Retrieval Algorithm For Sea And Land boundary temperature And Effect Of Atmospheric Radiation Correction

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Abstract: An algorithm have been presented to retrieve sea and land surface temperature from NOAA satellite radiative measurements. We used the atmospheric radiation in the adjacent sea area to correct the atmosphere in the land and sea area. Because the self-consistency atmospheric radiant information is adopted at the same time and condition, this method has important actual efficiency. Simultaneity, several atmosphere patterns are selected by using atmosphere MODTRAN radiative transfer model program, the different retrieval algorithms are contrasted. The results show that practical effect is good, correct and feasible.

1. Introduction
The surface temperature is one of the most important environmental parameters of the balance between the earth's energy and water. The accurate surface temperature value is needed in many applications, especially in military affairs, environment, climate and agricultural weather study. At present, NOAA satellite image has been widely used in the surface and sea temperature retrieval. Besides, the theoretical research and practical application have made gratifying achievements. There are basically three kinds of methods can be summarized as follows [1]:

(1) The single-channel method: it operates the atmospheric influence correction to the radiation equation applying a single channel radiation value on the satellite sensor combined with the atmospheric profile data made by the sounding or satellite remote sense.

(2) The multichannel method: also called dividing window method. In the atmospheric, window there is a certain relationship between the infrared radiation through performance of several thermal infrared channel. Through certain mathematical processing, it can eliminate the influence of atmosphere by applying the combination of temperature between a few channels so as to calculate the true surface temperature. The common expression is a first order form, namely surface temperature can be expressed as the linear combination of the temperature value1 on each band.

(3) The multi-angle method: The surface temperature can be figured out by observing the same feature from different angles, obtaining many sets of radiation data and combining a certain mathematical model.
Comparing the three methods, single channel method needs to detect some relative atmospheric parameters, which is more suitable for the meteorological department\(^2\)-\(^4\). Due to the need of more observation parameters, the multi-angle method is limited to research stage in short term; For the common remote-sensing workers, the dividing window method may be more practical, which needs less parameters, and has certain advantages considering the coupling relationship between the terrestrial surface radiation rate and temperature. But dividing window method depends more on radiation rate so when the radiation rate is more than 0.98, the temperature error of retrieval can be less than 1 \(^K\). And when the radiation rate falls, the error will increase sharply, as the radiation rate is equal to 0.72, the error can reach 6-10 \(^K\).

We know that the surface consists of the following several parts: the sea surface, the land surface and the sea and land boundary\(^5\). Although people have achieved quite good results by applying the inversion of the sea and land temperature parameters from the satellite data, there is no good solution to retrieve the parameters of the mainland coastline by using the same model which can combine the sea surface with the land surface. As far as sea and land boundary is concerned, the atmospheric state and terrain emission rate on temperature retrieval is a major influence; in addition, the temperature retrieval result needs the synchronous test between the field test and satellite measurement. However, until now, there’s still a lack of the high quality measuring data of the surface temperature of the sea and land boundary, and the key problem is that it’s difficult to synchronize. Therefore, almost all the published articles concentrate on the theory processing or the inversion formula of the derivation dividing window algorithm applying the atmospheric radiation transmission model simulation. So deriving the practical method for sea and land boundary temperature retrieval becomes a key problem for satellite image retrieval. We have done something in this respect and obtained the ideal retrieval temperature of the sea and land boundary.

In this paper, NOAA satellite images are used to extract the information affected by atmospheric radiation from the same image, which is used to correct the atmospheric radiation to the image. In the process of correction, the measured atmospheric water vapor pressure \(\epsilon_r\) of the sea and land boundary surface and the object emissivity \(\epsilon\) of the sea and land boundary surface are selected reasonably. This atmospheric correction method based on NOAA satellite image information has a good correction effect, simple operation and strong practicability\(^6\)-\(^9\).

2. The theory of atmospheric correction

In order to eliminate the influence of atmospheric radiation and make target bright temperature directly inversed by the radiation brightness received by the sensor closer to the real target temperature, we start from the \(L = \epsilon B(T) \tau + L_{atm}\), take \(T\) as a known temperature, and calculate the atmospheric radiation part in turn. In which \(L\) is total radiation brightness received by the sensor; \(L_{atm}\) is the contribution of atmospheric radiation. By substituting \(T\) into the formula above, two groups values of \(L_{atm4}\) and \(L_{atm5}\) on channel 4 and 5 can be obtained, respectively corresponding with the radiation of the image pixel points. In order to simplify the calculation, the average values of \(L_{atm4}\) and \(L_{atm5}\) will be obtained in the study of the small-scale model, which will be attached to the \(L\) for their own atmospheric correction. Then the key point is to consider the calculation of the radiation rate \(\epsilon\) and the value \(\tau_0\) of the atmospheric transmittance.

2.1 The calculation of the radiation rate \(\epsilon\)

As we know, the types of the surface land cover can generally be divided into 6 categories: rock, soil, vegetation, water, ice and snow. According to the analysis of the radiation rate measurement data by Salisbury J. W. et al. Under vertical conditions in the laboratory, it can be known that the radiation rate changes slowly in the band ranged from 10.5 to 12.5 \(\mu m\), except for a few types of the rock. Liu
Qinhuo et al. calculated and summarized the average values of the earth surface radiation rate corresponding to the fourth and fifth channel of AVHRR, the fluctuation degree (mean-square deviation) of the radiation rate of things on earth in each type and the difference of the radiation rate between the two channels, As shown in Table 1. The average value of the sea water radiation rate $\varepsilon$ and the land cover radiation rate $\varepsilon$ will be regarded as the radiation rate $\varepsilon$ of sea and land boundary $^{[10]}$.

**Table 1. the chart of the common radiation rate of the things on earth**

| The Surface type | Name of objects | $\varepsilon_4$ ($10.5–11.5$ μm) | $\varepsilon_5$ ($11.5–12.5$ μm) | $\varepsilon_5 - \varepsilon_4$ |
|-----------------|----------------|-----------------|-----------------|-----------------|
| soil            | Average        | 0.968           | 0.973           | 0.007           |
|                 | mean-square deviation | 0.0054          | 0.0033          | 0.0028          |
| rock            | Average        | 0.947           | 0.962           | 0.0175          |
|                 | mean-square deviation | 0.017           | 0.106           | 0.0099          |
| vegetation      | Average        | 0.957           | 0.960           | 0.0026          |
|                 | mean-square deviation | 0.019           | 0.021           | 0.0035          |
| snow            |                 | 0.997           | 0.996           | -0.001          |
| sea water       | Smooth         | 0.977           | 0.973           | 0.004           |
|                 | Rough          | 0.984           | 0.970           | -0.006          |

2.2 The calculation of the atmospheric transmittance $\tau_0$

In atmospheric infrared window region ranged $8 \sim 13$ μm, atmospheric attenuation mainly comes from water-vapor absorption which consist of the two parts—the water-vapor-line absorption in the window region and the extension of continuous absorption spectrum of water-vapor outside the window region to the edge of the window region. The research shows that the absorption of the latter is much stronger than that of the former. In this case, the absorption varies slowly with the wavelength.

The exponential relationship between the transmittance function $\tau_a$ of the atmosphere that has a certain bandwidth and low resolution and the equivalent content $W^*$ that absorbs the material is as follows:

$$\tau_a = \exp (-C a W^*)$$

(1)

The strength of the water-vapor absorption depends on its content in the whole-layer atmosphere. Therefore, it’s particularly important and practical to select a method to calculate the atmospheric transmittance $\tau_0$ directly using parameter measurement values of the target atmosphere. For this reason, two empirical formulas are selected to calculate the atmospheric transmittance $\tau_0$:

$$W = 0.0502 + 0.6115 \times \varepsilon_D$$

(2)

$$\tau_0 = \exp (A_0 + A_1 W + A_2 W^2)$$

(3)

In which the $\varepsilon_D$ is the inversion vapor pressure of the surface atmospheric; For channel four $A_0 = -0.011, A_1 = -0.043, A_2 = -0.0222$; For channel five $A_0 = -0.011, A_1 = -0.031, A_2 = -0.0388$.

3. The result and discussion

In order to test the effect of the atmospheric correction in this method, an area with both sea and land is selected from NOAA satellite images. The correction steps are shown in figure 1:
Figure 1. The correction process chart of the satellite image

Table 2 shows the inversion result of the 3843 pixels in the selected 61 pixels * 63 pixels of the sea and land boundary applying the above correction process chart.

Table 2. The data result of the program operation

| Bright temperature correction method | The average of the bright temperature on channel 4 (K) | The average of the bright temperature on channel 5 (K) | variance | mean-square deviation |
|--------------------------------------|------------------------------------------------------|------------------------------------------------------|----------|-----------------------|
| Image information correction result  | 296.94                                               | 294.45                                               | 3.64     | 1.90                  |
| The target result after removing cloud | 296.30                                               | 293.24                                               | 3.70     | 1.91                  |
| Original image                       | 296.21                                               | 293.15                                               |          |                       |

The result shows: (1) The brightness temperatures of channel 4 and channel 5 after cloud removal and the atmospheric correction are higher than that of the original image, which is due to the influence of atmospheric components on the radiation of land-sea boundary. Due to the influence of atmospheric absorption, only part of radiation of the sea and land boundary reaches the space-borne microwave radiometer through atmosphere and the rest is absorbed by some gases such as the water vapor, carbon dioxide, carbon monoxide and the methane. Since the atmospheric radiation contribution is usually lower than the amount of radiation that is impaired, equivalent radiation temperature (bright temperature) retrieved by the satellite radiation value is usually lower than the actual temperature of the sea and land boundary. Therefore, the bright temperature should be increased after correction, which is in agreement with theoretical analysis. (2) The variance and mean-square deviation of atmospheric correction on channel 4 and channel 5 are smaller than those of cloud removal, which indicates that the fluctuation of the retrieved bright temperature is decreasing, and the corresponding retrieval bright temperature error will be reduced. In other words, the accuracy of retrieval bright temperature will be improved.

4. Test verification and analysis

In the field of retrieving the temperature of sea and land boundary, it is difficult to obtain the ground validation data, so it is still impossible to directly evaluate the correction accuracy. With the approval of state general bureau of standardization, American 1976 standard atmosphere can be used as a national standard before establishing our own standard atmosphere. In order to obtain an indirect evaluation, three mode correction methods, namely, mid-latitude summer model, Mid-latitude Winter model and American 1976 standard atmosphere model, were selected to correct the image information...
correction method we have tried for the inversion in the same area of the sea-land boundary. The image information correction method is used to retrieve the same area of sea and land boundary. The statistics data of the program are shown in table 3.

Table 3. The chart of the data comparison of the program operating

| Bright temperature Correction method | The average of the bright temperature on channel 4 (K) | The average of the bright temperature on channel 5 (K) | variance | mean-square deviation |
|-------------------------------------|-----------------------------------------------|-----------------------------------------------|----------|-----------------------|
| Original image                      | 296.21                                         | 293.15                                         |          |                       |
| American standard atmospheric correction | 297.18                                        | 294.18                                        | 3.65     | 1.91                  |
| Mid-latitude summer atmospheric correction | 297.18                                        | 295.20                                        | 3.68     | 1.91                  |
| Mid-latitude winter atmospheric correction | 295.86                                        | 294.63                                        | 3.67     | 1.91                  |
| Image information atmospheric correction | 296.94                                        | 294.45                                        | 3.64     | 1.90                  |

The inversion results of the three models are similar; there is some deviation between the bright temperature inversion results of image information atmospheric correction method and those of various model correction methods, but the deviation is very small. The result is in accord with our reasoning result that the variance and mean-square deviation of bright temperature of the channel 4 and 5 retrieved by using the image information correction method are lower than those of the model correction methods. Comparing to the American standard atmospheric correction method, the image information correction method is desirable in small range of temperature inversion of the sea and land boundary within the allowed error range.

By comparing the images before and after correction, the image corrected by image information correction method has clear boundary and obvious effect on atmospheric correction, which shows that the image information correction method deduced by our theory is effective.

5. Conclusion
From the data of the program operation, we can see that the variance and mean-square error of the bright temperature of image information correction are lower than those of American standard atmospheric correction. We know that the variance and mean-square deviation reflect the discrete degree of a group of data, and The smaller their values are, the closer the brightness temperature values of channels 4 and 5 are. We know that theoretically, for the same inversion region, the inversion results of Channels 4 and 5 should be exactly the same, and the closer the two sets of data are, the smaller the error is. This is the result we expect. Through the comparison above, it can be concluded that it is feasible to use the image information atmospheric correction method to retrieve the bright temperature of the sea-land boundary. Within the allowable range of error, image atmospheric correction method is more suitable for the study of sea and land boundary temperature inversion in a small area. This method is good enough when the accuracy requirement is not high.

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