Forest Fire Intensity Monitoring Using the Himawari Weather Satellite—Taking Liaoning Forest Fires as Examples

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Abstract. Almost all forest fires in Liaoning were caused by the act of men. Between 15:00-19:00, which is when the frequencies of human activities and the occurrence of fire peak, Liaoning is out of the path of the polar-orbiting satellites, making these 4 hours the blind spot domain in fire-incidence monitoring. At the same time, the trend of fire accidents changed quickly under the influence of local meteorological conditions, leading to the demand for a higher temporal resolution. Therefore, there is an urgent need to utilize the Himawari satellite in the forest fire intensity monitoring so as to compensate for the drawbacks of the polar-orbiting satellites. By improving the forest fire identification model of the Himawari-8 satellite, a forest fire monitoring done every ten minutes was realized, thereby enhancing the effectiveness of fire monitoring and rescue within a given period of time.

1 Introduction

Different countries worldwide have already acknowledged the importance of forest resources and have made great efforts to explore the means of protection and rational use of forest resources. They have taken positive measures, such as building forest reserves, increasing vegetation coverage, and forestation. However, no good solution against the bulk deposition of combustibles in the forest, global warming, and other causes of the high frequency of forest fire, has been figured out^[1]. In terms of protecting forest resources, fire prevention is the key factor, while the timely and accurate forecasting and monitoring, aided by scientific and technological means, are the basis. Therefore, the active development of research of forest fire monitoring is of great significance^[2]. Forest fires oftentimes occur in remote, steep, and hard-to-reach areas; as a result, the traditional forest fire monitoring methods have met many practical difficulties, including its failure in meeting the monitoring requirements for high density, high frequency, and high quality, the omission of fire points, and the poor post-fire real-time monitoring. The presence of remote-sensing technology has made up for such problems. As an important method of forest fire monitoring, it helps obtain the scope and dynamic spreading of fire in a timely manner, which will, when combined with computer-aided statistical analysis, provide relatively detailed data on forest fire^[3].

Scholars at both home and abroad have done much research in this regard, mainly focusing on the use of high temporal resolution sources, such as meteorological satellite data from FY^[4] or NOAA/AVHRR^[5-7] and remote sensing data from EOS/MODIS, in conjunction

with the use of high spatial resolution satellites^[8, 9] to perform post-fire evaluation. The outcome of such approach has been satisfactory. Himawari-8 is a second generation geostationary meteorological satellite (GMS) developed by Japan Meteorological Agency (JMA), and was successfully launched in October 2014 before being put into service in July 2015; it is a new geostationary satellite currently in service that is capable of forest fire monitoring^[10-11]. 15 minutes after the release of JMA's data, the real-time satellite data would be made available on the platform for meteorological agencies of different countries to download. At present, National Meteorological Information Center (NMIC) provides related data downloading services to users at the provincial level via CMACast and the broadband network. Himawari-8 (hereinafter referred to as H8) has 16 channels, including the 3.9um natural (fire) disaster monitoring channel with routine observation interval of 10 minutes, capable of conducting forest fire intensity monitoring.

2 Sources of data

H8 is a new geostationary satellite currently in service, capable of conducting forest fire monitoring, having visible light resolution as far as 0.5km, and an observation interval of 10 minutes. Compared with the GMS of the previous generation, it has become the testament of a greater improvement. Zheng Wei et al.^[12] and Chen Jie et al.^[13] employed H8 to monitor the dynamics of straw burning and grassland fire, in which the errors of fire positioning was within 1 pixel. The data was obtained from Liaoning Meteorological Information Center in .dat format. The whole data distribution

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process took about 40 minutes and guarantee for the efficiency of fire monitoring at a given time can be given. As required for research and operation, the .dat data format obtained from the H8 satellite was transformed into: 1) HDF5, so as to facilitate the processing with ENVI of different versions compatible for the study on the application of multi-source satellite remote sensing; 2) LD3, so as to facilitate the operation. The format conversion system was developed on Eclipse.

3 The principles and methods of forest fire monitoring using Himawari

3.1 The principles of forest fire monitoring

Based on Wien's displacement law, when the blackbody temperature increases, the quantity of radiant energy increases correspondingly, while the maximum radiation value shifts towards the direction of the short wave. It has been verified through experiments that the radiation peak of the forest fire is at around $3.7\mu\text{m}$ ^[14]. Channel 7 of the H8 satellite, corresponding to the wavelength range of $3.74 \sim 3.96\mu\text{m}$, is sensitive to changes at abnormally high temperature points; on the other hand, channel 14, corresponding to the wavelength range of $11.10 \sim 11.30\mu\text{m}$, is sensitive to surface temperature changes. These two channels were usually employed together in fire point monitoring. When conducting data identification with Channel 7 only, some hot spots could not be identified (Figure 1a); when a combined identification using both Channel 7 and Channel 14 were carried out, all the fire points could be highlighted and identified (Figure 1b).

(a) Channel 7

(b) Combination of Channel 7 and Channel 14

Fig. 1. The results of channel combination for forest fire identification

3.2 Methods of Forest Fire Monitoring

For those of low spatial resolution, H8 adopted the relevance (or context) fire point recognition algorithm proposed by Giglio et al.^[15], which helped the identification of small fire points by integrating the multi-threshold method and the absolute threshold method. The context fire recognition algorithm was proposed on the basis of the MODIS satellite. As a result, H8 needed to adjust the model parameters and thresholds during the forest fire identification.

Potential Fire Point Pixel Recognition: Those meeting the following conditions are categorized as potential pixels, otherwise they are treated as non-fire pixels; thresholds are adjusted according to time at which the territory is passed and size of the fire point.

$$\begin{cases} T_7 > T_{7th} \\ T_7 - T_{14} > \Delta T_{th} \text{ or } \begin{cases} T_7 > T_{7th} \\ T_7 - T_{14} > \Delta T_{th} \end{cases} \\ \rho_4 < \rho_{4th} \end{cases} \quad (1)$$

Background Fire Point Pixel Recognition: Potential pixels are identified with the split-window algorithm; those meeting the following conditions are treated as background fire point pixels;

$$\begin{cases} T_7 > T_{7th} \\ T_7 - T_{14} > \Delta T_{th} \end{cases} \quad (2)$$

Context Fire Point Pixel Recognition: The background fire point pixels are further identified with context fire point identification; those meeting (3) and either one of (4) and (5) during daytime, and those meeting (3) at night, are fire points;

$$\begin{cases} T_7 - T_{14} > \overline{T_7 - T_{14}} + 3.5 \delta \\ T_7 - T_{14} > \overline{T_7 - T_{14}} + 6K \\ T_7 > \overline{T_7} + 3 \delta_7 \end{cases} \quad (3)$$

$$T_{14} > \overline{T_{14}} + \delta_{14} - 4K \quad (4)$$

$$\delta_7' > 5K \quad (5)$$

where T_7 and T_{14} are brightness temperatures of Channel 7 and Channel 14 of H8, in K;

$\overline{T_7}$ and $\overline{T_{14}}$ are average brightness temperatures of Channel 7 and Channel 14, in K; δ_7 and δ_{14} are mean absolute deviations of the brightness temperature in Channel 7 and Channel 14;

$\overline{T_7 - T_{14}}$ and δ are the average brightness temperature difference and mean absolute deviation of Channel 7 and Channel 14;

δ_7' is the mean absolute deviation between fire pixels of Channel 7 and the neighborhood pixels;

T_{7th} , ΔT_{th} and ρ_{4th} are corresponding reference threshold values.

4 Equations and mathematics

4.1 Construction of the Himawari forest fire monitoring model

By extracting 11 parameters, including brightness temperature, average value, mean absolute deviation, and reflectivity in different channels of Himawari from 20 fires that occurred from 2016 to 2018, the modeling threshold was revised (Table 1). The revised algorithm is as follows:

Potential Fire Point Pixel Recognition:

$$\begin{cases} T_7 > 290 \\ T_7 - T_{14} > 10 \\ \rho_4 < 30 \end{cases} \quad (6)$$

Background Fire Point Pixel Recognition:

$$\begin{cases} T_7 > 300 \\ T_7 - T_{14} > 10 \end{cases} \quad (7)$$

Context Fire Point Pixel Recognition:

$$\begin{cases} T_7 - T_{14} > \overline{T_7 - T_{14}} + 5 \delta \\ T_7 - T_{14} > \overline{T_7 - T_{14}} + 5K \\ T_7 > \overline{T_7} + 3 \delta_7 \end{cases} \quad (8)$$

$$T_{14} > \overline{T_{14}} + \delta_{14} - 7K \quad (9)$$

$$\delta_7' > 4K \quad (10)$$

Table 1. The parameters and reference thresholds of Himawari 8 Forest Fire Model

Data	T_7	T_{14}	ρ_4	$\overline{T_7}$	$\overline{T_7 - T_{14}}$	δ_7	δ_{14}	δ_7'
16.04.08	319	13	22	314	8	0.6	0.9	5.3
	318	17	21	313	9	1	0.7	4.5
	318	12	22	312	8	1.4	1.3	5.8
	320	22	21	307	9	1.5	1.1	13
	350	54	18	309	8	1.2	2.3	40
	333	34	17	305	6	1.6	1.2	27
	336	42	17	299	7	0.9	0.7	37
	323	28	12	299	6	1.5	1.3	24
	310	28	9	291	10	0.9	0.7	19
	299	13	7	291	5	1.4	0.6	8
	319	38	10	295	16	0.5	0.9	24
	308	26	7	290	6	0.7	0.7	18
	325	24	17	307	6	2.0	1.8	18
	316	15	13	302	4	1.7	1.6	14
17.04.03	306	10	13	299	4	1.5	1.1	7
	320	19	15	306	5	1.9	1.4	14
	313	14	14	302	5	0.9	0.8	11
	311	28	8	299	6	1.1	1.1	12
17.04.11	300	21	6	296	6	1.4	1.1	4.2
	304	17	12	295	6	1.8	2	4.2

4.2 Testing of Himawari Forest Fire Model

The 2016-2018 polar-orbit satellite fire points and ground feedback RS data indicated that: out of the 42 fire points monitored by the polar-orbit satellites, 30 were identified by H8; in the monitoring of polar-orbit satellites with a 1km resolution, about 71% fire points could be identified by H8 with a 2km resolution; unidentified fire points were all 1 pixel in size in polar-orbit satellite monitoring.

4.3 Examples of Forest Fire Monitoring using the Himawari satellite

According to the Himawari fire point monitoring data extracted at 13:30 April 8, 2016, a total of 6 fires were identified. Feedback information from Liaoning Center of Early Warning and Monitoring of Forest Fire was as follows: out of all the identified data, 5 were forest fires and 1 was fire on a barren hill.

Figure 2. H8 fire point distribution at 13:30 April 8, 2016

Table2. Feedback of H8 fire points monitored at 13:30 April 8, 2016

No.	Longitude	Latitude	Fire Location	Feedback
1	124°05'24"	41°12'36"	Baozi Village, Jianchang, Xiaoshi Township, Benxi	Forest fire
2	123°43'12"	40°55'12"	Guangong District, Lianshanguan Forest, Benxi County	Forest fire
3	123°12'36"	40°47'24"	Beihuanglingzi Village, Jidongyu Township, Liaoyang County	Fire on a barren hill
4	123°35'24"	40°48'36"	Baiyunshan Village, Qingchengzi Township, Fengcheng City	Forest fire
5	120°20'60"	40°51'36"	Baotun Village, Xintaimen Township, Huludao City	Forest fire
6	120°20'60"	40°47'24"	Jinjia Village, Yaowang County, Xingcheng City	Forest fire

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