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Study of high temperature targets identification and temperature retrieval experimental model in SWIR remote sensing based Landsat8

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ABSTRACT

For surface features in short-wave infrared (SWIR, 1.3–3.0 μm) in remote sensing imagery, pixel values depict the total energy including reflection and emission. For surface features at normal temperature in SWIR band, emission energy can be ignored. While for surface features at high temperature in SWIR band, emission energy is equal to or even higher than the reflection energy. So remote sensing imagery of SWIR band can be used to separate emission and reflection energy as well as to realize temperature retrieval of high temperature targets. In this study, the seventh band (SWIR band) of Landsat8 OLI remote sensing imagery is used to perform the theoretical model research for temperature retrieval of high temperature targets. In the meantime, it is also used with the corresponding observation experiment of synchronization satellite to check the theoretical model. The result shows that the radiant flux density for mixed pixels with high temperature targets is higher than adjacent pixels without high temperature targets. Thus, the high temperature pixels can be identified in SWIR band. The retrieval results of temperature and fractional area for high temperature targets are consistent with reality. In the study, the result illustrates that it is effective to identify high temperature targets in remote sensing imagery of SWIR band and the model is appropriate for temperature retrieval use.

1. Introduction

High temperature targets (temperature above 500K+) such as coal seam spontaneous combustions, heap coking, forest fires, prairie fires, volcanic eruptions are distinguished from those of normal surfaces at lower temperatures. Its identification and temperature retrieval techniques are worthy of research for their significant use in environmental monitoring, disaster warning, resource investigation and so on (Yu et al., 2013).

High temperature target identification has customarily relied on two spectral regions, thermal infrared (TIR, 8–12 μm) and middle infrared (MIR, 3–5 μm) (Dennison and Roberts, 2009; Kaufman et al., 1989; Prins and Menzel, 1992; Giglio et al., 2003; Ichoku et al., 2003). Based on Planck's Law, emitted radiance can be measured in the SWIR at temperature above 500 K, and peak emission in the SWIR is at temperature 1150 K. Plentiful high temperature targets emit radiance in SWIR with no need to account for background emitted radiance when comparing with MIR and TIR (Thomas, 1993), the SWIR spectral region should used for high temperature target identification.

Remote sensing identification in SWIR has been listed in the application of Landsat8 (Jin, 2013) for now, and some scholars are already on their ways in developing methods for identification and temperature retrieval of SWIR bands (Yu et al., 2013, 2014a,b; Pan et al., 2009; Giglio and Kendall, 2000; Fan et al., 2004; Barducci et al., 2004; Zhu et al., 2011; Yu, 2014; Kong et al., 2005). We will make use of SWIR to conduct our research subject. A new experimental setup specifically designed to test the high temperature target detectability thresholds on OLI SWIR images.

2. Theory

When there are only surface features at normal temperature on the earth's surface, the energy (of the visible light and near-infrared) received by detecting unit of the sensor comes from reflection of solar radiation of surface features at normal temperature. Under this condition, the order of radiance magnitude is 10^{-1}–10^{1} W m^{-2} μm^{-1} ster^{-1} (Pan et al., 2009), while the order of emitted energy magnitudes of surface features at normal temperature (in SWIR) is 10^{-4}–10^{-3} W m^{-2} μm^{-1} ster^{-1}, which is much smaller than the reflection energy under the same condition. Therefore, the emitted energy can be ignored in this case. But when there are high temperature targets on the earth's surface, the situation above is no longer valid. In this condition, the order of emitted

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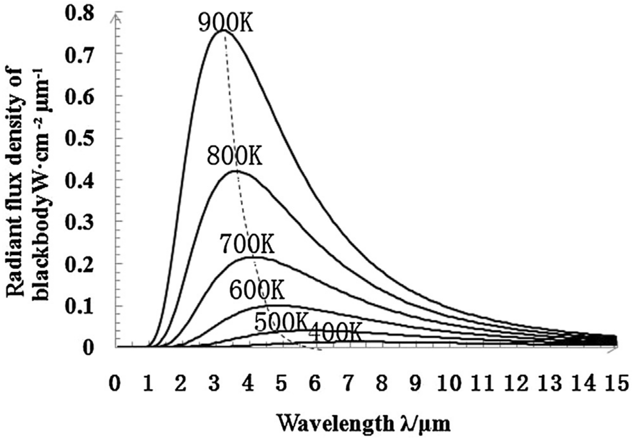

Fig. 1. Radiation flux density of blackbody in different temperatures.

energy magnitudes can reach 10^0–10^2 W m^{-2} µm^{-1} ster^{-1} or even higher, that is far beyond the magnitude of reflection energy.

Based on Planck formula (Dozier, 1981), we know that radiation flux density of surface features is a function of temperature and wavelength. The higher the temperature is, the higher radiation flux density of the blackbody is (Fig. 1). As there are surface features at normal temperature and high temperature in a pixel, the energy of mixed pixels which is received from the sensor's detecting unit of instantaneous field of view (IFOV) includes reflection energy and emission energy.

When the temperature of surface features reaches a certain extent (500 K+ or higher), the emission energy in SWIR bands will approach or exceed reflection energy. In such situation, their spectral features are marked differently from those of surface features at normal temperature in pure pixel. Visual or quantified identification method can be used in remote sensing imagery to extract information of mixed pixel of high temperature targets. If emission energy of high temperature targets can be separated from mixed pixel, temperature retrieval of high temperature targets will be achieved on the basis of Planck's equation. Compared with MIR and TIR data, an increase in radiance above background level is larger in the SWIR than that in the TIR, so the Planck function is of major importance. Thus high temperature targets which area is even smaller can be identified in SWIR rather than in TIR.

3. Theory model

3.1. Model of temperature retrieval in SWIR bands

In reality, pixels' DN values for remote sensing images which are obtained via radiation correction in SWIR bands, represent comprehensive electromagnetic radiation energy of surface features in the IFOV. For surface features at normal temperature, pixels' DN values show reflection energy of surface features in the IFOV (In the case, emission energy can be ignored). For mixed pixels of surface features at both high temperature and normal temperature, pixels' DN values show reflection energy of surface features at normal temperature and emission energy of high temperature targets, and we call the equivalent reflectivity of a pixel visual reflectivity (Zhu et al., 2011), which is caused by comprehensive energy.

The visual reflectivity of a mixed pixel represents the comprehensive energy of surface features in the IFOV, as the law of energy conservation states that it includes surface features' reflection and emission energy at both normal temperature and high temperature.

In order to simplify the model and make the actual application simple, some conditions are assumed as follows:

1. Surface features of all kinds on the earth's surface are Lambert reflector.
2. Components and temperatures for surface features at normal temperature and high temperature are uniform.
3. Radiation energy of surface features at normal temperature and high temperature is linear superpositioned.

Therefore, the physical model of temperature retrieval for mixed pixel on the earth's surface in SWIR band can be established mathematically as: (Fig. 2) (Kaufman et al., 1998).

$$M = M_1 S + M_2 (1 - S) + M_3 S + M_4 (1 - S) \tag{1}$$

In the expression, M is the total radiation flux density of mixed pixels; M_1 is the emission flux density of high temperature targets in mixed pixels; M_2 is the reflection flux density of surface features at normal temperature in mixed pixels; M_3 is the reflection flux density of high temperature targets in mixed pixels; M_4 is the emission flux density of surface features at normal temperature in mixed pixels; S is the fractional area of high temperature targets.

(1) Emission flux density of high temperature targets in mixed pixels M_1

As the radiation law of blackbody states, emission energy of high temperature targets is the product of emissivity (ε) and Planck function (B), expressed mathematically as:

$$M_1 = \varepsilon B(\lambda, T) = 2\varepsilon\pi hc^2\lambda^{-5}\left[\exp\left(\frac{hc}{\lambda kT}\right) - 1\right]^{-1} \tag{2}$$

In the expression, ε is emissivity of surface features; λ is wavelength; $B(\lambda, T)$ is radiation flux density of blackbody at absolute temperature (T) and wavelength (λ); h is Planck constant ($h = 6.63 \times 10^{-34}$ Js); c is speed of light in vacuum($c = 3 \times 10^8$ m/s); and k is Boltzmann constant ($k = 1.38 \times 10^{-23}$ J/K).

(2) Reflection flux density of surface features at normal temperature in mixed pixels M_2

$$M_2 = \rho E = \frac{\rho T_\theta E_0 \cos\theta}{d_s^2} \tag{3}$$

In the expression, ρ is the reflectance of surface features at normal temperature; T_θ is the transmittance of the atmosphere; E is the solar irradiance of earth's surface; E_0 is the solar irradiance of the upper-bound atmosphere; θ is sun zenith angle; d_s is the distance between sun and earth's surface.

(3) Reflection flux density for high temperature targets in mixed pixels M_3

$$M_3 = (1 - \varepsilon)E = \frac{(1 - \varepsilon)T_\theta E_0 \cos\theta}{d_s^2} \tag{4}$$

(4) Emission flux density of surface features at normal temperature in mixed pixels M_4

$$M_4 = (1 - \rho)B\left(\lambda, T'\right) \tag{5}$$

In the expression, T' is the absolute temperature of surface features at normal temperature, and the value is 300 K.

(5) Total Radiation flux density of mixed pixels M

$$M = \rho_0 E = \frac{\rho_0 T_\theta E_0 \cos\theta}{{d_s}^2} \tag{6}$$