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

Jinwen Wu 1, Yushu Zhang 1, Longyu Sun 2 Ruipeng Ji 1, Wenyeng Yu 1, Rui Feng 1

1Institute of Atmospheric Environment(IAE), CMA, Shenyang,110166
2Meteorological bureau of Shenyang, Shenyang,110168

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. 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. 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.

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 or NOAA/AVHRR and remote sensing data from EOS/MODIS, in conjunction with the use of high spatial resolution satellites 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. Within 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. 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

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).
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 3.7μm\(^{[14]}\). Channel 7 of the H8 satellite, corresponding to the wavelength range of 3.74 ~ 3.96μm, is sensitive to changes at abnormally high temperature points; on the other hand, channel 14, corresponding to the wavelength range of 11.10 ~ 11.30μm, 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).

\[ \begin{align*}
T_7 > T_{7th} & \quad \text{or} \quad \Delta T_{th} > T_{7th} \\
T_7 - T_{14} > \rho_{4th} & \quad \text{or} \quad \Delta T_{th} > T_{7th}
\end{align*} \]

\[ \begin{align*}
T_7 > T_{7th} & \quad \text{or} \quad \Delta T_{th} > T_{7th}
\end{align*} \]

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.

\[ \begin{align*}
T_7 > T_{7th} & \quad \text{or} \quad \Delta T_{th} > T_{7th} \\
T_7 - T_{14} > \rho_{4th} & \quad \text{or} \quad \Delta T_{th} > T_{7th}
\end{align*} \]

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;

\[ \begin{align*}
T_7 > T_{7th} & \quad \text{or} \quad \Delta T_{th} > T_{7th}
\end{align*} \]

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;
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; \( \delta_7 \) and \( \delta_{14} \) are mean absolute deviations of the brightness temperature in Channel 7 and Channel 14; 
\( \overline{T_7 - T_{14}} \) and \( \delta \) are the average brightness temperature difference and mean absolute deviation of Channel 7 and Channel 14; 
\( \delta_7' \) is the mean absolute deviation between fire pixels of Channel 7 and the neighborhood pixels; 
\( T_{7th}, \Delta T_{7th} \) and \( \rho_{4th} \) 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: |
|-----------------------------------------|
| \( \left\{ \begin{array}{l} T_7 > 290 \\ T_7 - T_{14} > 10 \\ \rho_4 < 30 \end{array} \right. \) |

| Background Fire Point Pixel Recognition: |
|------------------------------------------|
| \( \left\{ \begin{array}{l} T_7 > 300 \\ T_7 - T_{14} > 10 \end{array} \right. \) |

| Context Fire Point Pixel Recognition: |
|---------------------------------------|
| \( \left\{ \begin{array}{l} T_7 - T_{14} > \overline{T_7 - T_{14}} + 5 \delta \\ T_7 - T_{14} > \overline{T_7 - T_{14}} + 5K \\ T_7 > \overline{T_7} + 3 \delta_7 \end{array} \right. \) |
| \( T_{14} > \overline{T_{14}} + \delta_{14} - 7K \) |
| \( \delta_7' > 4K \) |

### 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.

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

| Data | \( T_7 \) | \( \overline{T_7} \) | \( T_7 - T_{14} \) | \( \delta_7 \) | \( \delta_{14} \) | \( \delta_7' \) |
|------|----------|----------|-------------------|-------------|-------------|------------|
| 16.04.08 |
| 319  | 13       | 22       | 314               | 8           | 0.6         | 9.0        | 5.3        |
| 318  | 17       | 21       | 313               | 9           | 1.0         | 7.0        | 4.5        |
| 318  | 12       | 22       | 312               | 8           | 1.4         | 1.3        | 5.8        |
| 320  | 22       | 21       | 307               | 9           | 1.5         | 1.1        | 13.0       |
| 350  | 54       | 18       | 309               | 8           | 1.2         | 2.3        | 40.0       |
| 333  | 34       | 17       | 305               | 6           | 1.6         | 1.2        | 27.0       |
| 336  | 42       | 17       | 299               | 7           | 0.9         | 0.7        | 37.0       |
| 323  | 28       | 12       | 299               | 6           | 1.5         | 1.3        | 24.0       |
| 310  | 28       | 9        | 291               | 10          | 0.9         | 0.7        | 19.0       |
| 299  | 13       | 7        | 291               | 5           | 1.4         | 0.6        | 8.0        |
| 319  | 38       | 10       | 295               | 16          | 0.5         | 0.9        | 24.0       |
| 308  | 26       | 7        | 290               | 6           | 0.7         | 0.7        | 18.0       |
| 17.04.03 |
| 325  | 24       | 17       | 307               | 6           | 2.0         | 1.8        | 18.0       |
| 316  | 15       | 13       | 302               | 4           | 1.7         | 1.6        | 14.0       |
| 306  | 10       | 13       | 299               | 4           | 1.5         | 1.1        | 7.0        |
| 320  | 19       | 15       | 306               | 5           | 1.9         | 1.4        | 14.0       |
| 313  | 14       | 14       | 302               | 5           | 0.9         | 0.8        | 11.0       |
| 17.04.11 |
| 311  | 28       | 8        | 299               | 6           | 1.1         | 1.1        | 12.0       |
| 300  | 21       | 6        | 296               | 6           | 1.4         | 1.1        | 4.2        |
| 18.03.25 |
| 304  | 17       | 12       | 295               | 6           | 1.8         | 2.0        | 4.2        |

**ChinaBiofilms 2019**
Figure 2. H8 fire point distribution at 13:30 April 8, 2016

Table 2. 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 | 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, Fencheng 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″  | Jinju Village, Yawang County, Xingcheng City | Forest fire      |

Funding information:

This work was financially Co-sponsored by the Natural Science Foundation Guidance Plan of Liaoning Province (2019-ZD-0857), the basic scientific research projects of the central public welfare research institutes (20151AE-CMA04, 2018SYIAEZD1, 2018SYIAEHZ1), and the industrialization of CHEOS application project (70-Y40G09-9001-18/20)

References

1. J. Raic, E. B. Rastetter, J. M. Melillo, et al. Potential net primary productivity in South America: application global model. Ecological Application. 1:399-429(2001).
2. Anderws, PL and LP Queen, Fire modeling and information system technology international Journal of Wildland Fire,10:343-352(2001).
3. P Xiong, M Z Ding, Z Q Liu. Disaster Prevention and Mitigation using GIS and RS. Geomatics & Spatial Information Technology,6:7-10(2009)
4. W J Zhang, C Liu, X Y Pan, et al. Principle and Technology of Atmospheric and Environmental Monitoring by Satellite Remote Sensing. China Meteorological Press,150-153(2004)
5. Kennedy P J, Belward A S, Gregoire J M. An improved approach to fire monitoring in west Africa using AVHRR data. Remote Sensing of Environment, 15: 2235-2255 (1994).
6. Pereira J M C. A comparative evaluation of NOAA AVHRR vegetation indices for burned surface detection and mapping. IEEE Transactions on Geoscience and Remote Sensing, 37: 217-226 (1999).
7. L X Mao, Y Y Hou, S Qian, et al. Estimation of pasture output and livestock carrying capacity using remote sensing. Transactions of the CSAE, 24(8): 147-152 (2008).
8. Kaufman Y J, Justice C O, Flynn L P, et al. Potential global fire monitoring from EOS/MODIS. Journal of Geophysical Research, 103: 32215-32238 (1998).
9. Y Zhou, X Wang, L T Wang, et al. MODIS database automatic extraction of information on fire spot. Journal of Natural Disasters, 16(1): 88-93 (2007).
10. NOAA Meteorological Satellite Conference: Wind and Cloud International Conference Stage, China Meteorological Daily/2015/June/004 Edition
11. Japan’s First New Generation Meteorological Satellite Himawari-8 Orbited, International Space Phase 434.
12. W Zheng, M Wang, J Chen, et al. Application of Himawari-8 Satellite Data in Environmental Monitoring. Papers of the Annual Meeting of the Chinese Society of Environmental Sciences, 1146-1152 (2016).
13. J Chen, W Zheng, C Liu. Journal of Natural Disasters, 26(4): 197-204 (2017).
14. X L Qin. Forest Fire Satellite Remote Sensing Monitoring. Beijing: China Forestry Press, 163-174 (2016).
15. Giglio L, Desclotres J, Justice C O, Kaufman Y J. An enhanced contextual fire detection algorithm for MODIS. Remote Sensing of Environment, 87: 273-282 (2003).