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Evaluation and improvement of a dual-channel method for detection and quantification of high-temperature events based on FireBIRD data

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Abstract

Key words:

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Chapter 1

Introduction

1.1 Introduction

1.1.1 Impacts of high-temperature events

High Temperature Events (HTE), such as fire hazards and volcanic eruptions, occur widely all over the world and exert great impacts on the environment in both space and time domain from global to local scales. These HTEs, without doubt, play crucial roles for the environental equilibrium (Chuvieco, 2008). HTEs might bring benefits at appropriate time and places, for example by speeding up the procedure of returning nutrients to the soils after vegetation senescence (Zhukov et al., 2005a). However, the potentially hazardous characteristics of HTEs and the serious lack of knowledge about their fundamental roles in Earth system processes in the context of global climate change and population explosion will cause a multitude of problems (Bowman et al., 2009).

Volcanoes represent a serious potential hazard for both the population and environment. Volcanic eruptions usually cause numerous loss of lives and damages to the surrounding environment (Pergola, Marchese, and Tramutoli, 2004). Besides the devastation caused by lava erupted, another significant and obvious effect of volcanic eruptions is the release of a host of gases and volcanic ashes, which might cause climate chage and serious air pollution. The 2010 eruptions of Eyjafjallajökull, a volcano in Iceland, although relatively small for volcanic eruptions, ejected a multitude of ashes into the atmosphere and created unprecedented disruptions to European air traffic during 15 - 20 April 2010, costing the aviation industry an estimated $250 million per day (Gudmundsson et al., 2010). Furthermore, the population exposed to the eruption, had a higher prevalence of respiratory and mental symptoms (Carlsen et al., 2012).

Fire, another kind of high-temperature event, might be one of the most prevalent of all terrestrial disturbance agents for the modification of the Earth's surface and occurs worldwide (Bond and Wilgen, 1996). On one hand, fires in forests stimulate vegetation regeneration, increase plant biodiversity and optimize vegetation structure (Moritz et al., 2014). On the other hand, fires, especially severe fires, can burn up vegetation and organics, resulting in hydrophobic layer on the soil surface or at certain depth of the soil, which makes the soil much more prone to be eroded by wind and rain and might lead to desertification in the end (Gabet, 2003).

Due to the threats mentioned above, high-temperature events monitoring becomes more and more important. Besides, because of the huge areas affected by high-temperature events and its potentially dangerous characteristics, a critical role in the monitoring and investigating of HTE belongs to satellite remote sensing. Higher spatial and spectral resolution data is demanded to better detect and quantify high-temperature events.

1.1.2 DLR's missions dedicated to high-temperature events monitoring

The first DLR's satellite specially designed for HTE monitoring was the Bi-spectral InfraRed Detection (BIRD) satellite. The primary objective of the BIRD satellite was detection and quantitative analysis of high-temperature events like fires and volcanoes. The principal BIRD imaging payload includes the HotSpot Recognition System (HSRS) with one channel in Mid-InfraRed (MIR: 3.4 - 4.2μm) spectral range and one channel in Thermal-InfraRed (TIR: 8.5 - 9.3 μm) spectral range, the Wide-Angle Optoelectronic Stereo Scanner (WAOSS-B) with a nadir channel in Near-Infrared (NIR: 0.84 - 0.90μm) spectral range. The ground resolution was 185 meters in the NIR channel and 370 meters in the MIR and TIR channels (Zhukov et al., 2005b).

Due to the success of the BIRD mission, DLR continues making efforts to HTE monitoring with the new Fire Recognition with Bi-spectral InraRed Detector (FireBIRD) mission. It consists of two small satellites Technology Experiment carrier (TET-1), launched in July 2012, and Berlin InfraRed Optical System (BIROS), launched in June 2016. Together, these two small satellites form the FireBIRD mini-constellation (Rücker et al., 2011). Both of them carry a HSRS which is identical to BIRD. In addition, there are an additional 3-line VIS camera. Details about the sensors of TET-1 is shown in Table 1.

Because BIROS is still undergoing an extensive testing program and does not put into use yet, the focus lies on TET-1 imageries in this thsis.

1.2 Outline of the thesis

This thesis consist of six chapters. The remaining chapters are organized as follows.

Chapter 2 gives a brief intorduction of thermal infrared remote sensing, including the thermal infrared spectrum, atmospheric windows as well as some basic laws important for the quantitating fire pixels' characteristics. Furthermore, a practical and solid method for detection and characterization of sub-pixel fire and its pixel

TABLE 1.1: Main FireBIRD camera parameters (Altitude 510km) (Frauenberger et al., 2015)

	3 line-VIS camera	**2 infrared cameras**
Wavelength	Green: 460 - 560 nm Red: 565 - 725 nm NIR: 790 - 930 nm	MWIR: 3.4 - 4.2 μm LWIR: 8.5 - 9.3 μm
Focal length	90.9 mm	46.39 mm
FOV	19.6°	19°
Aperture (F-Number)	3.8	2.0
Detector	CCD lines	CdHgTe arrays
Pixel size	7 μm $\times$ 7 μm	30 μm $\times$ 30 μm
No. of pixel	3 $\times$ 5,164	2 $\times$ 512 staggered
Quantization	14 bit	14 bit
Ground resolution	42.4 m	356 m
Sampling size	42.4 m	178 m
Swath width	211 km	178 km
In-flight calibration	No	Black body flap
Data rate	max 44 MBit/s nom 11.2 Mbit/s	0.35 MBit/s
Accuracy	100 m at ground	100 m at ground

fraction is reviewed in section 2.2.

Then, a newly developed mehtod, called MITIP, which is used for atmospheric correction and thermal infrared image processing, is introducted in Chapter 3. The required input data for it and the necessary pre-processings are stated in section 3.1. Its procedures and principles, which are based on the theories and method introduced in Chapter2, are given in section 3.2. Section 3.3 gives a description of the outputs of the MITIP.

Chapter 4 presents the validation and improvements of the MITIP method. Its outputs are compared with the MODIS temperature products, namely MODIS Sea Surface Temperature (SST) and MODIS Land Surface Temperature (LST). These comparisons are done by means of time-series analyses for the purpose of further improvements of the MITIP method and finding suitable scale factors for the radiometric correction of TET-1 imageries. Finally, the calibration results are presented and the tests of the choosen scale factors for transferability with imageries of other test sites are shown as well.

In Chapter 5, the processing results of TET imageries of different test sites from the MITIP method are demostrated in section 5.1. The outcomes of the MITIP method and the results of Zhukov's algorithm, which is used to process TET-1 imageries originally, are compared in this chapter. In order to do the comparisons, a procedure is developed to convert the pixel-based results to cluster-based results, which is described in section 5.2. The comparison results are presented in section 5.3.

Finally, the conclusions and outlooks are given in Chapter 6.

Chapter 2

Theoretical background of thermal infrared remote sensing

This chapter reviews some fundamentals on the thermal remote sensing (Section 2.1), as well as a useful approach, which is also used in the MITIP method, to identify and determine target temperature of subpixle resolution (Section 2.2).

2.1 Principles of thermal infrared remote sensing

Thermal remote sensing depends on the fact that any object with a temperature above absolute zero (0 K or -273.15 °C) emits electromagnetic (EM) radiation in the infrared range. For example, the Earth we live has an average temperature around 300 K and its maximum emittance falls on thermal infrared (TIR) domain (Tipler and Mosca, 2007). The spectral intensity and composition of the emited radiation are determined by its surface temperature, which is also called kinetic temperature T_{kin}, and the emissivity of the object. The emissivity ϵ_λ, ϵ for short, is a ratio of the radiant flux of an object at a certain temperature to teh radiant flux of a blackbody at the same temperature. The blackbody is an idealized physical object that aborbs all incident EM radiation, which means its emissivity is 1. The emissivity varies as a function of wavelength λ and also depends on the surface type of the object, but is not temperature-dependent (Tetzlaff, 2004; Flynn, Harris, and Wright, 2001).

The satellite remote sensing snesors responsive in te thermal infrared domain are capable to record the EM radiations emited by Earth surface objects. Thus these sensors will produce thermal radiance images which record the equivalent blackbody radiances of the object on the Eearth's surface. From that the derivation of the so-called radiance temperature, or brightness temperature, T_{rad} is possible (Kuenzer and Dech, 2013; Trishchenko, 2006). Radiance temperature T_{rad} is the radiance measured at the sensor in terms of temperature of a equivalent blackbody (Prakash, 2000). Notice that the brightness temperature T_b and the kinematic temperature T_{kin} are two different terms and the conversion between them will be introduced later.

2.1.1 The thermal infrared domain and atmospheric windows

2.1.2 The Planck's law and Stefan-Boltzmann law

2.2 A dual-channel method for the identification of subresolution high temperature sources

Chapter 3

The MITIP, an atmospheric correction and image processing method

3.1 Data preparation and pre-processing

3.1.1 Data preparation

3.1.2 Data pre-processing

3.2 Procedure of the MITIP

3.3 Outcomes of the MITIP

Chapter 4

Validation and improvement of the MITIP

4.1 Analysis of normal temperature environments

4.1.1 Data preparation

4.1.2 Results comparision with MODIS SST and calibration

4.1.3 transferability test (SST)

4.1.4 Results comparision with MODIS LST and calibration

4.1.5 transferability test (LST)

4.2 Conclusion of the comparisons and calibrations

Chapter 5

Analysis of high-temperature events

5.1 High-temperature events

5.1.1 Volcanoes

5.1.2 Fire events

5.2 Comparison with the results of the Zhukov's algorithm

5.2.1 Brief description of Zhukov's algorithm

5.2.2 From pixel-based to cluster-based analysis

5.2.3 Comparision

Chapter 6

Conclusion and outlook

6.1 Conclusion

6.2 Outlook

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