SEA FOG DETECTION BASED ON DYNAMIC THRESHOLD ALGORITHM AT DAWN AND DUSK TIME

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ABSTRACT:

Dawn and dusk time is the high frequency period of sea fog occurrence, which is very important for all-day sea fog remote sensing detection. Most polar orbit satellites are limited by time resolution and transit time, and can not detect sea fog at dawn and dusk. Based on the Himawari-8 geostationary satellite data and the analysis of the spectral characteristics of sea fog at dawn and dusk, this paper determines the variation law of the reflectivity and brightness temperature of sea fog at dawn and dusk, chooses sensitive bands, sets the detection index of sea fog and its corresponding dynamic threshold, and realizes the detection of sea fog at dawn and dusk. The case study results indicate that our dynamic threshold algorithm can effectively detect the sea fog at dawn and dusk.

1. INTRODUCTION

Sea fog is a condensation phenomenon occurring in the lower atmosphere of the sea or coastal areas under the influence of the ocean. It is a weather phenomenon that a large number of water droplets or ice crystals suspended in the atmospheric boundary layer make the atmospheric horizontal visibility less than 1 km (Wang, 1985).Sea fog has a great impact on maritime and coastal transportation, military activities, fishing, air quality and other aspects, such as aircraft landing, delays and other phenomena when fog occurs, low visibility often leads to collision and grounding of ships, etc. The interaction between sea fog droplets and atmospheric pollutants may be converted into acid fog, which seriously endangers human health. Research shows that fog, as a disastrous weather, causes the same economic losses and casualties as typhoon (Daegeun et al., 2018).As an important part of marine environmental monitoring, the research of sea fog detection technology is of great significance to social security (Wang et al., 2018).

The traditional sea fog detection is mainly based on the point observation of coastal meteorological stations, buoys, ships and so on. Its advantages lie in high accuracy and representativeness, while its disadvantages lie in the instability of time and frequency, the limited observation range and the inability to achieve effective observation of all sea fog events. As remote sensing satellite technology has the advantages of fast information updating, wide coverage and low cost, it has become an important means of sea fog detection (Zhang et al., 2018).At present, the research of sea fog remote sensing detection technology mainly focuses on daytime and night-time, while the research of dawn and dusk time is relatively few. However, sea fog mostly occurs in the dawn (Jung-Hyun et al., 2019; Tang et al, 2012; Zhang et al., 2015), and the spectral characteristics of sea fog in this period are different from those in daytime and night-time. Therefore, the technology of sea fog remote sensing detection in daytime and night-time is no longer applicable. In order to realize the real-time monitoring of sea fog and provide data support for marine economic and military activities, the research of sea fog detection at dawn and dusk is indispensable and of great significance. Based on the analysis of the spectral characteristics of sea fog samples at dawn and dusk, a dynamic threshold method is constructed to detect sea fog at dawn and dusk in the Yellow Sea and Bohai Sea.

2. THE DATA AND RESEARCH AREA

2.1 Satellite Datasets

Himawari-8 is a new generation of Japanese geostationary satellite, was successfully launched in October 2014 and put into operation in July 2015.Himawari-8 data has 16 bands, including three visible bands, three near infrared bands and ten infrared bands, the central wavelengths ranging from 0.47μm to 13.3μm(as shown in Table1).

Full disk data has a temporal resolution of 10 minutes and a spatial resolution of 0.5-2 km, of which the resolution of bands 1, 2 and 4 is 1 km, the resolution of band 3 is 0.5 km, and the resolution of other bands is 2 km.

Himawari-8 satellite data pre-processing includes: (1) geometric correction by reading the affine transformation parameters of the header file, (2) image clipping to extract the image data of the study area, (3) land mask, using vector data to remove the land area and retain the data of the Yellow Sea and Bohai Sea.

Band	Spatial resolution /km	Band Range /μm	Central Wavelength /μm
1	1	0.43~0.48	0.47

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2	1	0.50~0.52	0.51
3	0.5	0.63~0.66	0.64
4	1	0.85~0.87	0.86
5	2	1.60~1.62	1.6
6	2	2.25~2.27	2.3
7	2	3.74~3.96	3.9
8	2	6.06~6.43	6.2
9	2	6.89~7.01	6.9
10	2	7.26~7.43	7.3
11	2	8.44~8.76	8.6
12	2	9.54~9.72	9.6
13	2	10.3~10.6	10.1
14	2	11.1~11.3	11.2
15	2	12.2~12.5	12.4
16	2	13.2~13.4	13.3

Table 1. Band information of Himawari-8

2.2 Study Area

The Yellow Sea and Bohai Sea belong to China's offshore waters, with a total area of about 450,000 square kilometres, and are sea fog-prone areas. Especially in the Yellow Sea, due to the impact of the warm current south of Jezhou Island in the north-eastern part of the East China Sea and the cold current along the coast of the Yellow Sea, coupled with the appropriate meteorological conditions, the occurrence frequency of sea fog in the Yellow Sea is relatively high, and it has become the most frequent area of sea fog occurrence in China's coastal waters (Wang et al., 2018). The exact location of the study area is shown in Figure 1.

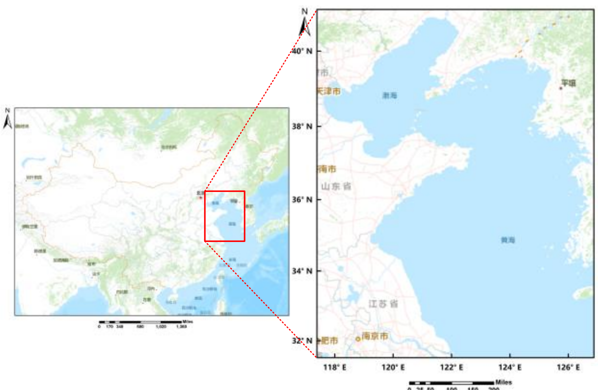


Figure 1. Location map of study area

3. METHOD

3.1 Dynamic Threshold Algorithm

Threshold method has the advantages of simplicity and high efficiency, and it is the main algorithm of sea fog remote sensing detection in daytime or night. In the daytime or at night, the spectral characteristics of sea fog are basically stable. Therefore, based on the analysis of the characteristics of a large number of sea fog samples, the fixed empirical threshold can effectively realize the detection of sea fog in daytime or at night. However, for the sea fog at the dawn and dusk time, its spectral characteristics change greatly, especially the reflectance of visible-near infrared bands, so the fixed threshold can not realize the detection of sea fog in the dawn and dusk time. Considering that the change of spectral characteristics of sea fog depends on the solar zenith angle, after analysing the relationship between spectral characteristics (reflectance and brightness temperature) of sea fog samples and solar zenith angle, a dynamic threshold method based on solar zenith angle is constructed to detect sea fog at dawn and dusk. In this paper, the range of solar zenith angle at dawn and dusk time is set at [81 °, 90 °).

3.2 Spectral Characteristics Analysis of Sea Fog at Dawn and Dusk

By selecting sea fog samples from the images of 10 sea fog events at dawn and dusk time, the relationship between the reflectance of sea fog in visible bands and the solar zenith angle is obtained. (Figure 2).From Figure 2, it can be concluded that at dawn and dusk, with the increasing of the solar zenith angle, the reflectance of sea fog in visible-near infrared bands decreases gradually to 0, the solar zenith angle has a linear relationship with the reflectance of sea fog, and the determination coefficients are greater than 0.9, which shows that the linear regression equation has a high goodness of fit and can accurately express the linear relationship between the two. The reflectance of sea fog decreases in each band, but it always keeps the characteristics of maximum reflectivity in band 1 and minimum reflectance in band 6, and the reflectance in bands 2 and 4 are second only to that in band 1.

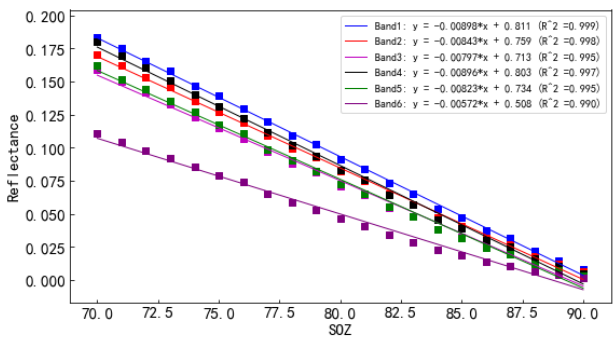


Figure 2. Linear relationship between reflectance of sea fog and solar zenith angle at dawn and dusk in the Yellow Sea and Bohai Sea

Similarly, after statistics of the brightness temperature of sea fog in the far infrared bands and the corresponding solar zenith angle information, we obtain the relationship between the two. It is found that there is only a linear relationship between the brightness temperature of band 7 and the corresponding solar zenith angle (Figure 3 top). The brightness temperature of sea fog fluctuate irregularly in a small range with the increase of solar zenith angle in other infrared bands. (Figure 3 bottom).

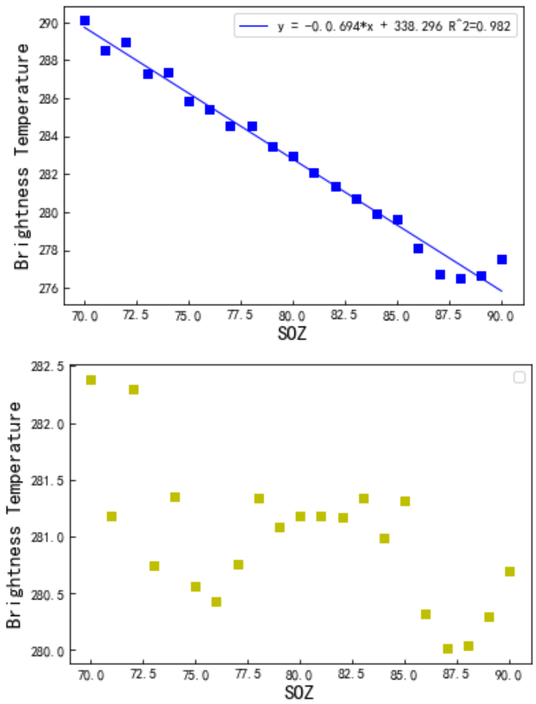


Figure 3. (Top) Linear relationship between brightness temperature of sea fog and solar zenith angle in band 7 (bottom) Relation between brightness temperature of sea fog and solar zenith angle in band 14

3.3 Algorithmic Construction

Based on the analysis of the spectral characteristics of sea fog at dawn and dusk, the sensitive band of sea fog detection is selected, and then the detection index of sea fog at dawn and dusk is constructed (Table 2). The algorithm of sea fog detection at dawn and dusk (the range of solar zenith angle (SOZ) is constructed. The specific flow chart is shown in Figure 4.

Sea Fog Detection Index	Threshold Setting
B_7	Th1= SOZ * -0.694 + 338.296 - 3
$R\_Sum = B_1 + B_4$	Th2=SOZ * -0.0179 + 1.615 - 0.015
$R\_D_{value} = \lvert B_4 - B_1 \rvert$	Th3=0.015
$DE = B_3 - B_5$	Th4=0.004
$BTD = B_7 - B_{14}$	(Th5=SOZ * -0.633 + 52.451 - 3 , Th6=SOZ * -0.633 + 52.451 + 3)

Table 2. Sea fog detection index and threshold setting used in detection algorithm at dawn and dusk

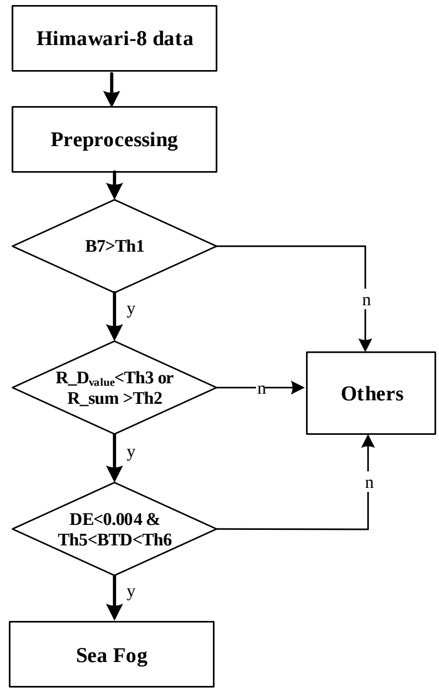
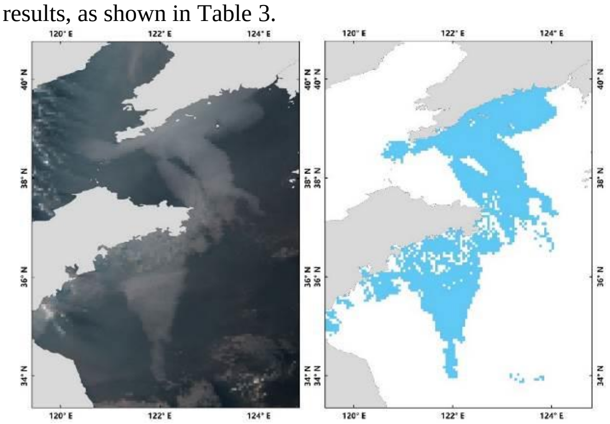


Figure 4. Flow chart of sea fog detection algorithm at dawn and dusk

4. RESULTS AND ANALYSIS

The marine weather bulletin issued by the China Meteorological Administration at 7:25 on May 2, 2017 (Beijing time) shows that there will be heavy fog in the northern Bohai Sea, the Bohai Strait, most of the Yellow Sea and the northern East China Sea during the daytime from May 2 to 3. Through visual interpretation of the Himawari-8 image of May 2, there will be milky white sea fog with fine texture and neat boundary (Zhang et al., 2009; Deng et al., 2013; Chen et al., 2017).Taking the sea fog event as an example, the performance of the sea fog detection algorithm at dawn and dusk is illustrated (Figure 5).In addition, in order to verify the accuracy of the detection results, the visibility data of coastal meteorological stations at the same time are used to verify the results, as shown in Table 3.



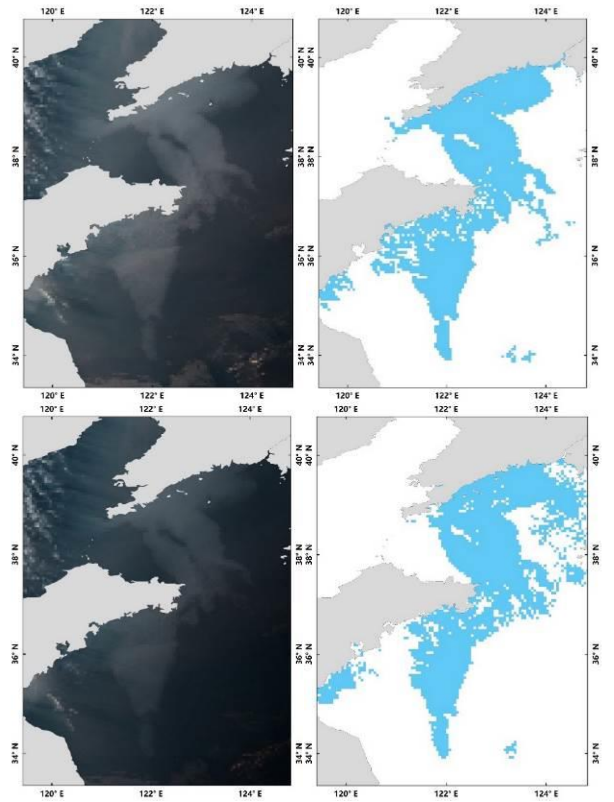


Figure 5. 2017.5.2 Dawn and Dusk Sea Fog Event (top) 10:00 UTC Himawari-8 true colour map and sea fog detection results (middle) 10:10 UTC Himawari-8 true colour map and sea fog detection results (bottom) 10:20 UTC Himawari-8 true colour map and sea fog detection results (blue part is sea fog, gray part is land, white part is other objects)

Index / Station	Height /m	Horizontal visibility /KM
DaLian54662	91.5	0.7
ChengShanTou54776	47.7	0.0
QingDao54857	76.0	8.7
RiZhao54945	64.4	0.3

Table 3. Visibility Information of Coastal Meteorological Station Data at 10:00 UTC

By comparing the detection results with the visibility data of coastal meteorological stations, it can be found that the algorithm can more accurately identify the sea fog in the Yellow Sea and Bohai Sea at dawn and dusk, and has certain accuracy, but there are also some errors: (1) At 10:00 UTC, the visibility of Qingdao meteorological station is far greater than 1km, indicating that there is no sea fog near it. However, the results of this algorithm suggests near the station is blue (i.e. sea fog). The misclassification of cloud and sea fog may be due to the low cloud over Qingdao Station, whose spectral characteristics are similar to those of sea fog.(2) At 10:20 UTC, the misclassification of sea surface into sea fog occurs in the northern Yellow Sea (near 39°N, 124°E). The reason may be that the solar zenith angle reaches 88 at that time, the reflectance of all kinds of objects in visible-near infrared bands are close to 0, which leads to the very small difference of reflectance between different objects, because the temperature of sea surface is close to that of sea fog, it is more difficult to separate them.

5. CONCLUSION

On the basis of spectral characteristics analysis, a sea fog detection algorithm for the Yellow Sea and Bohai Sea at dawn and dusk based on Himawari-8 satellite data is constructed, and the range of sea fog is extracted. The detection results and visibility data of coastal meteorological stations are verified and analysed, and the following conclusions are drawn:

1) At dawn and dusk, the reflectance of sea fog in visible-near infrared bands decreases with the increase of solar zenith angle, and there is a linear relationship between them. For the relationship between brightness temperature and solar zenith angle in infrared bands, only the brightness temperature of sea fog in band 7 has a linear relationship with solar zenith angle, while the others only fluctuate within a certain range and do not form a linear relationship.

2) Separation of sea fog and low cloud has always been a difficult problem in sea fog detection. Dawn and dusk are no exception. Because of the similarity of their spectral characteristics, it is difficult to distinguish them by the sea fog detection index based on spectral characteristics alone.

3) When the solar zenith angle reaches 88° or above, it will enter the night state immediately (SOZ >= 90°). The reflectance of all kinds of objects in visible-near infrared bands are close to 0. Therefore, the contribution of the reflectance to the distinction between sea fog and other objects is weak. The brightness temperature of infrared band becomes the main means, but the temperature of sea fog and sea surface changes seems similar. Therefore, there may be a misunderstanding between the two.

4) In a word, the sea fog detection algorithm in this paper has some limitations, and more data are needed to verify the accuracy and stability of the algorithm.

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