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Improved Cloud Detection Technique at South China Sea

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1. Introduction

The sea surface temperature (SST) algorithm was only valid for cloud free water pixels. The cloudy pixels should be separated before the SST algorithm could be applied. The cloud masking algorithm was used to separate the cloudy pixels from non-cloudy pixels. The cloud surface, ocean surface and vegetated, arid or snow covered land surfaces have different response to reflectance, brightness temperature and emissivity. The cloud detection or masking tests were based on the different response patterns of the earth surfaces or clouds to the reflection or emission of the wave radiation. The threshold values were different for the different seasonal and regional areas. Therefore the threshold values for each test would be determined before cloud masking test were performed.

Kriebel(1989) had proposed a procedure to derive suitable temperature thresholds for new areas of application. The land and sea areas which seen likely to be the coldest but cloud free were identified visually by users. However this method is subjective and quite time consuming. The results were varying with the users. Sauders (1986) had determined the threshold for local uniformity test with SD value less than 0.2 K for cloud free pixels over the sea in Northeastern Europe. France and Cracknell (1994, 1995) found SD values less than 0.4 K for cloud free pixels over the sea in northeastern Brazil.

In this study, histograms of the cloud over land, cloud free land, cloud over sea, cloud free sea areas would be utilized. It was different with the suggested method that utilized whole sea area. The histogram was expected to be bimodal, a clear separation between the digital number for the colder clouds and the warmer sea surface (Cracknell, 1997). However, in practical, it was difficult to get the clear bimodal histogram for whole sea area. Therefore the new method generated the four histograms by using the ROI tool of software Envi V.4.4 to select the four separate areas.

2. Methodology

The images of calibrated reflectance for channel 1 and 2 were created, and the brightness temperature for channel 4 and 5 were calibrated. After that, the function of Band Math in software ENVI was used to create the image of R_2/R_1 . The ROI (Region of Interest) tool in ENVI was used to choose the region of cloud, sea and land. The selected regions were then applied to the image of brightness temperature for channel 5 and channel 4.

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(a) The case when $\mu_{cf} > \mu_c$

(b) The case when $\mu_{cf} < \mu_c$.

Fig. 1. The value of threshold was determined from the mean and standard deviation of cloud free and cloudy water pixels.

To determine the threshold for the cloud masking techniques, the mean, μ and standard deviation, σ for the cloud free water pixels (μ_{cf}, σ_{cf}) and cloudy water pixels (μ_c, σ_c) were determined. The value of n was set to three. Then the mean of the cloudy water pixels and

cloud free water pixels were compared. If the mean of cloud free water pixels greater than cloudy water pixels, then we compared the values of $\mu_{cf}-n\sigma_{cf}$ and $\mu_c+n\sigma_c$. The value of threshold was assigned the value of $\mu_{cf}-n\sigma_{cf}$ if $\mu_{cf}-n\sigma_{cf}>\mu_c+n\sigma_c$ or $n=1$, otherwise the value of n was decreased by one until $\mu_{cf}-n\sigma_{cf}>\mu_c+n\sigma_c$ or $n=1$ (Figure 1(a)). However, if the mean of cloud free water pixels less than the mean of cloudy water pixels, then the values of $\mu_{cf}+n\sigma_{cf}$ and $\mu_c-n\sigma_c$ were compared. The value of threshold was assigned the value of $\mu_{cf}+n\sigma_{cf}$ if $\mu_{cf}+n\sigma_{cf}<\mu_c-n\sigma_c$ or $n=1$, otherwise the value of n was decreased by one until $\mu_{cf}+n\sigma_{cf}<\mu_c-n\sigma_c$ or $n=1$ (Figure 1(b)).

The concept of determining the threshold for separating the cloudy from non-cloudy water was based on the six sigma techniques. There were 99.9996% of data lie between $\mu-3\sigma$ to $\mu+3\sigma$ and 99.38% data lie between $\mu-2\sigma$ to $\mu+2\sigma$. Therefore, if more than 99% of the data for cloudy and cloud free pixels were not intersected, the value of $\mu\pm n\sigma$ could be selected as the threshold value.

3. Result and discussion

(i) Test: Gross cloud check

Image: Channel 5 brightness temperature

A histogram of channel 5 brightness temperature was generated. The brightness temperature for cloudy pixels and brightness temperature for cloud free water pixels were significant different. A threshold value was determined to separate the cloudy pixels from the non-cloudy pixels.

Fig. 2. The histogram of channel 5 brightness temperature for cloud over water and cloud free water pixel.

Weilbull Distribution was used as the fitted distribution in Figure 2. It was used instead of Normal Distribution because the data was not distributed normally. The Weilbull distribution was also more suitable on showing the peak value and shape of the histogram in this case. There is a significant difference between cloud free water pixels and cloudy water pixels from Figure 2. Therefore, the clear water pixels could be separated from cloudy pixels if a proper threshold value was selected. There is no significant different between clouds free water pixel and cloud free land pixels from Figure 3. This indicates that we could not discriminate between land and sea by using the image of brightness temperature. The Figure 3 also shows that the cloud tend to have the lower channel 5 brightness temperature compared to land and sea.

Fig. 3. The histogram of Channel 5 brightness temperature for cloud over land, cloud over water, cloud free land and cloud free water pixels. The Weilbull distribution was used as the fitted distribution for the histogram.

After that, a box-plot with median inter-quartile range box was generated to give an overview of the distribution of channel 5 brightness temperature for land, sea and cloud. The value of threshold for separating the cloudy and cloud free water pixels was then determined by using the mean and standard deviation of these pixels. The methodology had been discussed in previous section.

Fig. 4. The boxplot of channel 5 brightness temperature for cloud over land, cloud over water, cloud free land and cloud free water pixels.

	Cloud Over Water	Cloud Free Water
Mean	190.8	285.2
Std. Dev.	15.82	3.445

Table 1. The statistics of the channel 5 brightness temperature for cloudy and cloud free water pixels.

$\mu_c=190.8, \mu_{cf}= 285.2, \sigma_c=15.82, \sigma_{cf}=3.445$
 $\mu_{cf}> \mu_c$ and $\mu_{cf}-3 \sigma_{cf}> \mu_c+3 \sigma_c$
Therefore, threshold = 274.87 K
The pixels were masked as cloudy pixels if the channel 5 brightness temperature was less than 274.865K. The same procedure was repeated for the image of channel 4 brightness temperature.

(ii) Test: Minimum channel 4 temperature

Image: Channel 4 brightness temperature
The cloudy water pixels showed a wide variation in terms of T_4 compared with the cloud free water pixels. The cloudy pixels also had a lower value of T_4 compared with the cloud free sea pixels. Therefore if a pixel value less than a certain value of T_4 , it can be masked as a cloudy pixel.

Fig. 5. The histogram of channel 4 brightness temperature for cloud over water and cloud free water pixel.

Fig. 6. The histogram of Channel 4 brightness temperature for cloud over land, cloud over water, cloud free land and cloud free water pixels. The Weilbull distribution was used as the fitted distribution for the histogram.

The channel 4 brightness temperature of land and sea was not significant. The land and sea area could not be discriminated by using brightness temperature, but the land and sea areas could be discriminated from cloud by using T_4 . The median of T_4 for cloud over land and cloud over water were 199.5K and 177.7 K respectively. However, the median of T_4 for cloud free land and cloud free water were 291.4K and 287.0K respectively. The cloud was significantly colder than the land and sea.

Fig. 7. The boxplot of channel 4 brightness temperature for cloud over land, cloud over water, cloud free land and cloud free water pixels.

	Cloud Over Water	Cloud Free Water
Mean	203.2	286.7
Std. Dev.	18.82	3.383

Table 2. The statistic of the channel 4 brightness temperature for cloudy and cloud free water pixels.

$\mu_c=203.2, \mu_{cf}= 286.7, \sigma_c=18.82, \sigma_{cf}=3.383$
 $\mu_{cf}> \mu_c$ and $\mu_{cf}-3 \sigma_{cf}> \mu_c+3 \sigma_c$
Therefore, threshold = 276.55

(iii) Test: Dynamic Visible Threshold Test

(a) Image: Channel 1 albedo/ reflectance
A histogram of channel 1 reflectance was generated. The reflectance of sea was around 0 to 18%, but the reflectance of cloud was around 36% to 100% (Figure 8).

Fig. 8. The histogram of channel 1 reflectance for cloud over water and cloud free water pixel.

Fig. 9. The histogram of Channel 1 reflectance for cloud over land, cloud over water, cloud free land and cloud free water pixels. The Weilbull distribution was used as the fitted distribution for the histogram.

The reflectance of land and sea at channel 1 was lower than the cloud reflectance. Majority of the land and sea area had the reflectance lower than 18%. However, majority of the cloudy area had the reflectance greater than 36% (Figure 9).

There was a clear discrimination between cloudy and cloud free water pixels, but no significance difference between cloud free water and land pixels (Figure 10). Therefore the cloud free water pixels could be separated from cloudy pixels but the cloud free water pixels cannot be separated from the cloud free land pixels from channel 1 reflectance.

Fig. 10. The boxplot of channel 1 reflectance for cloud over land, cloud over water, cloud free land and cloud free water pixels.

	Cloud Over Water	Cloud Over Land	Cloud Free Land	Cloud Free Water
Mean	60.359	83.778	8.137	7.426
Std. Dev.	12.161	15.024	1.133	3.568

Table 3. The statistic of the channel 1 reflectance for difference surface cover.

$\mu_c=60.359, \mu_{cf}=7.426, \sigma_c=12.161, \sigma_{cf}=3.568$

$\mu_{cf}< \mu_c$ and $\mu_{cf}+3 \sigma_{cf}< \mu_c-3 \sigma_c$

threshold = 18.13

Therefore, the pixel was masked as cloudy water pixels if the reflectance was greater than 18.13%.

(b) Image: Channel 2 Albedo

There was a clear discrimination between cloudy and cloud free water pixel (Figure 11). The mean of channel 2 reflectance for cloudy water pixels is significant higher than the mean of the channel 2 reflectance for cloud free water surface. The higher value of standard deviation of cloud over water pixels was due to the inhomogeneous of cloud surface.

Fig. 11. The histogram of channel 2 reflectance for cloud over water and cloud free water pixel.

Fig. 12. The histogram of Channel 2 reflectance for cloud over land, cloud over water, cloud free land and cloud free water pixels. The Weilbull distribution was used as the fitted distribution for the histogram.

There was a clear separation between the mean of cloud free land, sea and cloudy surface (Figure 12). Therefore the land, sea and cloud could be separated if a proper value of threshold was selected.

The channel 2 albedo of the cloud over sea, cloud over water, cloud free land and cloud free water pixels was significant different among each other. 75% or majority of cloud over land pixel had the channel 2 albedo between 52.1 % and 58.4%, and the cloud over sea pixels was between 67.8 %and 82.7%. However the albedo for cloud free water pixels and was between 23.4%and 24.5%, and cloud free land pixels was between 2.2% and 5.9% (Figure 3.13).

Fig. 13. The box-plot of channel 2 reflectance for cloud over land, cloud over water, cloud free land and cloud free water pixels.

	Cloud Over Land	Cloud Over Water	Cloud Free Land	Cloud Free Water
Mean	62.9	83.778	8.137	4.163
Std. Dev.	10.93	15.024	1.133	2.655

Table 4. The statistic of the channel 2 reflectance for difference surface cover.

Cloud free and cloudy water pixels:
 $\mu_c=60.358545$, $\mu_{cf}=7.426386$, $\sigma_c=12.161196$, $\sigma_{cf}=3.568147$
 $\mu_{cf}<\mu_c$ and $\mu_{cf}+3\sigma_{cf}<\mu_c-3\sigma_c$
Therefore, threshold = 12.228
Therefore, the pixel was masked as cloudy if the reflectance was greater than 12.228%.

Sea and land pixels:
 $\mu_l=8.137$, $\mu_s=4.163$, $\sigma_l=1.133$, $\sigma_s=2.655$

(iv) Test: Ratio of near infrared to visible reflectance test
Image: Ratio of Channel 2 albedo and Channel 1 Albedo, R_2/R_1 .

Fig. 14. The histogram of reflectance ratio for channel 2 and channel 1 for cloud over water and cloud free water pixel.

Fig. 15. The histogram of ratio reflectance for channel 2 and channel 1 for cloud over land, cloud over water, cloud free land and cloud free water pixels. The Weibull distribution was used as the fitted distribution for the histogram.

Fig. 16. The box plot of reflectance ratio for channel 2 and channel 1 for cloud over land, cloud over water, cloud free land and cloud free water pixels.

	Cloud Over Land	Cloud Over Water	Cloud Free Land	Cloud Free Water
Mean	0.9019	0.8745	2.931	0.5441
Std. Dev.	0.1079	0.0239	0.3802	0.0755

Table 5. The statistic of reflectance ratio for channel 2 and channel 1 for difference surface cover.

$\mu_c=0.8745$, $\mu_{cf}=0.5441$, $\sigma_c=0.0239$, $\sigma_{cf}=0.0755$
 $\mu_{cf}<\mu_c$ and $\mu_{cf}+3\sigma_{cf}<\mu_c-3\sigma_c$
Therefore, threshold = 0.7706
The pixels were classified as cloud free water pixels if the ratio of reflectance was less than 0.7706.
Overall, the threshold values for all of the cloud masking tests were summarized as table below:

Test	The threshold value for cloud masking
Gross Cloud Check	T5<274.87 K
Minimum Channel 4 Temperature	T4<276.55K
Dynamic Visible Threshold Test	R1>18,13%, R2>12.23%

Table 6. The Threshold values for Cloud Masking Tests

The cloud masking algorithm

First of all, we had to determine whether the daytime algorithm or night time algorithm was used. We check the solar zenith angle and channel 2 albedo. The entire solar zenith angle for the image was below 56.61°. Almost all of the pixels’ reflectance was greater than 1%, and

only 0.0079% of the pixels' reflectance was less than 1%. Therefore the daytime algorithm was used.

Fig. 17. The frequency distribution for the solar zenith angle and channel 2 albedo viewed with the image processing software.

Daytime algorithm

Step 0. If Satellite zenith angle $< 53^\circ$, then go to step 1. Otherwise, reject or mask the pixel.

Step 1. If solar zenith angle $< 1^\circ$, then mask the pixel, end.

Step 2. If $T_{B5} < 274.87$ or $T_{B4} < 276.55K$, then mask the pixel.

Step 3. For land, if corrected albedo channel 1, $R_{corr1} > 0.1813$, mask the pixel ($R_{corr1} = R_1 / \cos \theta_s$). For sea water, if corrected albedo channel 2, $R_{corr2} > 0.1223$, then mask the pixel, end.

Step 4. If the vegetation index (ratio of channel 2 albedo and channel 1 albedo, R_2/R_1) > 0.7706 , then mask the pixel, end.

Step 5. Accept the pixel.

The image after geo-referenced and cloud masking was shown in the figure below. The cloud masking area was represented by the black colour (Figure 18).

Fig. 18. The SST image after cloud masking.

4. Conclusion

Although the cloud masking tests suggested were not able to be used for cloud classification or did not provide the good quality of cloud detection, but it gives an easier and practical way to separate the cloudy pixels from clear water pixels. The albedo of visible channel (channel 1 and channel 2) and brightness temperature of thermal infrared channels were good enough to be used for filtering the cloudy pixels in the application of sea surface temperature calibration application. Besides of that, the study also provided the database for determining the thresholds values at the South China Sea.

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