Research on Retrieving LandSAT8 Sea Surface Temperature Based on Neutral Regression Equations

Lu Huang1,2,a, Caiyun Zhang1,2,b*, Yan Li2, Hao Shao3, Qi Zhang1 and Xifan Yin1

1 Preparatory Office of Zhangzhou Base, NOTC, Xiamen, Fujian, China
2 College of Ocean and Earth Sciences, Xiamen University, Xiamen, Fujian, China
3 Unit No.91039 of PLA, Beijing, China;
aemail: huangyie321@163.com
bCorresponding author: email: cyzhang@xmu.edu.cn

Abstract. To verify the feasibility of applying Neutral Regression Equations to retrieve LandSAT8 sea surface temperature (SST), and compares the retrieval accuracy and difference of the two thermal infrared bands, this paper establishes Neutral Regression Equations based on 32 MODIS SST training points, and uses buoy SST and MODIS SST to validate and compare the retrieval results. The results show that the landSAT8 SST retrieved by these Equations has high accuracy and good consistency with MODIS SST. Buoy SST verification shows that the root mean square error (rmse) of the two bands is less than 0.5°C, and the deviations range is less than 1°C; MODIS SST verification shows that the mean deviation (bias) of the 10th and 11th bands are -0.16°C and -0.22°C, respectively, and their deviations range is basically within ±1°C; the retrieval accuracy of the 10th band is higher than that of the 11th band. Using Neutral Regression Equations to monitor the thermal discharge from Houshi Power Plant has achieved a wonderful effect, the temperature rise plume is jet-like, and affects a large range with a total area of 1.88km² and a maximum thermal pollution distance of 2.5km.

1. Introduction

Sea surface temperature (SST) is an important variable connecting the atmosphere and the ocean boundary layer. On a global scale, SST contributes to an in-depth understanding of the earth's heat balance [1], climate change [2], and large-scale SST anomalies, such as El Niño [3] and La Niña [4]; on a local scale, SST is also used to study fronts [5], fishing grounds [6], chlorophyll [7], ocean thermal pollution [8] and other small-scale temperature events. Satellite remote sensing can easily obtain large-scale or even global SST data, with the characteristics of fast data updating, low cost, and long-term repeated observation, so it has become an important way for people to monitor the spatiotemporal changes of SST. The commonly used remote sensing data sources have Terra and Aqua MODIS, NOAA19 and Metop-B/C AVHRR, JPSS1 VIIRS, which SST retrieval algorithms are relatively mature and have high accuracy, while the ability to analyze coastal water or small-scale oceanographic phenomena is still limited due to their spatial resolution of 1km-5km.

Some high-resolution earth observation sensors, such as LandSAT TM/ETM+/TIRS, HJ-1B IRS, CBERS IRMSES, provide good data sources for people to monitor small-scale SST changes. Among them, the LandSAT series satellites have been providing high quality thermal infrared data to the public since 1982, the latest in orbit LandSAT8 satellite has two thermal infrared bands, the 10th and 11th band, with central wavelengths of 10.9μm and 12.0μm, respectively, their return period is 16 days, and spatial
resolution is 30m after resampling. The remote sensing retrieval algorithms related to LandSAT8 SST mainly include Mono Algorithm [9], Generalized Single Channel Method [10] and Radiative Transfer Equation Method [11] and Split Window Algorithm [12], etc. Given the relatively homogeneous underlying surface of the ocean, many scholars [13-15] ignore the atmospheric effects and use the empirical regression method to establish the correlation between LandSAT TM/ETM and real SST to retrieve LandSAT5/7 SST. This method does not need to study the physical meaning of the formula and avoids the cumbersome atmospheric correction process, so it is very simple and fast. But it also results in the situation that there will be two different regression equations for the same group of regression data points, to minimize the fluctuation and variability of the regression coefficients, some scholars [16] proposed to establish Neutral Regression Equations to minimize the sum of the squares of the distances from the points on this regression line to the two regression lines \( y = a_1 + b_1 \cdot x \) and \( x = a_2 + b_2 \cdot y \), however, this Equation is rarely used to retrieve LandSAT8 SST. Besides, the frequency setting, signal-to-noise ratio, and radiation resolution of LandSAT8 satellite have been greatly changed compared with the previous LandSAT5/7 satellites, the actual retrieval effects and differences between the two thermal infrared bands need to be further verified and compared, but such work has rarely been carried out.

So, this paper proposes to establish Neutral Regression Equations to retrieve LandSAT8 SST, and uses buoy SST and MODIS SST to validate and compare the retrieval results of the two thermal infrared bands, finally, the thermal discharge from Houshi Power Plant is taken as an application case of this Equation.

2. Data and methods

2.1. Study area

Taking Xiamen bay and its surrounding sea area as the study area, five sections were delineated to the east of the Houshi-Weitou line, as shown in Figure 1, and 32 training points are randomly and uniformly selected in these sections. These points are under strict quality control to avoid interference from clouds, islands, ships, buoys, and other mixed pixels; secondly, the temperature range of the training points should be representative, in this paper, it is 13.04°C -14.35°C, which can cover 75% of the temperature range of the study area.

2.2. Data source and preprocessing

The 10th and 11th bands grayscale images of LandSAT8 and the Aqua MODIS SST on the same day are downloaded from the U.S. Geological Survey (http://glovis.usgs.gov/) and the NASA Ocean color Satellite website (https://oceancolor.gsfc.nasa), respectively, the time is January 27, 2014, these images have good quality with clear sky condition, less cloud coverage, and uniform water vapor content. The buoy SST data are obtained from Fujian Provincial Marine Forecasting Station (http://www.fjhyyb.cn/), and all of them are distributed in the coastal area, far away from the position of training points, which
can better verify the retrieval accuracy of the Neutral Regression Equation in the coastal area. Use Envi5.3 software to perform geometric precision correction on the two thermal infrared images, and accurately register them with MODIS SST image; separate water and land, mask non-water pixels, and retain pure water pixels as much as possible; finally cut out the study area.

2.3. Neutral Regression Equation

This Equation is expressed as:

\[ y = b_{yx} \cdot x + a_{yx} \]  

where \( y \) and \( x \) represent LandSAT8 SST and LandSAT8 DN values of 10th or 11th band, respectively, and the slope \( b_{yx} \) is calculated by the following equation:

\[ b_{yx} = \left[ \frac{b_1}{b_2} \right]^{1/2} \]  

Regression equation 1 established based on training points:

\[ y_i = a_1 + b_1 \cdot x_i \]  

Regression equation 2 established based on training points:

\[ x_i = a_2 + b_2 \cdot y_i \]  

\( y_i \) and \( x_i \) represent MODIS SST and LandSAT8 DN values of the 10th or 11th band corresponding to the \( i \)th training point respectively; \( a_{yx} \) is obtained by substituting the intersection point of equations (3) and (4) into equation (1).

The linear regression results of equations (1), (3), and (4) are shown in Figure 2. Among them, the blue line and the green line represent the regression line of MODIS SST to DN values and the regression line of DN values to MODIS SST respectively; the red line represents the Neutral Regression line, and the fitting coefficients \( r \) of the 10th and 11th bands are 0.934 and 0.879, respectively, which shows that it has a strong correlation between the DN values of the two LandSAT8 thermal infrared bands and MODIS SST. The calculated Neutral Regression Equations of the 10th and 11th bands as follows:

\[ \text{SST}_{10} = 0.002713 \cdot \text{DN}_{10} - 46.3759 \]  

\[ \text{SST}_{11} = 0.004867 \cdot \text{DN}_{11} - 86.5112 \]

Figure 2. Linear regression results of LandSAT8 10th and 11th bands.

3. Results & discussion

3.1. Accuracy validation

The buoy SST verification results are shown in Table 1. The SST \( rmse \) of the two bands is less than 0.5°C, and the deviations range is less than 1°C. Because the training points used to establish the Neutral Regression Equations are mainly outside of the bay, and the buoy SST points used for accuracy
verification are inside of the bay, so it is not difficult to see that this Equation has a good effect of "extending" to the bay. Further comparison shows that the SST bias and rmse of 10th band are -0.24°C and 0.28°C, respectively, which has a smaller retrieval error than the 11th band, the latter is -0.40°C and 0.49°C.

The MODIS SST verification results are shown in Figure 3. The SST biases of the 10th and 11th bands are -0.16°C and -0.22°C, respectively, and the deviations range is basically within ±1°C. The difference between landSAT8 SST and MODIS SST in cold water area (left side of Figure 3) and warm water area (right side of Figure 3) is about 1°C, and there is no particularly large fluctuation, which indicating that LandSAT8 SST retrieved by the two bands maintains good consistency with MODIS SST over the entire study area, and it overcomes the temperature jump in the high or low-temperature area to a great extent.

Further comparing the SST differences of the two bands, similar to the buoy SST verification results, SST deviations of the 10th band are more convergent around the bias line, and its bias is also closer to 0, so we can see that the 10th band is better than the 11th band in terms of SST retrieval accuracy.

| Band                | Deviations range | Bias  | Rmse  |
|---------------------|------------------|-------|-------|
| SST10-SST<sub>in situ</sub> | (-0.35) - (-0.13) | -0.24 | 0.28  |
| SST11-SST<sub>in situ</sub> | (-0.72) - (-0.19) | -0.40 | 0.49  |

Figure 3. MODIS SST accuracy verification.

### 3.2. Spatial distribution of LandSAT8 SST

The SST distribution of landSAT8 10th and 11th bands is shown in Figure 4. SST spatial distribution of the two bands is consistent with that of MODIS SST, e.g., the SST gradually decreases from the outer sea to the nearshore, and then increases towards the inside of the bay. The spatial features reflected by LandSAT8 SST are much richer than those of MODIS SST, which can identify the temperature gradient changes and its frontal features more clearly, because radiation resolution of LandSAT8 satellite image is extended from LandSAT5/7’s 8-bit to 16-bit, as a result, the improvement of radiation resolution correspondingly increases the sensitivity to detect ground targets. Besides, the LandSAT8 SST coverage also includes coastal waters, where often lacks high-quality MODIS SST data, so LandSAT8 SST can be used as a means to fill the data gap in these areas.

Further comparison finds that the SST distribution of the 10th band is closer to MODIS SST than that of the 11th band, it can better reflect the distribution characteristics of high-temperature water bodies in the outer sea and low-temperature water bodies on the north-south sides of Kinmen Island, while these low-temperature features have an obvious position shift on the image of the 11th band, above conclusions are also supported by the more serious on-satellite calibration uncertainty on the 11th band image than that on the 10th band image. In summary, whether the accuracy verification results or the reflected SST spatial characteristics, using the 10th band image to retrieve LandSAT8 SST is more advantageous than the 11th band image.
3.3. Application of monitoring thermal discharge from Houshi Power Plant

The location of the Houshi Power Plant is shown in Figure 1, it started operation in November 1999, with a total installed capacity of 3.6 million KW. This power plant belongs to surface heat emissions, compared with bottom emissions, this type of emissions usually has a more significant effect on temperature rise. Cut out the study area of Houshi Power Plant based on LandSAT8 SST image of the 10th band, as shown in Figure 5. Count the average SST outside of the power plant as the background temperature, and calculate the thermal pollution ranges of temperature rise 0-1°C, 1-2°C, 2-3°C, 3-4°C, and above 4°C, as shown in Table 2.

LandSAT8 SST retrieved by Neutral Regression Equation can clearly see the traces of the temperature rise plume near the outlet of the power plant, the closer to the outlet, the greater the temperature rise; the temperature rise plume is jet-like and presents an obvious gradient change, the farther away from the outlet, the larger the diffusion area. The total area of temperature rise is 1.88 km², and the maximum thermal pollution distance can reach 2.5 km, which shows that the thermal pollution of this power plant has a large range of influence.

| Temperature rise area (km²) | Total area (km²) | Maximum distance (km) |
|-----------------------------|------------------|-----------------------|
| 1-2°C                       | 0.90             | 2.51                  |
| 2-3°C                       | 0.65             |                       |
| 3-4°C                       | 0.32             |                       |
| >4°C                        | 0.01             |                       |

The Neutral Regression Equation provides a simple method for fast retrieving LandSAT8 SST, but attention should be paid to the use of this method: the LandSAT8 images selected in this paper have better quality with uniform water vapor content, while in summer, the water vapor content is usually higher or there are more thin clouds that are not easily removed, so in the above case its retrieval accuracy needs to be further verified.
4. Conclusions
This paper discusses the feasibility of using the Neutral Regression Equation to retrieve LandSAT8 SST and compares the retrieval accuracy and difference of the two thermal infrared bands. The main conclusions obtained are as follows:

1) There is a strong correlation between the DN values of the two LandSAT8 thermal infrared bands and MODIS SST, the fitting coefficients of the 10th and 11th bands are 0.934 and 0.879, respectively.

2) The LandSAT8 SST retrieved by the Neutral Regression Equation has high accuracy and maintains good consistency with the MODIS SST. Buoy SST verification results show that the SST $\text{rmse}$ of the two bands is less than 0.5 °C, and the deviations range is less than 1°C. MODIS SST verification results show that the SST $\text{bias}$ of the 10th and 11th bands are -0.16°C and -0.22°C, respectively, and the deviations range is basically within ±1°C. Regardless of the accuracy verification results or the reflected SST spatial characteristics, the 10th band has a better SST retrieval effect than the 11th band, and it is more suitable for retrieving LandSAT8 SST.

3) The Neutral Regression Equation has achieved good results in monitoring thermal discharge from Houshi Power Plant, the temperature rise plume is jet-like, and presents an obvious gradient distribution; The total area of temperature rise is 1.88 km², and the maximum thermal pollution distance can reach 2.5 km, which show that the thermal pollution of this power plant has a large range of influence.

Acknowledgments
Thanks to the National Key Research and Development Program (2016YFE0202100) and the National Natural Science Foundation of China (U1805241) for funding.

References
[1] Anika, A., Suryachandra, A.R., Chattopadhyay, R., et al. (2016) Role of Indian Ocean SST variability on the recent global warming hiatus. Global and Planetary Change, 143: 21-30.
[2] Harrison, L., Funk, C., Mcnally, A., et al. (2019) Pacific Sea Surface Temperature Linkages with Tanzania's Multi-season Drying Trends. International Journal of Climatology, 39: 3057-3075.
[3] Wang, M., Guo, J.R., Song J., et al. (2020) The correlation between ENSO events and sea surface temperature anomaly in the Bohai Sea and Yellow Sea. Regional Studies in Marine Science, 35: 101228.
[4] Bhavani, T., Chowdary, J.S., Bharathi, G., et al. (2017) Response of the tropical Indian Ocean SST to decay phase of La Niña and associated processes. Dynamics of Atmospheres & Oceans, 80: 110-123.
[5] Mustapha, Slima, Ben, et al. (2016) Spatial and temporal variability of sea-surface temperature fronts in the coastal Beaufort Sea. Continental Shelf Research, 124: 134-141.
[6] Ashida, H., Okochi, Y., Ohshimo, S., et al. (2021) Differences in the reproductive traits of Pacific bluefin tuna Thunnus orientalis among three fishing grounds in the Sea of Japan. Marine Ecology Progress Series, 662: 125-138.
[7] Huynh, H., Alvera-Azcárate, A., Beckers, J. (2020) Analysis of surface chlorophyll associated with sea surface temperature and surface wind in the South China Sea. Ocean Dynamics, 70: 139-161.
[8] Yavari, S.M., Qaderi, F. (2020) Determination of thermal pollution of water resources caused by Neka power plant through processing satellite imagery. Environment Development and Sustainability, 22: 1953-1975.
[9] Qin, Z. H., Kamieli, A., Berliner, P.A. (2001). Mono-algorithm for retrieving land surface temperature from Landsat TM data and its application to the Israel-Egypt border region. International Journal of Remote Sensing, 22: 583-594.
[10] Jiménez-muñoz, J.C., Sobrino, J.A. (2003) Generalized single-channel method for retrieving land surface temperature from remote sensing data. Journal of Geophysical Research, 108: 1-9.
[11] Huang, L., Zhang, C.Y., Li, Y. (2020) Two improved Radiative Transfer Equation Algorithm for retrieving sea surface temperature from HJ-1B IRS data. Journal of Marine Sciences, 38: 1-7.
[12] Rozenstein, O., Qin, Z.H., Derimian, Y., et al. (2014) Derivation of Land Surface Temperature for Landsat-8 TIRS Using a Split Window Algorithm. Sensors, 14: 5768-5780.

[13] Miller, R.L., Liu, C.C., Buonassissi, C.J., et al. (2011) A Multi-Sensor Approach to Examining the Distribution of Total Suspended Matter (TSM) in the Albemarle-Pamlico Estuarine System, NC, USA. Remote Sensing, 3: 962-974.

[14] Shahi, N.R., Agarwal, N., Mathur, A.K., et al. (2011) Atmospheric correction for sea surface temperature retrieval from single thermal channel radiometer data onboard Kalpana satellite. Journal of Earth System Science, 120: 337-345.

[15] Han, H., Lee, H. (2012) Inter-satellite atmospheric and radiometric correction for the retrieval of LandSAT sea surface temperature by using Terra MODIS data. Geosciences Journal, 16: 171-180.

[16] Sprent, P., Dolby, G.A. (1980) The geometric mean functional relationship. Biometrics, 36: 547-550.