A method applied the boundary of sea and land temperature retrieval for atmospheric information correction

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Abstract

A method applied in the boundary of sea and land for atmospheric correction was analyzed by the radiation information which was adopted from the same picture, and radiance ε of the boundary of sea and land was estimated by prorating the mixed element The estimation of the atmosphere transmissivity τ_0 could be given out, in which atmosphere parameter e_D was measured. And the effects were important actual efficiency and authentic. Simultaneity, several atmosphere patterns were selected by using atmosphere MODTRAN radiation transfer model program, and the different retrieval algorithms were contrasted by presuming the standard atmosphere from America. The fact that derives from study of the boundary of sea and land bears out that the correction method has evident effects and simple operation.

Keywords: sea and land boundary, atmospheric correction, retrieval, channel

1 Introduction

Since 1970s, the remote-sensing technology has obtained the development which progresses by leaps and bounds. The earth-resource satellite acquired a lot of remote sensing images which contain a τ_0 large amount of information about the surface of the earth and sea, so using remote-sensing image data of the satellite to study the optical properties of the ground and target (the reflectivity, radiation degree and reflection characteristics, temperature and changing with time of the thermal infrared) is a kind of method and means which has too much application value [1]. However, in the research of the military, environment and climate, surface, temperature has important significance. At present, NOAA satellite images have been widely used in the temperature inversion of earth surface and seas. Moreover, there are gratifying achievements in the theoretical research and practical application [2] in the aspect of the temperature inversion on the land surface, and all kinds of algorithm are worked out. In view of different parts of the inversion, in temperature inversion of the boundary between the sea and the land, there is not a very good solution as for the inversion of the continental coastline parameter combined by the sea and land surface. Besides, the open literature doesn't exist at present.

NOAA/AVHRR has five channels. Generally speaking, because the purpose and the direction of the research are different, there are great differences in the adaptation of the methods and the satellite channel. Based on the purpose of the research we choose channel 4 and 5 of the atmospheric window. The two channels are transparent in relation to the atmosphere. But it will be influenced greatly with the change in the content of the water vapor in the atmosphere. Any atmospheric window channel will be influenced differently in the degree by the atmospheric radiation. In this paper the researchers use the related characteristics of atmosphere with image to correct the effect of the atmosphere so as to weaken the negative influence to the measurement from the atmosphere.

2 The principle of the image-information correction to the sea-land boundary temperature

2.1 THE INVERSION THEORY FOUNDATION OF THE REMOTE-SENSING BRIGHT TEMPERATURE

From AVHRR digital information to acquire the calculated value D (gray) of the 4 (CH4) and 5 (CH5) channel, we can calculate the corresponding radiation intensity value L.

$$L = 4S \cdot D + I . \quad (1)$$

In Equation S and I are the calibration coefficient of the channel sensor.

Starting from the blackbody radiation formula, we can reverse the bright temperature of the sensor. The brightness temperature T of the sensor can be found out by the radiation intensity value L received by the sensor and blackbody radiation formula [3]

$$L = \frac{c1 \cdot v_3}{e^{c2 \cdot v/T} - 1}, \quad (2)$$

$$T = \frac{c2 \cdot v}{\ln\left(1 + \frac{c1 \cdot v_3}{L}\right)}. \quad (3)$$

In which:

$c1 = 1.190659 \cdot 10_{-5} (W \ .cm)$, $c2 = 1.438833 \ (cm \ .k)$ is the constant. v is the wave number cm^{-1}. If adapting to the Equation (2), what we calculate is the only radiation brightness of the single wavelength. We all know that every channel has certain bandwidth. In order to make the inversion bright temperature much closer to the true temperature and decrease the error, we deal with the formula as follow:

$$L = \sum_{i=1}^{n} B(v_i, T)\phi(v_i)\Delta v \,. \quad (4)$$

In the Equation, $B(v_i, T)$ is the Planck function; v_i is the wave number; $\phi(v_i)$ is the spectrum-channel normalized response function; Δv is the wave-number interval; n is the number of the wave-number interval.

It follows that we can calculate the corresponding bright temperature T by connecting the bright temperature with the radiation intensity value received by the star-load sensor in accordance with the Equation (4).

2.2 TO CORRECT THE THEORY OF THE ATMOSPHERE WITH THE IMAGE-ATMOSPHERE INFORMATION

In order to eliminate the influence of atmospheric radiation and make target bright temperature directly inversed by the radiation brightness received by the sensor more closer to the real target temperature, we start from the $L = \varepsilon B(T)\tau + L_{atm}$, considering the T as a known temperature, in turn for atmospheric radiation part. In which L is total radiation brightness received by the sensor, L_{atm} is the contribution of atmospheric radiation. When T is substituted in the equation above, the researchers can get two groups value of the L_{atm4} and L_{atm5} on channel 4 and 5, respectively corresponding with the radiation of the image pixel. In order to simplify the calculation, the researchers respectively average for the L_{atm4} and L_{atm5} in the study of the small range model, attached to the L for their own atmospheric correction. Then the key is that consider the calculation of the radiation rate ε and the value τ_0 of the atmospheric transmittance.

2.2.1 The calculation of the refractivity ε

We know that the type of the surface coverage generally can be divided into 6 types: rock, soil, vegetation, water, ice and snow (Table 1).

TABLE 1 The chart of the common radiation rate of the things on eart

The Surface type	**Terrain name**		
	$\varepsilon_4(10.5-11.5)\mu m$	$\varepsilon_5(11.5-12.5)\mu m$	$\varepsilon_4-\varepsilon_5$
rock average	0.947	0.962	0.0175
rock mean-square deviation	0.017	0.106	0.0099
soil average	0.968	0.973	0.007
soil mean-square deviation	0.0054	0.0033	0.0028
vegetation average	0.957	0.960	0.0026
vegetation mean-square deviation	0.019	0.021	0.0035
sea	0.99	0.985	-0.005
Sea ice Smooth	0.977	0.973	0.004
Sea ice rough	0.984	0.970	-0.006
snow	0.997	0.996	-0.001

According to the researchers Salisbury J. W. and so on, analyzing the measurement data of radiation rate under the condition of the vertical laboratory, it can be known that the radiation rate changes slowly in the band ranged from 10.5 to 12.5 μm in addition to a few types of the rock. Liu Qinhuo, etc, calculated and summarized the average of the earth surface radiation rate corresponding with the fourth and fifth channel of AVHRR and in every type the fluctuation degree (standard deviation) of the radiation rate of earth surface or the differential form of the radiation rate of the two channels [4, 5], As follows the chart one. We take the average rate of radiation rate ε of the sea and the cover on land as the radiation rate ε of the sea-land boundary.

2.2.2 The calculation of the atmospheric transmittance

In atmospheric infrared window area ranged 8～13 μm , atmospheric attenuation mainly comes from water-vapor absorption which consists of the two parts--the water-vapor-line absorption in the window and the vapor continuous absorption spectrum outside the window to two wings on the edges in the window. The research shows that the latter is much stronger than the former about the absorbing. In this case, the absorption changing as the wavelength is slow. The atmospheric which has a certain bandwidth of the low resolution through the function τ_a and the equivalent content W * that absorbs the material and obeys the exponential relationship [6]

$$\tau_a = \exp(1 - C_\lambda W^*) \quad (5)$$

The strength of the water-vapor absorption depends on its content in the whole-layer atmosphere. Therefore, choosing a kind of direct method which uses the parameters-measurement value of the target atmosphere to calculate the rate of the atmospheric transmittance is particularly important and practical. For this reason, we choose the two empirical formulas [7] as follows to calculate the atmospheric transmittance rate:

$$W = 0.0502 + 0.6115 \cdot e_D \quad (6)$$

$$\tau_0 = \exp(A_0 + A_1 W + A_2 W_2) \quad (7)$$

In which the e_D is the inversion vapor pressure on 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 checking and analysis to all kinds of correction methods by the experiments

The inspection to the result of the temperature inversion needs the field experiment and the synchronous data materials of the satellite measurement. In the field of the temperature inversion on the surface of the sea-land boundary, because of the difficulty for getting the ground-validation data, we still lack the high quality measuring data on the surface temperature of sea-land boundary now. Therefore, it is still impossible make the direct evaluation for the correction to the precision In order to get a indirect evaluation, we selected the three atmospheric models: middle-latitude summer, middle-latitude winter, the standard atmosphere in United States in 1976 to do the inversion to the area of the corresponding sea-land boundary, and set the correction result of the standard atmosphere in the United States in 1976 as a standard(Due to the approval of the national standard administration, the standard atmosphere in the United States in 1976 can be used as a national standard before establishing it and conduct the comparative analysis to the image-information correction method. Table 2 has given the result by using the correction method above and the American correction method of the standard atmosphere for the inversion to the selected 8184 pixels of line 66 and column 124 in the same area of the sea-land boundary.

TABLE 2 Data comparison chart of program operation (1)

Bright temperature The correct methods	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	296.17	293.13		
Image-information atmospheric correction	296.98	294.49	3.65	1.91
American standard atmospheric correction	297.08	294.10	3.67	1.92

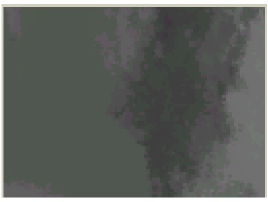
From the data of the program operation we know that the two kinds of atmospheric correction light-temperature of channel 4 and 5 improved compared to the bright temperature of the original image; the variance and mean-square deviation of the image-information atmospheric correction reduced compared to correction result of the standard model in the United States in 1976. We know that the variance and mean-square deviation reflect the discrete degree of a group of data whose value of number is much smaller, indicating the light-temperature value of the channel 4 and 5 are far closer. Theoretically in the same inversion region, the inversion results of the channel 4 and 5 should be completely consistent. The closer the two sets of data, the smaller the error will be, which is our expected results. Comparing to the American standard atmospheric correction method we know that within the allowed error range, image-information correction method is desirable in small range of temperature inversion on the sea-land boundary.

We select the three models--middle latitude summer, middle latitude winter and the standard atmosphere in the United States in 1976 to correct the image-information correction method we have tried for the inversion in the same area of the sea-land boundary. The statistics data of the program execution as Table 3.

TABLE 3 Chart of the data comparison of the program operating (2)

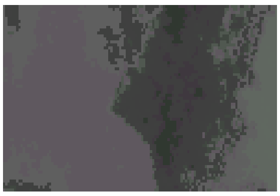
Bright temperature The correct methods	The average of the bright temperature on channel 4 (K)	The average of the bright temperature on channel 5 (K)	Variance	Mean-square deviation
Original image	296.17	293.13		
American standard atmospheric correction	297.08	294.10	3.67	1.92
Middle-latitude summer atmospheric correction	297.26	295.27	3.69	1.92
Middle-latitude winter atmospheric correction	296.95	294.74	3.67	1.92
Image-information atmospheric correction	296.98	294.49	3.65	1.91

Throughout the bright-temperature data inversed by all kinds of atmospheric correction methods, for channel 5 the bright temperature has only an average of 1-2 Celsius degrees deviation; for channel 4the deviation is less than 1 Celsius degree; the various results of the three kinds of the inversion models of are close to each other; there is some deviation in the result between the bright temperature of inversed by the image-information atmospheric correction method and the correction methods inversion of all kinds of models, but it is very small. The result is in accord with our reasoning result that the variance and mean-square deviation inversed by of bright temperature of the channel 4 and 5 by using the image-information correction method are lower than the correction of those models. Through the comparison above we know that it is feasible to use the image-information atmospheric correction method for inversion to the bright temperature on the sea-land boundary. Within the allowable range of error, image- atmosphere correction method is relatively suitable for the inversion study of the temperature in the small area on the sea-land boundary. In order to more intuitively reflect the efficiency of this method, we respectively show the image results of the atmospheric correction in the same region of channel 4 and 5 on line 66,row 124 of the NOAA satellite images.



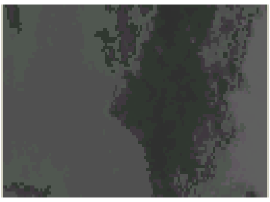
The original

American standard correction



Middle-latitude summer correction

Middle-latitude winter correction



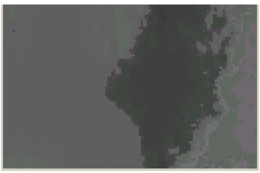
Last correction image

FIGURE 1 The image correction results of channel 4

The original

American standard correction

Middle-latitude summer correction



Middle-latitude winter correction

Last correction image

FIGURE 2 The image correction results of channel 5

Through the image comparison before and after the correction, the image after the correction by using image-information correction method has a clear boundary and is obvious for the effect on the atmospheric correction, which shows that our image-information correction method by the theoretical derivation is effective.

4 The analysis to the deviation

From the theory, in the same inversion region, the inversion result of channel 4 and 5 should be completely consistent. But the inversion temperature can be concluded that the result of channel 4 and 5 are not exactly same, adding the instrument noise and failed to completely eliminate part of the atmospheric effect, so the final result is still influenced by a portion of the atmospheric composition. Meanwhile, the atmospheric condition of the sea-land boundary region is special and the existence of great range of the cloud and mist are also the main factors causing the error. The selection of several atmospheric models in the inversion is not the actual model of the image-detection inversion. These approximate method errors inevitable exist although our method of ε acquiring value is carefully screening. The research data shows that if ε changes 1% it will cause about $1K$ error of the bright temperature. All of these will influence the inversion result.

Taking the inversion result of the standard atmosphere in the United States as the standard, we analyze the bright -temperature error inversed by the image-information correction method in small range. From the data of the program operation we can see that the variance and mean-square error of the bright temperature with the image-information correction are lower than the result of American standard atmospheric correction. We know that the variance and mean-square error reflected the discrete degree of a group of data. The value of number is much smaller, which explains that the light-temperature value of channel 4 and 5 are much closer. We know that from theory, for the same inversion region, the inversion results of channel 4 and 5 should be completely consistent. The closer the two sets of data are, the smaller the error is, which is the result we expect.

Ignoring other influences, we analyze that the main source to cause the error have two parts: one is the random error σT because of noise generated by the measuring instrument and the other is the random error ΔT caused by the radiation rate. That is to say, the total error can be simple presented as the following form: $\Delta T_{total} = \sqrt{\Delta T_2 + \sigma T_2}$. Seen from the formula form of the total error, if you want to reduce the ΔT_{total} , it is necessary to reduce the ΔT in maximum. We know that there are some error of measurement to the ε_4 .Assuming that the of the error magnitude is 0.01, that is $\Delta\varepsilon = 0.01$, its influence to the surface temperature 0.50°C (Spectral radiation ratio has effect to surface temperature of the satellite remote-sensing research Yang Wen plateau weather 1997). Taking the center wavelength of the channel 4 as an example, American standard atmospheric model $\varepsilon_4 = 0.994$, The calculated radiation rate $\varepsilon_4 = 0.973$, $\varepsilon_4 \approx 0.02$ of inversion calculation will cause nearly 10 c error the inversion surface temperature. If there is larger difference, the total inversion error will increase relatively. Usually, the difference of single ε cause the temperature difference ranged 2~3°C. It can be seen that the calculation method we adopted has reduced the error to the temperature inversion in small range on the sea-land boundary.

5 Conclusion

It is known that the model correction method to be applied is the result of yearly statistical summary, which has the generality and good applied effect for the statistical area. When the mode atmospheric correct the software application, it needs to choose a large number of parameters. But the selection of the parameters is mainly decided by the operator. There must is the deviation between this kind of human decision and the actual information of the objective atmosphere, thus it is not incomplete practical to atmospheric correction in non-statistical area. In this study, the calculated value of radiation rate applies to the mixed pixel proportion distribution method; and the calculation of the atmospheric transmittance chooses the atmospheric measured parameters on the sea-land boundary. The calculation of radiation rate and through rate is relatively simple and need less parameter, so image-information atmospheric correction method is convenient and practical. In addition, the most important fact is atmospheric correction value, namely atmospheric radiation value, completely from the image information. Although the calculation precision is not high, it is good enough if the accuracy is not high. From the practical application sense, it is a kind of convenient and very practical method.

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