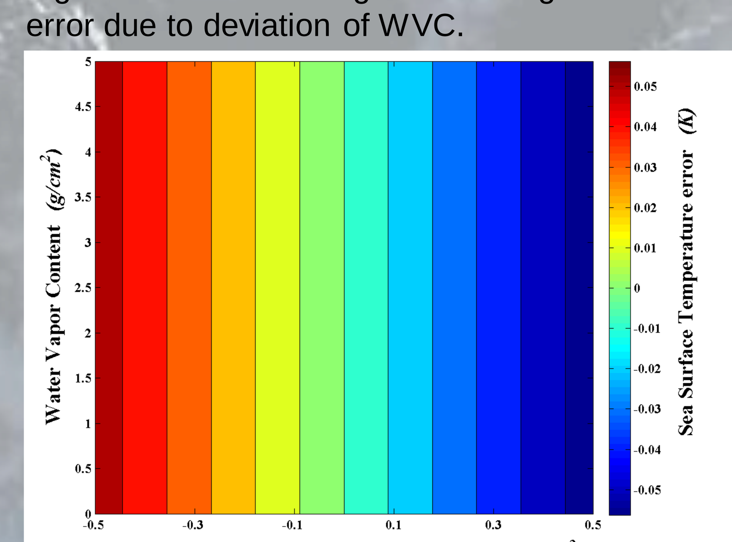

Figure 3. Plot showing the SW algorithm SST error due to deviation of WVC.

SST errors are slightly larger than negative ones at same WVC deviation level. An order of 0.1 g/cm^2 WVC difference would introduce an average SST error of 0.070 K for a given actual input WVC range from 0 to 5 g/cm^2. Similarity, Figure 3 shows SST errors derived from SW algorithm due to deviations of WVC. The average SST error due to 0.1 g/cm^2 change is 0.012K, which is less than SC algorithm.

2. Sea Surface Emissivity

An error in SSE estimation can occur simultaneously for both of the TIRS bands, but a separate error for each of the bands is possible.

We take ε_{10}=0.991 and ε_{11}=0.986 as the original emissivity for each channel. Figure 4 denotes SST error caused by the deviation of emissivity ε_{10}. Result shows that the positive deviation of WVC produce positive SST error, and vice versa at different brightness temperature levels. The SST error is greater than at low WVC. A 0.005 SSE change could yield average SST error lower than 0.4K for SC, depending on WVC and sensor brightness temperature. Figure 5 presents the example of a simultaneous SST error in both bands. The SST error become larger when absolute deviation of emissivity of each band, comparing with original emissivity, is bigger. However, SSE error of SW owning to SSE relies on WVC, 0.005 change in the value of SSE would generate SST average error of 0.2K ~ 0.4K , which lies on the SSE variations of one or both two thermal channels.

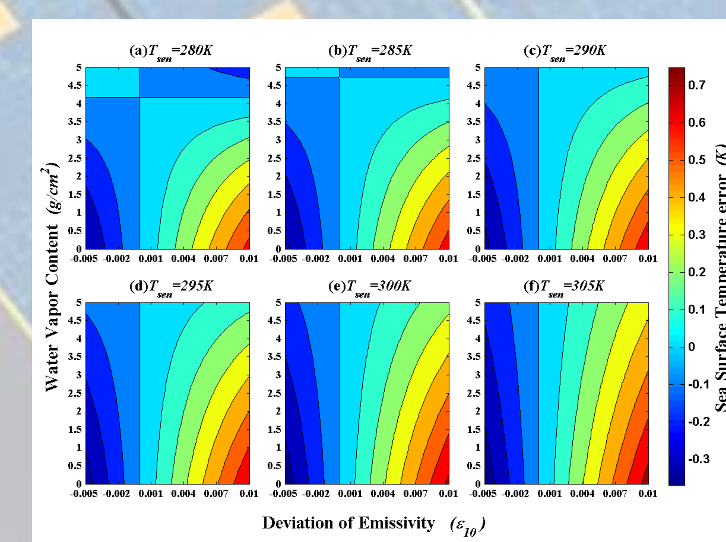

Figure 4. Plot showing the SC algorithm SST error due to deviation of SSE.

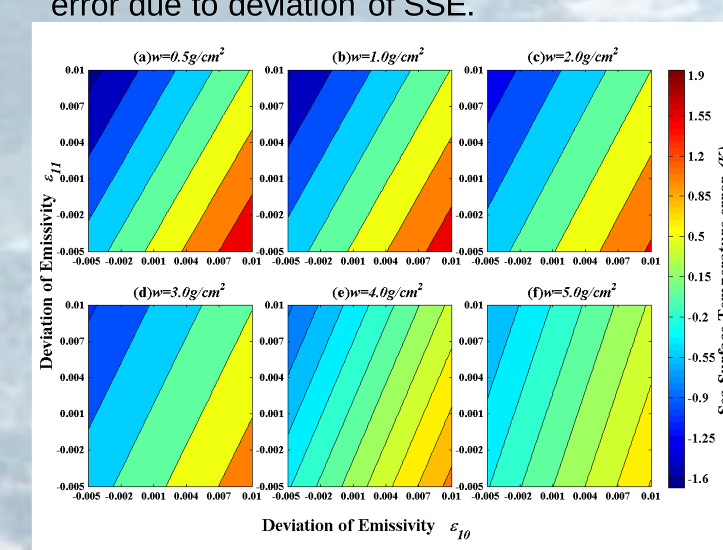

Figure 5. Plot showing the SW algorithm SST error due to deviation of SSE.

Validation of Algorithms

Fifty clean sky Landsat-8 scene images were collected since 2013 (image sensing and acquisitions from Dec.2014 to Mar. 2015 were removed, due to TIRS band11 was broken). In situ data used for validation (eighty points) were obtained from National Oceanographic Data Center (NODC) of the National Oceanic and Atmospheric Administration (NOAA). Considering input factors (WVC and SSE) in both algorithms, validation results indicate that SW (Figure 6. (b)) possess higher measurement accuracy than SC (Figure 6. (b)) with lower standard deviation and RMSE.

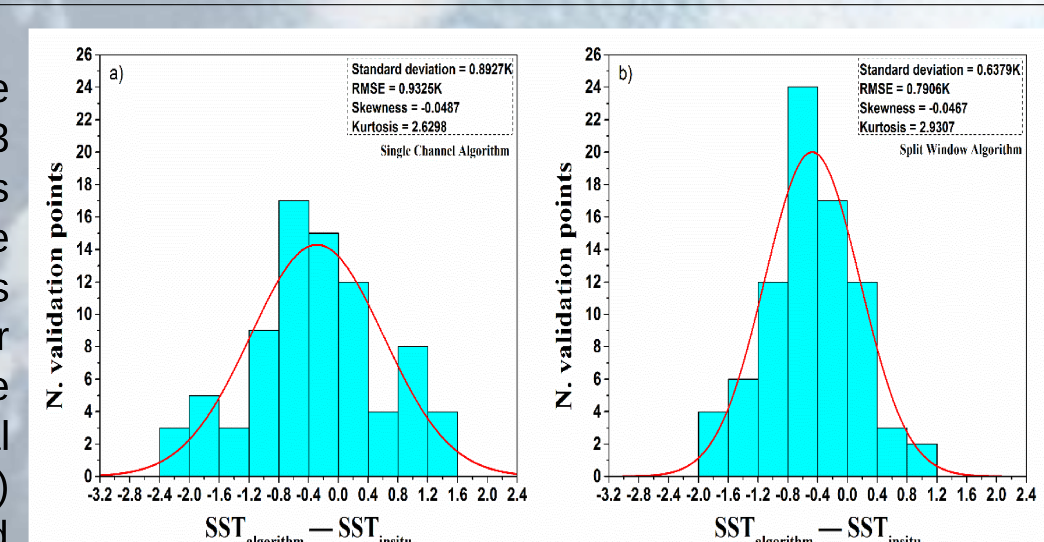

Figure 6. Histograms of the SST differences between the results of the algorithm and the in situ data

A Case of Coastal Region in West America

A cloud-free Landsat-8 image was acquired at UTC 18:40:30 on March 16, 2016. We used the MODIS WVC as the WVC of atmosphere when processing SST algorithms with Landsat-8 data.

In general, the pattern shown in Figure 7 (a) and (b) possesses similar chromatic attributes. Although there exists some difference in SST estimation result with the two algorithms (red square frame), the largest SST difference between SC and SW algorithm is lower than 0.25K. The SST retrieved from SC algorithm, ranges from 285.793 K ~ 290.030 K, with a mean value of 286.943 K and a standard deviation of 0.457 K. While SST retrieved from SW algorithm, ranges from 285.750 K ~ 290.019 K, with a mean value of 286.883 K and a standard deviation of 0.378 K.

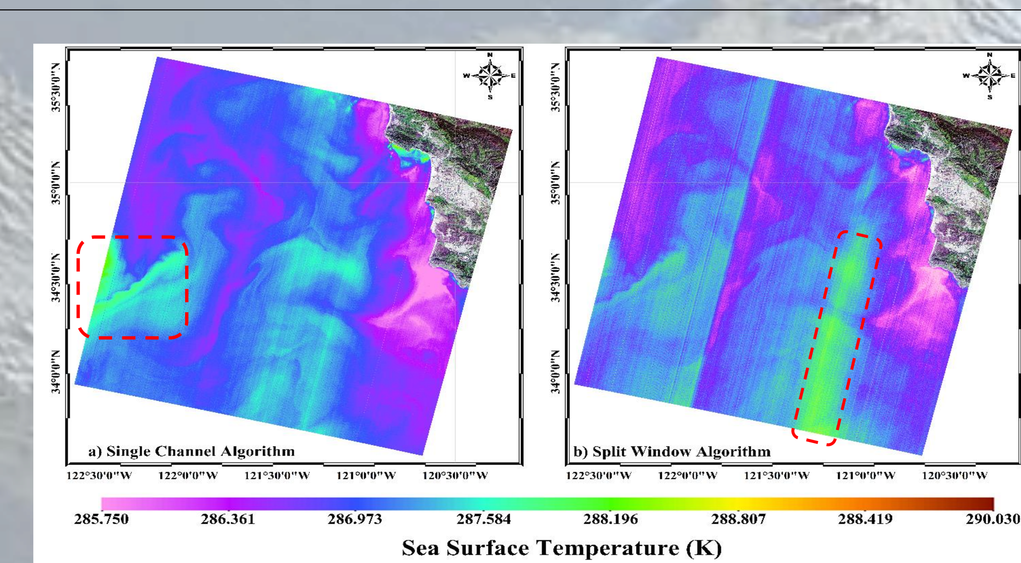

Figure 7. SST of coastal region. a) SC algorithm; b)SW algorithm

Conclusion

1) SC and SW algorithms are dependence on WVC and SSE.
2) SSE is more sensitive to SST result than WVC.
An order of 0.1 g/cm^2 WVC deviation would introduce an average SST errors of 0.012K and 0.070K in SW and SC, respectively. However, 0.005 SSE change could yield SSE errors lower than 0.4K for SC, while 0.2K ~ 0.4K for SW, which lies on the SSE variations of one or both two thermal channels.
3) Validation result show that indicate that SW algorithm possess higher measurement accuracy than SC algorithm with lower standard deviation and RMSE.