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Application of Himawari-8 Satellite Data in Daytime Sea Fog Monitoring in South China Coast

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Abstract: Based on the high temporal and spatial resolution of Japanese Himawari-8 geostationary meteorological satellite data and visibility observation data, the band and band combination was selected suitable for daytime sea fog identification in coastal areas of South China, including $R_{0.64}$ 、 $NDVI$ 、 $BT_{11.2}$ 、 $BT_{10.4}$ 、 $BT_{11.2}$ 、 $BT_{3.9}$ 、 $BT_{11.2}$ etc, and taken into account the influence of solar elevation angle on the reflectivity channel, and constructed a new coastal fog monitoring model (SFM) in the coastal area of South China for the identification of sea fog in the coastal areas of South China And applications. According to the fog judgment standard promulgated by the China Meteorological Administration, the sea fog monitoring model (SFM) was used to remotely monitor the coastal fog events in South China from January to April 2018, and further used the three provinces of South China (Guangxi, Guangdong, Hainan). Visibility data from coastal and island observatories are verified. The results show that the accuracy of sea fog recognition based on SFM model is about 68.6%, which has a good business application prospect.

1.Introduction

The fog is a weather phenomenon in which the water vapor in the air condenses into fine water droplets suspended in the air and the visibility of the ground level is lowered when the relative humidity reaches 100% in the case of sufficient water vapor, breeze and atmospheric stability. The horizontal visibility of fog is less than 1km, which is also a kind of disaster weather. Because there is sufficient water vapor and abundant condensation nuclei on the surface of the sea, it has sufficient conditions for generating fog. Compared with the land fog generated on land, once the sea fog is formed, its concentration and thickness are large and the influence range is wide. In recent years, with the continuous development of the social economy, especially the strategic conception of the 21st Century Maritime Silk Road, the coastal transportation industry in South China has developed rapidly. When the sea fog occurs, the visibility of the sea level is reduced, which has a great impact on maritime transportation, ship in and out, fishing, and maritime military activities. Therefore, accurate monitoring of the time and space distribution of sea fog and mastering the formation and dissipation of sea fog The law is of great significance.



Conventional fog monitoring is limited by the distribution of observation sites and observation time, especially in the vast oceans, where the number of observatories is small, and only coastal or island stations have fog or visibility observations, and the observation frequency and observation density of these stations are very limited, far from meeting the monitoring needs for the occurrence, development, extinction, and scope and intensity of sea fog. In recent years, with the development of satellite remote sensing technology, satellite remote sensing has become an important means of sea fog monitoring. It has the advantages of wide observation range, high timeliness, large amount of information and low cost, which can effectively obtain important information such as spatial distribution, change and area of sea fog in the observation area, and make up for the shortcomings of traditional ground measurement. Domestic and foreign scholars have carried out a large number of fog monitoring studies using satellite remote sensing technology. In 1974, Gurka^[1] first proposed to estimate the fog dissipating time by using the brightness of the research of cloud image recognition and dissipation mainly using visible light images. At night, Eyre and Turner et al.^[2-3] used NOAA/AVHRR mid-infrared and far-infrared data to study the identification of night fog. Ellord and Lee^[4-5] used the two infrared channels of GOES satellite to detect the fog and analyzed the technical defects in the recognition mode. Xi Liu et al.^[8] used the MTSAT satellite data to use the visible light reflectance threshold method, the infrared brightness threshold method and the two-channel difference method to carry out monitoring of the eastern coastal fog area. Zhang et al.^[6] based on the analysis of China's offshore sounding data, studied the difference between cloud top temperature and sea surface temperature of fog and stratus, and proposed a sea fog dynamic threshold detection algorithm based on this. Wu et al.^[7] improved the quality of MOSF data sea fog monitoring by using the vertical resolution high resolution LASIPS (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) data. Hongmei Zhou et al.^[9] based on multi-source satellite data, firstly used the threshold method to separate the cloud, and then based on the structure, texture, shape and other characteristics of the fog area, using a variety of practical and effective fog detection and cloud and fog separation technology models. The fog area is automatically extracted. From the literature on remote sensing monitoring of fog at home and abroad, there are few studies on sea fog monitoring^[10-14], especially the research on sea fog monitoring using Himawari-8 satellite data.

In this paper, using the new generation of geostationary meteorological satellites, Himawari-8, with many spectral channels and high time resolution, the spectral characteristics of sea fog in South China coastal areas are analyzed, and the sea fog monitoring model (SFM) is constructed in the coastal area of South China. Disaster reduction provides a reliable basis for decision making.

2.Data and Processing

2.1 Satellite data

The satellite data used in this paper is the 16-channel visible and infrared data of the second generation of geostationary meteorological satellite Himawari-8 of the Japan Meteorological Agency (JMA). The band data is pre-processed for reflectivity and brightness. Since the spatial resolution of the Himawari-8 satellite data channels 1, 2 and 4 is 1 km, the channel 3 is 0.5 km, and the remaining 12 channels are all 2 km. For the convenience of analysis and calculation, the Himawari-8 satellite channel 3 data is used by the proximity method. Sampling and 5 to 16 channels of data are interpolated to form data with a spatial resolution of 1 km. The time resolution of Himawari-8 satellite data is 10 min, and the data projection method is equal latitude and longitude projection. The algorithm research area of this paper is the coastal area of South China. The data selection range is from 104° to 118° east longitude and 16° to 27° north latitude.

2.2 Meteorological data

The visibility data used in this paper is mainly derived from the CIMISS database standard data of the China Meteorological Administration, including the observation data of the hourly visibility of the coastal areas of the three provinces of South China (Guangxi, Guangdong, Hainan) and island observation stations

3. Sea fog spectral characteristics analysis

Since seawater has the uniform characteristics of the underlying surface, the corresponding clear sky area is easier to identify. Therefore, the difficulty in sea fog recognition lies in the separation of clouds and fog, especially the separation of low clouds and fog. Based on the multispectral characteristics of Himawari-8 satellite data, this paper analyzes and selects the band and band combination suitable for clear sky, cloud and sea fog separation.

3.1 Visible light band (0.64 μ m) detection

The visible (e.g., 0.64 μ m) band reflectivity of the Himawari-8 satellite data is chosen to effectively distinguish between oceans, land and clouds. The ocean has a low reflectance value in the visible light band, which can darken the light cloud image, and the cloud reflectivity is high, which is beneficial to the distinction between cloud and water. In the terrestrial area, because the vegetation has a high reflectance value in the near-infrared band, it is easy to be confused with thin clouds, cirrus clouds, etc., while the visible light band of the vegetation has a lower reflectivity and a higher cloud, and has better cloud recognition effect. From the texture point of view, the performance of the sea fog in the visible light cloud is similar to that on the land, the fog top is smooth, the edges are clear, the shape is regular, and it is easy to identify. Since the value of the band is greatly affected by the solar elevation angle, the threshold is dynamically set within a certain angle range. The band (0.64 μ m) threshold setting is proposed by H Shang et al. ^[15]:

$$TH_3 = -0.014 \times SA + 1.207 (SA > 72^\circ) \quad (1)$$

$$TH_3 = 0.2 (SA \leq 72^\circ) \quad (2)$$

Among them, TH_3 represents the band (0.64 μ m) threshold, and SA represents the solar zenith angle. When the band reflectance is greater than the threshold, it indicates that it is recognized as a cloud or a fog.

3.2 Normalized Differential Vegetation Index (NDVI) Detection

The NDVI (Normalized Difference Vegetation Index), also known as the change in biomass indicators, allows the land containing vegetation to be separated from water and clouds. Because the near-infrared in the normalized difference vegetation index (NDVI) is sensitive to vegetation and water, the clear-sky vegetation value is large, and the water body value is usually negative, which can effectively distinguish the clear-sky water body and the cloud system over the vegetation. NDVI can partially eliminate the effects of radiation changes related to atmospheric conditions such as solar elevation angle, satellite observation angle, terrain, cloud shadow, etc. The numerical value has certain stability, which is beneficial to the identification of clouds, water, land and sea fog. Usually, the clear sky threshold above the ocean is set to $NDVI > 0.4$ or $NDVI < -0.2$.

3.3 $BT_{11.2}$ (11.2 μ m) bright temperature band detection

Since the temperature of the cloud is relatively low, the emitted radiation is low, the display value in the bright temperature channel is low, and the land and water body temperature values are high, the emitted radiation is high, and the bright temperature value is high, which is favorable for the cloud to distinguish. The infrared (e.g., 11.2 μ m) band of the Himawari-8 satellite data has weak gas absorption, and the band has a good cloud recognition effect, especially high clouds. The recognition threshold of the cloud is $BT_{11.2} < 270K$.

3.4 $BT_{11.2}(11.2\mu m) - BT_{3.9}(3.9\mu m)$ bright temperature difference detection

The intensity of gas absorption in different bands is different. The specific characteristics of the mid-infrared band (3.9 μ m) are affected by solar radiation and ground radiation during the day, mainly due to solar radiation, while fog or low clouds are close to the surrounding ground temperature. The cloud top temperature value is high, and the infrared wavelength of the cloud (11.2 μ m) is low, so the cloud brightness temperature difference (11.2 μ m-3.9 μ m) is large, and the fog or low cloud brightness temperature difference is small, so the detection parameter is Sea fog has a good detection effect. The fog recognition threshold for the coastal area of South China is set to $BT_{11.2} - BT_{3.9} > -10.5$.

3.5 $BT_{11.2}$ ($11.2\mu\text{m}$)- $BT_{12.3}$ ($12.3\mu\text{m}$) split window detection

The split window, also known as the multi-channel method and the window method, refers to the use of two adjacent channels in the atmospheric window of 10~13 μm (generally 10.5~11.5 μm , 11.5~12.5 μm) in the thermal infrared remote sensing inversion of surface temperature. The difference in atmospheric absorption, and the combination of two channels of measurement values to eliminate the effects of the atmosphere, usually used for thin-roll cloud monitoring, the effect is better, the threshold is set to $BT_{11.2}-BT_{12.3}>2.5$.

4. Sea Fog Monitoring Model (SFM)

Based on the multispectral characteristics of Himawari-8 satellite data, analyze and select $R_{0.64}$, NDVI, $BT_{11.2}$, $BT_{11.2}-BT_{12.3}$, $BT_{11.2}-BT_{3.9}$, etc. suitable for clear sky, cloud and sea fog separation. And band combination, using the binary tree method to construct a sea fog monitoring model to achieve daytime sea fog monitoring in the coastal areas of South China.

A binary tree is a connected acyclic graph with a degree of no more than three for each vertex. A root binary tree must also satisfy the root node with a degree of no more than 2. With the root node, each vertex defines a unique parent node and a maximum of 2 child nodes. Child nodes are often referred to as subtrees and are divided into "left subtrees" and "right subtrees". A binary tree with a depth of k and 2^k-1 nodes is called a full binary tree. The characteristic of this tree is that the number of nodes on each layer is the maximum number of nodes. In a binary tree, except for the last layer, if the remaining layers are full, and the last layer is either full, or there are several consecutive nodes missing on the right side, the binary tree is a complete binary tree. The depth of a complete binary tree with n nodes $\lfloor \log_2 n \rfloor + 1$ (Note: $\lfloor \cdot \rfloor$ means rounding down). A complete binary tree with a depth of k , with at most 2^{k-1} leaf nodes, and at most 2^k-1 nodes. The SFM model uses a full binary tree algorithm structure of depth 3 (see Figure 1). The Himawari-8 satellite channel data used is preprocessed, including scaling and projection. In Figure 1, N1, N2 and N3 represent the identification nodes, $R_{0.64}$ represents the visible light band (0.64 μm), NDVI represents the normalized differential vegetation index, $BT_{11.2}$ represents the infrared band (11.2 μm), and $BT_{12.3}$ represents the infrared The band (12.3 μm), $BT_{3.9}$ represents the mid-infrared band (3.9 μm), SA represents the solar zenith angle, and TH3 represents the band (0.64 μm) threshold.

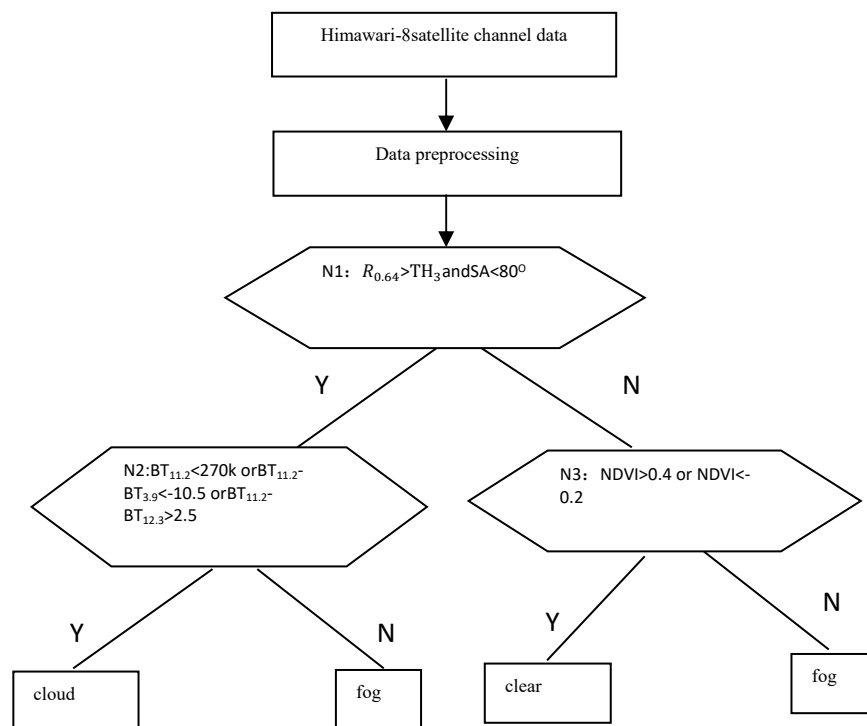


Figure 1 SFM algorithm structure

5. Results Analysis

The Meteorological Administration of China, “Technical Regulations for Surface Meteorological Observations (2016 Edition)” refers to the phenomenon of visual obstruction with a ground level visibility below 1.0km as fog. In this study, stations from the coastal meteorological observatory stations in South China (Guangdong, Guangxi, and Hainan) are selected within a distance of 20km from the sea. According to the sea fog climate characteristics in the south China coast^[16], the ground-level observation and monitoring effect evaluation of the sea-fog remote sensing monitoring model was carried out by selecting the hourly observation visibility data from 8:00 to 17:00 in January and April of 2018, the number of observation sites is the number of observation sites with fog phenomenon (visibility less than 1.0km). Sea fog monitoring model (SFM) can realize hourly Himawari-8 AHI channel data sea fog detection analysis, and match the observation station visibility data in time, so it can accurately reflect the accuracy of sea fog recognition. The precision analysis indicators proposed by Bendix et al.^[17], namely the hit rate (POD) and the missed detection rate (MDR), are used to test the accuracy of remote sensing monitoring results. The relevant index formula is:

$$POD = \frac{yy}{yy+ny} \quad (3)$$

$$MDR = \frac{ny}{yy+ny} \quad (4)$$

Where: POD is the probability of detection (POD); MDR is the missed detection ratio (MDR); yy is the number of stations with sea fog and ground measured results in remote sensing monitoring; ny is not monitored by remote sensing. The number of sites with sea fog and sea surface measured by sea fog.

The results show that from January to April 2018, the coastal area of South China was affected by the southwest warm and humid air current. The cloud was more disturbing to the satellite remote sensing sea fog monitoring. The sea fog monitoring hit rate (POD) was 68.6%, and the missed detection rate was 31.4%. (See Table 1)

Table 1 Himawari-8 satellite data daytime sea fog monitoring accuracy analysis table

Time	Number of samples	POD(%)	MDR(%)
2018.1-4	51	68.6	31.4

6. Conclusion

Based on the multi-spectral and high temporal and spatial resolution characteristics of the new generation meteorological satellite Himawari-8, considering the influence of the solar elevation angle, Sea Fog Monitoring Model (SFM) for the coastal fog in South China is established, and the sea fog monitoring in the coastal areas of South China is attempted, and coastal observation is used. The visibility data of the station is verified. The results show that it is feasible to use the satellite remote sensing data to carry out sea fog monitoring in the south China coast. The monitoring accuracy rate is 68.6%. Because the coastal areas of South China are greatly affected by clouds, the spectral characteristics of low clouds and sea fog are close, and sea fog monitoring is very complicated, which affects the accuracy of sea fog monitoring. At the same time, in the process of sea-sky remote sensing monitoring, the seasons are different and the conditions are different. Some problems, such as the threshold optimization and adjustment of remote sensing monitoring indicators, and how to use texture and other techniques to distinguish clouds and fog to improve the accuracy of sea fog monitoring and early warning, are necessary to continue to study in the future.

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