Monitoring Fog Using FY-1D Meteorological Satellite

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Abstract  FY-1D is the second national operation meteorological satellite of China, and is much better compared to monitoring fog. However, research on monitoring fog using FY-1D is very few. In this paper, based on the typical FY-1D data, a fog’s spectral characteristics in the different channels are analyzed using the histogram analysis method, and a method of monitoring fog using FY-1D is suggested. The results indicate that the 1st and 4th channels are the representative channels of FY-1D for the identification of fog. In the 1st channel, the fog is with uniform veins, smooth top, and clear-cut boundary, and its albedo is 20%~48%. In the 4th channel, the fog’s brightness and temperature is 272~289K, and the difference value between the fog’s and the ground surface’s is not more than 6K.

Keywords  fog; FY-1D; spectral characteristics

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Introduction

Fog can be a disastrous weather phenomena. Navigation, aviation, road transportation and military activities can be severely influenced by the low visibility caused by fog, especially heavy fog. Sometimes heavy fog results in catastrophic accidents. Studies of fog monitoring methods have been conducted for years and have achieved significant evolution. Generally, stations were laid out on the surfaces of land or sea for manual or instrumental automatic observation. However, these conventional methods not only waste a great deal of manpower and material resources, but also cannot meet the monitoring demands, considering the inadequate station density and monitoring frequency. It is especially more difficult for conventional methods to monitor and forecast the development or disappearance of dynamic fog. Satellite remote sensing technique is of particular advantage in this area because of its macroscopy, celerity and immediacy features. Fog and clouds had been recognized overseas using satellite remote sensing data since the 1970s\(^1\),\(^2\). Though domestic researches in this field are comparatively lacking, there have been many achievements. Liu\(^3\) analyzed the particle size distributions of clouds and fog by using the reflected sunlight data from NOAA / AVHRR channel 3, and discovered that the fog area coincided with the area where albedo in channel 3 is high. Li\(^4\),\(^5\) presented a technique for monitoring the tendency of fog dissipation by using the multispectral images from GMS-5 meteorological satellite. Sun\(^6\) studied visible light and the infrared spectral characteristics of clouds and fog in the meteorological satellite remote sensing images using the spectral analysis method, which is based on the atmospheric radiation transmission theory. Sun also described the spectrum response features and the related

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index in each channel of NOAA/AVHRR. Ma analyzed the spectral characteristics of water, cloud, snow, surface features and fog based on spectral profiles sampling EOS/MODIS data, and discovered the channels of EOS MODIS suitable for fog detection. However, the satellite data of China is little-used in fog detection studies. FY-1D is the second national operation meteorological satellite of China, which is highly advantageous for monitoring fog; however, very few have undertaken research of monitoring fog using FY-1D. In this paper, the spectral characteristics of fog in the channel images of the FY-1D meteorological satellite is analyzed and a method of fog detection by using FY-1D data is suggested.

1 Characteristics of FY-1D meteorological satellite

FY-1D launched successfully on 15th.5.2002 is the second national operation meteorological satellite of China, which has been running continuously and steadily up to the present. What’s more, FY-1D has been widely applied to the fields of meteorology, agriculture, forestry, water conservation, oceanography, military affairs, etc. Because of its significant role in these fields, FY-1D has been listed in the sequence of world meteorology operation application satellite by WMO, which offers abundant observation data of meteorology and earth environment to many countries. FY-1D carries 10 VIS (visible light) or IR (infrared) CH (channel) scanning radiometers shown in Table 1. When orbiting, it sends high resolution (1.1 km at nadir point) data of 10 channels in real time. FY-1D passes through China twice a day. One is between 7:00 and 9:00 Beijing Time, which is advantageous for monitoring fog; the other is between 19:00 and 21:00; during this time there is little probability for fog to appear.

| CH | Wavelength / mm | Application fields |
|----|----------------|--------------------|
| 1  | 0.58~0.68      | Day cloud, snow-ice, vegetation |
| 2  | 0.84~0.89      | Day cloud, vegetation, boundary of land and water, air condition, snow-ice |
| 3  | 3.55~3.93      | Night image, heat reservoir of high temperature, earth surface temperature, forest conflagration |
| 4  | 10.3~11.3      | Night image, temperature of sea and earth surface |
| 5  | 11.5~12.5      | Night image, temperature of sea and earth surface |
| 6  | 1.58~1.64      | Day image, differentiation between cloud and snow, drought monitor, difference of cloud image |
| 7  | 0.43~0.48      | Low concentration chlorophyll(ocean water bodies) |
| 8  | 0.48~0.53      | Middle concentration chlorophyll, sediment, seawater attenuation coefficient, ocean ice |
| 9  | 0.53~0.58      | High concentration chlorophyll(near ocean water bodies), ocean currents, water masses |
| 10 | 0.900~0.905    | Vapor |

2 Identifying fog by FY-1D

2.1 Fog’s spectral characteristic of VIS band

Fog is formed from drips and ice crystal particles close to the earth’s surface or floating in the air. The radius of the fog drops generally vary from several to tens of microns. However, fog usually contains masses of particles smaller than 1 micron and its density can reach thousands per cubic centimeter. As a result of these fog drops, optics characteristic and atmosphere visibility are considerably influenced. However, fog drops are much smaller than liquid drops in clouds; hence, the radiation characteristic of fog is different from clouds. These differences are correspondingly shown on the VIS images from FY-1D. For example, Fig.1 is the CH1 image from FY-1D at 9:45 on Jan 23, 2003. In the image, “A” represents an area covered with fog (ACF) in the Jiaogang Plain (Hubei, China); “B” is an area covered with cloud (ACC) where Hubei province joins with Jiangxi province; and, “C” stands for an ACF in the Qing Mountain (Shanxi, China). In Fig.1, it is found that compared with the area covered with the earth’s surface (ACE), ACF and ACC present higher brightness in the VIS images. It indicates that both ACF
and ACC show high albedo in VIS band. In addition, 2 areas of 50×50 pixels from “A” and “B” are chosen (rectangle “1” and “2” in Fig. 1) and their histogram analyzed. It is found that in ACF, the spectrum is narrower, and the albedo is between 30%~48%, but in ACC, the spectrum is wider, and the albedo is from 30% to 90%. In conclusion, the albedo of ACC is much higher than that of ACF (Fig.2).

On VIS images, the fog also shows uniform veins and regular boundaries. Sometimes, they coincide with the topography (see “c” in Fig.1).

![Fig.1 VIS (CH1) image at 9:45 on Jan 23, 2003 by FY-1D](image)

In contrast, clouds are of plentiful veins and indistinct boundaries. This is because fog particles are small and homogeneous. Furthermore, fog has a smooth top compared with the rough cloudtop. All these distinctions make the reflecting character of fog and clouds different.

Again, 2 areas of 50×50 pixels are designated in the image from Fig.1; one is a mixed area of ACF and ACE (rectangle “3” in Fig.1), and the other is a mixed area of ACC and ACE (rectangle “4” in Fig.1).

Comparing the histograms from Fig. 3, it is found that ACF and ACE are clearly distinguished by two obvious wave crests, while ACC and ACE are not so well divided.

Moreover, all these spectral characteristics of fog are also found in other VIS channel images from FY-1D.

![Fig.3 Histograms of different mixed areas in CH1](image)

2.2 Fog’s spectral characteristic of IR band

The temperature of fog is almost equal to the earth’s surface because of the close distance between them, so the temperature contrast in IR channels is very low. Compared with the VIS band, the fog’s spectrum characteristic in the IR band is so unclear that the fog cannot be distinguished from the earth’s surface. It is, therefore, more difficult to identify the fog using the IR images from FY-1D rather than using the VIS image.

Both CH4 and CH5 of FY-1D belong to a thermal
infrared band which mainly receives the radiation from the ground-object, fog and cloud, besides a little solar radiation. Because radiation obviously varies with the temperature fluctuation while the sensor mainly responds to thermal radiation from the ground object, cloud and fog themselves, ACF’s brightness temperature is close to or a little lower than ACE’s (Fig.4(a)), while ACC’s is much lower than ACE’s (Fig.4(b)).

The CH3 of the FY-1D belongs to the mid-infrared band, and its wavelength is between the crests of solar radiation (0.5 μm) and ground-object radiation (10.0 μm); hence, it includes both solar radiation and ground-object radiation. When the sun is below the horizon, CH3 only reflects the ground-object radiation and the characteristics of fog and cloud in CH3 are similar in CH4. When the sun is above the horizon, solar radiation gradually enhances and becomes the dominant radiation source of energy received by CH3. Moreover, the brightness temperature of ACF and ACC become higher so that it’s difficult to differentiate them; therefore, it is not very useful to identify fog by CH3.

3 Fog monitoring methods and instances of FY-1D

3.1 Monitoring methods

Based on the discussion above, it is known that CH1 and CH4 are the representative channels of FY-1D for the identification of fog. The characteristics of fog, cloud and the earth’s surface in CH1 and CH4 are described in Table 2, and a method of monitoring fog using FY-1D is suggested according to these different characteristics.

| Object      | CH1                          | CH4                          |
|-------------|------------------------------|------------------------------|
| Fog         | 1) Albedo between 20%~48%,   | Brightness temperature between 272K~289K, close to or little lower than the earth’s surface around (generally not more than 6K) |
|             | 2) Aniform veins, smooth top, and inconspicuous brightness change of fog area |                              |
|             | 3) Clear-cut boundary, sharp transition of brightness from fog area to the earth’s surface |                              |
| Cloud       | 1) Albedo between 25%~92%,   | Brightness temperature under 270 K, obviously under the earth’s surface around (generally more than 10 K) |
|             | 2) Plentiful veins, rough cloudtop, obvious brightness change of cloud area |                              |
|             | 3) Indistinct boundaries, slow transition of brightness from cloud area to the earth’s surface |                              |
| The earth’s surface | Albedo generally less than 20% | Brightness temperature generally above 274 K |

3.2 Application instances

On October 10, 2006, various extents of fog appeared at some places in Hubei province in the morning. In the CH1 image at 7:04 (Fig.5(a)), there are 2 south-north grey areas through Jianghan Plain and northeast Hubei, with uniform veins, clear-cut boundaries, and about 20%~30% albedo. Meanwhile, there are some southwest-northeast bright white areas in southeast and northeast Hubei, with coarse veins
and blurry boundaries, and about 25~70% albedo. However, in the CH4 image (Fig.5(b)), the brightness of the grey areas is lower, between 270 ~ 224 K.

According to the characteristics described in Table 2, it can be concluded that the grey areas are ACF while the bright white areas are ACC. The monitoring result of FY-1D is basically consistent with the actual situation.

4 Conclusions

In this paper, the spectral characteristics of the fog in the different channels of the FY-1D meteorological satellite are analyzed by typical examples. A method of monitoring fog using FY-1D is also suggested and subsequently proved feasible through practice. There are two points of view that need to be explained. First, the ACC noticed above generally is among middle or high clouds because it is very complex to divide low clouds and fog. Sometimes, low clouds and fog belong to the same matrix; hence, it is important to consult both the visibility observation data and the actual weather situation from the local weather station at this time. Second, because the FY-1D data used in the paper is in the range of Hubei and its neighborhood, the characteristics of cloud, fog and the earth’s surface described in Table 2 are usually only fit to the range above. Altogether, when using FY-1D data to identify fog, it is important to synthetically consider the spectral characteristics of the fog in the different channel images, sometimes to reference the actual weather situation and geographical background as well. In this way, the space-time distribution of the fog can be exactly determined.

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