The thermal discharge retrieve and analysis of Hongyanhe district with Landsat-8 and GF-5 Image

Yuanlin Liu¹, Shutao Huang, Piyuan Yi and Ding Wu

Beijing Research Institute of Uranium Geology, National Key Laboratory of Remote Sensing Information and Image Analysis Technology, Beijing 100029, China

¹E-mail: liuyuanlin89@126.com

Abstract. This paper based on the method of radiance transfer equation retrieved sea surface temperature (SST) of Hongyanhe district with the Landsat-8 and GF-5 Data. By the analysis of maximum value, average value and mean square deviation of the remote sensing image, this paper characterized the influence of thermal discharge water on the near coast region, discussed the uncertainty of remote sensing retrieve process. Furthermore demonstrated the advantages of GF-5 data in the application of SST monitoring.

1. Introduction

The sea water warming effect caused by the thermal drainage of nuclear power plant is not only an important factor of the environmental impact assessment, but also a direct reflection of the operation status of nuclear power plant. The warmer seawater is easy to cause excessive reproduction and invasion of some aquatic organisms. Jellyfish and algae have blocked the cooling system of nuclear power plants for many times around the world, resulting in emergency shutdown of nuclear power plants, which has become an outstanding danger to the nuclear facilities.

Using the thermal infrared remote sensing technology to retrieve temperature has the advantages of wide monitoring range, low cost and fast speed. Compared with the land, the ocean is not affected by the terrain fluctuation, the retrieve accuracy is higher [1-3]. The research of using Landsat and Modis satellites data to monitor power plant thermal discharge has been common, and already applied in Dayawan, Tianwan, Hongyanhe power plants, and achieved desired results [4-6]. The technical of using foreign satellite data is mature, but when it is used in nuclear emergency and nuclear safety fields, there are some disadvantages, such as difficult access to data, poor timeliness, which are difficult to meet the specific needs.

Chinese GF-5 satellite launched successfully in 2018. It not only has higher parameter indicators, but also has the advantages of completely independent controllability, and has opened special data acquisition channels. At present, there have been temperature retrieve and thermal discharge monitoring studies based on GF-5 in the academic community [7-9]. However, due to many factors GF-5 has not yet formed an industrial application; the technical methods are also in the experimental stage.

On this basis, this study compares the SST retrieve results of Landsat 8 and GF-5, to analysis the effect of thermal discharge in Hongyanhe area. And try to discuss the feasibility and reliability of the application of GF-5 to meet the needs of nuclear emergency and nuclear safety.
2. Experimental data and algorithm

2.1. Experimental data
In this study, 18 scenes of Landsat-8 satellite image and 1 scene of GF-5 VIMS image were collected, as listed in Table 1.

Table 1. Remote sensing image used in this research.

| Acquisition Time  | Remote sensing image                              | notes                                      |
|-------------------|---------------------------------------------------|--------------------------------------------|
| 2013              | LC08_L1TP_120032_20130726_20170503_01_T1         | L1 Product; Spatial resolution of thermal infrared band is 100m. |
| 2014              | LC08_L1TP_120032_20140102_20170427_01_T1         |                                            |
| 2015              | LC08_L1TP_120032_20150513_20170409_01_T1         |                                            |
| 2016              | LC08_L1TP_120032_20160108_20170405_01_T1         |                                            |
| 2017              | LC08_L1TP_120032_20170110_20170311_01_T1         |                                            |
| 2018              | LC08_L1TP_120032_20180129_20180207_01_T1         |                                            |
| 2019              | LC08_L1TP_120032_20190202_20190206_01_T1         |                                            |
| 2020              | GF5_VIMS_N39.7_E121.3_20190418_005031_L10        | L1 Product; Spatial resolution of thermal infrared band is 40m. |

2.2. SST Retrieval algorithm
In this SSR retrieve research radioactive transfer equation is selected. Firstly, estimate the influence of the atmosphere on the surface thermal radiation, then subtract this part of the atmospheric impact from the total amount of thermal radiation observed by the satellite sensor. Thus, the surface heat radiation intensity is obtained; finally transform the intensity into the surface temperature.

2.2.1. Radiometric Calibration. When calculating the spectral reflectance or spectral radiance of a target, Firstly, converted the original DN value of remote sensing image to the absolute radiance by calibration parameters. The radiometric calibration parameters of Landsat-8 TIRS thermal infrared sensor can be obtained from the image header files. As the same, the gain and offset parameters for radiometric calibration are given in of GF-5 header files.

2.2.2. Main parameters calculation. Both band 10 and band 11 of Landsat 8 are suitable for be retrieved by radiative transfer equation method, however the central wavelength of band 10 is in the spectral range with lower atmospheric absorption, higher transmittance witch better for SST retrieve [10].Therefore, band 10 is selected as the channel of SST retrieve in this study. Similarly, band 11 of VIMS is closer to band 10 of Landsat 8, is selected as the retrieve channel of GF-5.

The radiative transfer equation method mainly uses surface emissivity and atmospheric profile parameters. As the retrieved target is relatively flat sea surface, we set the surface emissivity value as 0.992[11].

In addition, the atmospheric radiation correction parameters (atmospheric transmittance, atmospheric upgoing&downgoing radiation) of Landsat-8 were from NASA. While the GF-5 image
atmospheric parameters are calculated by using Modtran6. During this period, Gauss function is used as the spectral response function for calculation, according to the central wavelength and bandwidth get from the header file (Figure 1).

**Figure 1.** The spectral response function of GF-5 VIMS sensor (Gaussian simulation).

### 2.2.3. Brightness temperature retrieve.

The $K_1$ and $K_2$ parameters for brightness temperature retrieve are given in the Landsat 8 header file, which can be used directly. However, the metadata of GF-5 does not provide the value, so it needs to use the central wavelength and other parameters for calculation, the process is as follows:

The radiance value detected by the sensor is the integral form of the product of the Planck blackbody radiation function and the sensor response function in the detection band, as formulas (1).

$$\theta(\lambda) = \frac{C_1}{\pi \lambda^2} \left[ \frac{C_1}{e^{C_2/\lambda} - 1} \right]^{1/2}$$

In the function above is the wavelength, $C_1 = 3.7404 \times 10^8 \text{W} \cdot \mu \text{m}^4 \cdot \text{m}^{-2}$, $C_2 = 14.387 \times 10^3 \text{K}$, $f_i(\lambda)$ is the spectral response function ($\int \frac{\lambda^2}{e^{C_2/\lambda} - 1} d\lambda = 1$), $T$ is the Brightness temperature. Transform formula (1) to get formula (2).

$$T = \frac{K_1}{\ln \frac{K_1}{\pi \lambda^2} + 1}$$

$$K_1 = \frac{C_1}{\pi \lambda^2}, \quad K_2 = \frac{C_2}{\lambda}.$$ 

Based on the above algorithm, the $K_1$ and $K_2$ values of the B11 and B12 of GF-5 VIMS are calculated combining the Gaussian function as the spectral response function $f_i(\lambda)$, the results are shown in Table 2.

| satellite sensor | wavelength range (um) | central wavelength (um) | K1       | K2       |
|------------------|-----------------------|-------------------------|----------|----------|
| GF-5 VIMS        | 10.5-11.3             | 10.89                   | 782.35   | 1321.77  |
| GF-5 VIMS        | 11.4-12.5             | 11.88                   | 505.84   | 1211.54  |
| Landsat-8 TIRS   | 10.6-11.19            | 10.9                    | 774.8853 | 1321.0789|
| Landsat-8 TIRS   | 11.5-12.51            | 12.0                    | 480.8883 | 1201.1442|
3. Experimental results and analysis

3.1. Experimental results

This study was conducted at the same area on 18 scenes of Landsat-8 images, three 5 * 5 pixel study areas were selected on each image, which corresponds to the range of 500m by 500m in geospatial, and marked by A, B, and C on the image. A is the area of the power plant cooling water drainage outlet; B is the outer sea area which is about 7km to the northwest of the outlet; C is the nearshore waters 2km to the southeast of the outlet.

From the retrieve image, affected by the thermal discharge of the nuclear power plant, the outlet water temperature is obviously higher than the sea surface and the near-shore area. It indicates that the thermal discharge effect of nuclear power plant can be clearly reflected in the remote sensing image of landsat8(Figure 2).

Figure 2. Landsat-8 SST retrieved result of Hongyanhe district(January 8, 2016).

3.2. Results analysis

In this study, the maximum value, mean value and standard deviation of the SST retrieve results of the three research areas were calculated and listed in chronological order as the table below.

| Date       | Area A | Area B | Area A | Area B | Area A | Area B | Area A | Area B |
|------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Date       | mean value | mean value | maximum value | maximum value | standard deviation | standard deviation | mean value | mean value | standard deviation |
| 2013/7/26  | 19.57  | 24.14  | 1.36   | 17.70  | 17.92  | 0.11   | 18.51  | 18.77  | 0.13   |
| 2014/1/2   | 2.00   | 4.56   | 0.95   | 1.63   | 1.79   | 0.05   | 1.03   | 1.27   | 0.08   |
| 2014/7/13  | 20.81  | 27.36  | 1.79   | 18.54  | 18.67  | 0.07   | 19.33  | 19.50  | 0.10   |
| 2014/10/17 | 16.08  | 17.77  | 0.77   | 13.56  | 13.72  | 0.06   | 13.60  | 13.81  | 0.09   |
| 2014/12/20 | 0.76   | 2.35   | 0.76   | 1.75   | 1.92   | 0.06   | -0.12  | 0.04   | 0.11   |
| 2015/5/13  | 13.54  | 19.99  | 2.16   | 9.91   | 10.13  | 0.09   | 11.18  | 11.44  | 0.10   |
| 2016/1/8   | -0.04  | 2.46   | 0.84   | -0.43  | -0.22  | 0.09   | -0.67  | -0.39  | 0.11   |
| 2016/3/12  | 1.39   | 7.31   | 1.88   | -1.70  | -1.37  | 0.11   | -0.08  | 0.20   | 0.11   |
| 2016/7/2   | 20.08  | 26.17  | 1.93   | 17.14  | 17.29  | 0.05   | 18.76  | 19.22  | 0.26   |
| 2016/10/6  | 16.45  | 18.60  | 0.94   | 15.82  | 15.94  | 0.06   | 15.77  | 15.93  | 0.06   |
| 2017/1/10  | 0.69   | 3.58   | 1.11   | 0.03   | 0.22   | 0.08   | -0.28  | -0.10  | 0.10   |
| 2017/6/3   | 16.00  | 21.84  | 1.82   | 11.94  | 12.05  | 0.05   | 13.83  | 14.03  | 0.08   |
| 2017/9/23  | 23.70  | 25.97  | 1.23   | 20.41  | 20.54  | 0.07   | 21.15  | 21.33  | 0.07   |
| 2018/1/29  | -4.31  | -0.69  | 1.66   | -6.32  | -5.23  | 0.36   | -6.35  | -4.08  | 0.79   |
| 2018/4/19  | 11.40  | 19.64  | 2.55   | 5.60   | 5.85   | 0.08   | 8.59   | 8.93   | 0.11   |
| 2018/8/9   | 22.68  | 25.87  | 1.25   | 20.46  | 20.72  | 0.11   | 21.41  | 21.67  | 0.10   |
| 2018/10/12 | 17.56  | 19.55  | 1.40   | 14.07  | 15.26  | 0.95   | 15.42  | 15.67  | 0.11   |
| 2019/2/1   | 1.05   | 4.61   | 1.96   | -1.77  | -1.64  | 0.06   | -1.10  | -0.81  | 0.14   |
3.2.1. The heating effect of warm drainage is obvious. The spatial resolution of Landsat-8 thermal infrared sensor is only 100 meters, and the influence range of power plant thermal discharge is limited. Therefore using the maximum value to analyse the temperature distribution of the study area is more accurate and distinctive to reflect the warming effect caused by the thermal discharge activities.

According to the relevant research, the cooling water of power plants will lead temperature rise of about 8°C at the drainage outlet. By retrieving 18 scenes of Landsat-8 remote sensing images, the result shows the maximum value of the water temperature of the drainage outlet area is 7.6°C higher than the of the outer sea surface averagely, this is consistent with existing information.

If we list the difference value between the maximum values of water temperature of the water outlet and the outer sea area of the 18 groups retrieve results in ascending order. The difference value of the first eight groups is small and within 5°C. Comparing the data collection time, these 8 data groups were all collected in the cold autumn and winter. However, the temperature difference of group 9-18 is between 8-14°C, which is larger and these data are almost collected in warmer spring and summer. Therefore, it can be inferred that in Landsat 8 image water warming effect caused by power plant thermal discharge is more obvious in the warmer seasons.

If we list the difference value between the water temperatures mean values of the water outlet and the outer sea area in ascending order. six of the first seven groups of data are collected in cold winter, and the last five groups of data with larger temperature differences are all from warmer spring and summer, it is the same as the maximum analysis result, and confirmed that the warming effect of thermal discharge in remote sensing images is more obvious in spring and summer.

3.2.2. Warm drainage affects the water temperature near the shore. One of the purposes of SST retrieve is to evaluate the impact of thermal discharge on the coastal environment. In this study, outlet and nearshore seawater are selected as study areas for temperature difference analysis. Generally, the water temperature in the nearshore area is slightly higher than the outer sea surface, so the outer SST is selected as the reference standard, and compares the maximum and average water temperature difference with the study areas of the outlet and the nearshore.

![Figure 3. The temperature difference value comparison using maximum(left) and average(right) value.](image)

In the Figure 3, Since 2013 the power station was connected to the grid, the temperature of the nearshore is 1-2°C higher than that of the outer area with a growing trend, this may be related to the increase number of power units connected to the grid. In the retrieve results, the water temperature changing trend of the two study areas is basically the same. And In the time sequence diagram of temperature difference calculated by average value, the synchronous trend is particularly obvious.

Because of the diffusion of the warming effect of thermal discharge, the seawater temperature of the nearshore area is easily affected by human activities, surface heat exchange and other factors,
which result in higher temperature of some pixels. Therefore, when analysing the temperature effect in the study area, it is more reasonable to use the average value. Through the analysis above, it can be infer that the thermal discharge of the power plant has a certain effect on the temperature of the nearby nearshore seawater.

Mean square deviation is the average value of the square value of the difference between the temperature value of each pixel and the average value of all pixels in the study area, which can be used to analyse the influence of the thermal discharge on the surrounding water temperature. The larger the mean square deviation, the more significant the difference of water temperature in the study area is, and the more significant the influence of thermal discharge is.

From the Table 3, the mean square deviation of water temperature statistics in the outlet area is significantly greater than that in the sea and nearshore areas, which shows that the water warming effect of power plant is very obvious in the outlet area, and the water temperature of this area significantly changed. The warming effect on the outer sea surface is weaker, and the temperature distribution is relatively stable, and the mean square deviation is quite small. The nearshore water is easily affected by thermal discharge, and its mean square deviation is generally slightly higher than the sea level, but it’s only 10% of the drainage outlet area. When the sets of data with the largest mean deviation are collected, the power station may be in the process of thermal discharge. The warm water followed the current to the coast, make the mean square deviation of the nearshore area increase obviously.

3.3. comparing with GF-5 retrieve result
This study is based on a GF-5 image which collected on April 18, 2019. The Band11 of VIMS sensor is selected as the channel and by the radiation transfer equation method the SST is retrieved.

![Figure 4. GF-5 VIMS temperature retrieve result.](image)

In the retrieve results, the water temperature of the outlet area (central position of the rectangle in Figure 4) is approaching 20 °C, which is 3-4 °C higher compared with surrounding area. Comparing the Landsat-8 retrieve result with the local meteorological records (6~13 °C), this result is quite accurate. Because the thermal infrared spatial resolution (40m) of GF-5 is much higher than that of landsat-8 (100m), it can be clearly seen from the result that the warm water flow at the outlet moves outward radially, and spread to the northwest with the ocean current, as the distance increases, the temperature of warm water gradually converges with the surrounding seawater.

Due to the data quality (cloud is too thick, VIMS data only has 7-12 bands) and some parameters of GF-5 are not certain, the accuracy of temperature retrieve is affected. However, from the results, not only the warm water flow near the outlet of the power plant is extracted accurately and obviously, but also the greenhouse with higher temperature was also detected on the land.

The thermal discharge effect of the power plant is affected by many factors. In this study, we did not get sufficient and sequential remote sensing images of GF-5, so no more systematic analysis and
demonstration can be carried out for the time being. However, this study shows that it is feasible and reliable to use the GF-5 VIMS image to monitor the thermal discharge effect, and compared with other data sources, GF-5 has more advantages such as higher spatial resolution.

4. Conclusions
This study based on 18 scenes of landsat-8 images from 2013 to 2019, retrieved the SST near Hongyanhe by radiation transfer function method. And calculated the maximum, minimum, mean and mean square deviation of the water temperature at the outlet, near shore water and sea surface for research. The results proved that satellite remote sensing is feasible for monitoring the thermal discharge effect of power plants. In addition the GF-5 VIMS SST retrieved result accurately reflects the warming effect caused by the power plants thermal discharge. Due to the higher spatial resolution of GF-5, the retrieve results also showed the diffusion direction of warm water, it fully demonstrates the potential of GF-5 in temperature retrieve and monitor, and also provides a reference for the future research.

However, because of the different mode of thermal discharge and the uncertainty of remote sensing technology, in order to get a better accuracy, it is necessary to combine multi-source data such as field sampling and meteorological monitoring. The amount of data and calculation are both very large, it is suggested to take more intelligent and comprehensive analysis means such as big data for best result.

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