A New Cloud Detection Algorithm for FY-2C Images Over China

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Abstract

FY-2C is a geo-stationary orbiting meteorological satellite designed by China independently. Based on statistical and spectral analysis of FY-2C data，this paper proposed a new cloud detection index operating accurately and quickly in spite of the low spatial resolution few spectral information. The diversity and sensitivity of cloud for each of the 4 bands of FY-2C data is also analyzed in this paper. The Infrared Red band 1, band 3 is found to be most suitable for cloud detection due to their spectral sensitivity of cloud.

1. Introduction

FY-2C meteorological satellite is the first geo-stationary orbiting meteorological satellite for public service designed by China independently. It is required as one of the fundamental processes to perform cloud detection, which refers to the process of distinguishing between cloudy and clear pixels, for most of the remote sensing data to be quantitatively applied in any further research about land surface.

Cloud detection mainly operates in three methods: threshold method, classification method and neural network method [1]. However, conventional studies mainly look at seasonal, monthly, or weekly variations of thresholds, or set restriction for studying region, or greatly effected by the selecting of training samples, all of which limit the application with a low efficiency.

The cloud detection index (FY-CDI) algorithm presented in this paper is relatively simple, completely automated, and can be applied to FY-2C data with no spatial and temporal limitation. It detects cloud with a new index defined in this paper, and sets thresholds automatically by investigating the histogram of images. Three conventional algorithms are also implemented in this paper, snow-mask product generated with MODIS data distributed by NASA is utilized to evaluate these algorithms, and the FY-CDI algorithm is proved to be the best one.

2. Study site and data analysis

2.1. Study area

The study was conducted in the whole land of China, with various kinds of landscapes and large spatial distribution of images. So, it is required to look for an algorithm applicable for all the images.

2.2. Data analysis

FY-2C covers the daytime data of visible band and infrared bands, nighttime data of infrared bands, which notes and distributes remote sensing image as meteorological, oceanic, hydrological data and so on. The satellite is located at 105° E above the equator. VISSR radiometer is the major load of FY-2C. The specifications of spectral wavelengths and spatial resolutions for FY-2C imagery are listed in Talbe1 [2]. For nomenclature, we shall donate the satellite measured infrared radiance as brightness temperature as BT, and infrared band as IR.

Table 1. Spectral and spatial resolution of VISSR on FY-2C

Band	visible	IR 1	IR 2	IR 3	IR 4
Range(μm)	0.55—0.90	10.3—11.3	11.5—12.5	6.3—7.6	3.5—4.0
Resolution(km)	1.25	5	5	5	5

e-Forensics 2008, January 21-23, 2008, Adelaide, Australia.

For multi-spectral data, cloud is generally characterized by higher reflectance and lower BT than the underlying earth surface, and diversity responses are shown among different bands for cloud due to spectral sensitivity [3]. In this study, 24 images covering China in 12 months were selected to be statistical and spectral investigated. Sample pixels of both cloud and underlying surface are selected based on specialist experience and textural information, with an overall descriptive comparison of cloud detection sensitivity for 5 parameters were considered in this study as listed in Table2.

Standard Deviation (S.D) and entropy are most informative statistics among these parameters. A large S.D. value means that the pixel value frequency distribution has more dispersion, while a large entropy value represents a large amount of disorder exists among the pixel values. Entropy is calculated as the following formula (Moddemeijer, 1989):

$$\textbf{\textit{Entropy}} = \sum - P_i * \log_2 P_i$$

Where Pi is the probabilities of occurrence for digital numbers i.

Table2 Band spectral statistics for cloud and underlying surface

Band	Min	Max	Mean	Standard Deviation	Entropy
spectral statistics for cloud samples（totally 17240 samples ）					
visible	0.497	0.839	0.6585	11.782	4.146
IR 1	189.7K	284.9K	258.2777K	6.039	5.089
IR 2	191.6K	284.1K	259.0609K	5.852	5.120
IR 3	204.6K	257.3K	245.4266K	1.952	4.402
IR 4	261.6K	311.5K	297.1006K	1.590	4.740
spectral statistics for underlying surface samples（totally 11098 samples ）					
visible	0.132	0.230	0.1690	0.640	2.673
IR 1	279.6K	315.2K	296.9143K	2.076	4.817
IR 2	280.6K	311.9K	295.9331K	1.472	4.503
IR 3	246.1K	271.5K	253.7066K	0.138	2.911
IR 4	288.8K	320.2K	303.9324K	1.255	4.740

3. Algorithms

Based on the investigation of conventional algorithms and statistics mentioned above, methods which could be utilized for FY-2C data are listed and evaluated.

3.1. General algorithms applicable for FY-2C data

Cloud detection algorithms which are currently available for FY-2C data are listed as follows:

(1) IR 3 cloud detection: The 6.7 μm radiation measured by satellite instruments mainly comes from radiation emitted by vapor in the atmospheric layer between 200 and 500 hPa, underlying surface radiation is absorbed by the upper atmospheric layers, and is seldom detected by the sensor[3]. Consequently, cloud on or above this layer shows a lower brightness temperature than clear pixel, which makes it possible to set a threshold to perform detection for high cloud. This algorithm was applied to MODIS data at southeast coastline in China and showed a good result [4], and GMS-5 data of Gansu Province also seems to operate cloud detection well with this algorithm [5].

(2) IR 1 and IR 2 cloud detection: According to the research issued by Saunders [6], cirrus shows different measurements in different IR bands. Compared with FY-2C IR 2, IR 1 shows a higher transmittance, so cloud detection could be performed by setting threshold for brightness temperature difference between these two bands.

(3) IR 4 and IR 1 cloud detection: Cirrus shows a larger transmittance at 3.7 μm than 11 μm [6], so FY-2C IR 4 and IR 1 could be utilized to perform cloud detection.

In spite of the algorithms mentioned above, single band could hardly lead to good cloud detection because there are always exceptions. For example, desert, snow and ice shows the same reflectance as cloud in visible band, and underlying surface shows the similar BT as thin cirrus. Simply assembling these algorithms helps a little to improve cloud detection [6], It is required to develop a new method which effectively inherit the useful information and remove useless information of these bands.

3.2. FYCDI algorithm

FYCDI is developed in this strategy: First, diversity of IR bands is analyzed. It could be observed from Table 2 that mean measured BT have a sharp change between IR 1 and IR 3 (43.2K for land surface, 12.8K for cloud), and also between IR 2 and IR 3 (42.2K for land surface, 14.6K for cloud), which means IR 1, IR 2, IR 3 are suitable to be involved in the new algorithm. Secondly, relativity between IR 1 and IR 2 is calculated with 24 images and the average value is 0.99, which indicates that there is a close correlation between these two bands. So, only one of the two will be selected. Thirdly, BT difference between cloudy and clear pixels is slightly larger between IR 1 and IR 3 (38.64K) than that between IR 2 and IR 3 (36.87K), so IR 2 is abandoned due to its close correlation and less diversity than IR 1. Finally, take consideration of the information of visible band, three bands are selected to build the new cloud detect index as the following format.

$$FYCDI = \frac{BT_1 - BT_3}{REF}$$

Here, BT_1 is the measurement in IR 1， BT_3 is the measurement in IR 3，REF is the solar reflectance measured in visible band.

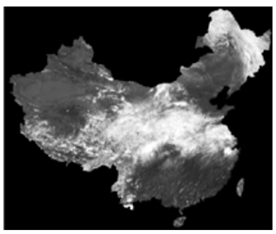

Fig2（a）Panchromatic band

Fig2（b）IR3

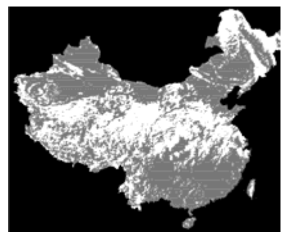

Fig2（c）IR1-IR2

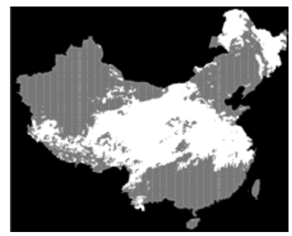

Fig2（d）IR4-IR1

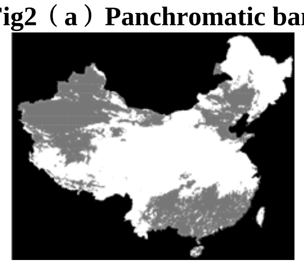

Fig2（e）FYCDI

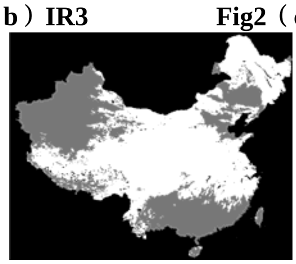

Fig2（f）FYCPP

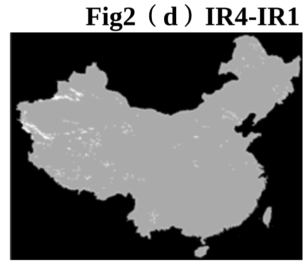

Fig2（g）Snow Product (MOD10A)

4. Comparison of results

4.1. Results

FY-2C data at 06:00 Jul. 22, 2006 (UTC) is selected randomly to show the results of different algorithms, as shown in Fig2 (b)-(f)

4.2. Accuracy assessment

Validation for cloud detection is usually operated with visual interpretation, by comparing the visible band imagery with detection results [6]. For cloud detection in a small study site, cloud products of other data（e.g. MODIS， AVHRR） could be utilized to perform relative validation. However, this method is not applicable in this study because FY-2C has a larger FOV and higher temporal resolution (30 minutes), which could hardly achieved by other kinds of RS data. Cloud classification product of FY-2C (FYCCP) is distributed by China Meteorological Administration, National Satellite Meteorological Center (NSMC). It is produced based on the analysis of histograms, but no validation is offered, which makes it impossible to check its accuracy. So, the only solution available in our study is to perform validation of results with both visual interpretation and FYCCP. Snow cover product MOD10A distributed by NASA with MODIS data is also utilized to facilitate the accuracy assessment.

(1) Single band algorithm: Many applications based on the 6.7 μm measurement lead to very good performance in cloud detection. However, it is hardly applicable for the FY-2C IR 3 with the same central wavelength in our study as shown in Fig.2 (b).

(2) BT difference algorithms: BT difference between IR 1 and IR 2 performs bourgeois due to the small

range of threshold (≤2K). It could be observed in Fig. 4 (c) that a lot of clouds are not detected in southeast and south China, while many clear pixels are incorrectly identified as cloud. However, BT difference between IR 4 and IR 1 shows a much better performance. It could be observed in Fig. 4 (d) that this algorithm performs well in central and northwest China, with a slightly poor performance in south and southeast China with some thin cirrus missed.

Table 3: Assessment of different algorithms for FY-2C cloud detection

Algorithm / FYCPP	IR 3		IR1 – IR2		IR 4- IR1		FYCDI	
	cloudy	clear	cloudy	clear	cloudy	clear	cloudy	clear
Threshold	249K		1K		25K		181.5K	
cloudy	60.33%	0.02%	33.37%	26.99%	41.19%	19.16%	53.86%	6.49%
clear	31.29%	8.35%	6.77%	32.87%	0.26%	39.39%	4.62%	35.03%
total accuracy	68.68%		66.24%		80.58%		88.89%	
Kappa	0.299		0.554		0.741		0.828	

(3) Validation for FYCDI algorithm is separated into 6 parts according to Fig.4(a), 4(e), 4(f) and 4(g): ① FYCDI algorithm and FYCCP performed consistently in most part of central and north China, cloud could be detected in both algorithms；②For northeast China, there is an illogical split in detected cloud for FYCCP, while FYCDI offers a smooth result, which is more close to real world; ③In Inner Mongolia, a small amount of pixels were incorrectly identified as cloud for FYCCP due to the high reflectance, while FYCDI distinguished cloud and high reflectance objects accurately; ④ In Tengri Peak area of Tianshan Mountains, fractal clouds were detected by FYCDI, which were considered to be underlying surface by FYCCP. No confirmation could be made since this place is covered by snow due to MOD10A; ⑤In the area of Altai Irtysh River and Wulungu River, Xinjiang, fractal cloud is detect by FYCDI, and again the FYCCP showed different result. It is highly possible that objects with a high reflectance in visible band in this area is incorrectly detected by FYCDI, as there was no snow in this area；⑥In Guangdong, Hunan and Fujian provinces, fractal cloud and thin cirrus were detected by FYCDI while undetected by FYCCP.

5. Conclusions

(1) BT difference between IR 4 and IR 1 turned to be most suitable for cloud detection among general algorithms; (2)The traditional algorithm with 6.7 μm threshold shows bad performance with FY-2C data in IR 3 although successful applications were gained with MODIS and GMS-5 data; (3)FYCDI is the only applicable algorithm for FY-2C data which covers a large area of land and time series, it also offers a satisfied performance in most parts of the image, but it is uncertainty to tell whether the algorithm could distinguish cloud from snow.

Acknowledgements

This paper was granted by the National Key Base Research and Development Program of China (No. 2004CB318206).

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