



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



Studienarbeit im Studiengang
Geomatics Engineering
an der Universität Stuttgart

Penghua Li

Stuttgart, May 2017

Supervisor: Dr.-Ing. Simon Manuel Plank
Deutsches Zentrum für Luft- und Raumfahrt (DLR)

Examer: Prof. Dr.-Ing. Uwe Sörge
Universität Stuttgart

Abstract

Key words:

Contents

Abstract	iii
1 Introduction and motivation	1
1.1 Motivation	1
1.1.1 Impacts of high-temperature events	1
1.1.2 DLR's missions dedicated to high-temperature events monitoring	2
1.2 Outline of the thesis	2
2 Theoretical background of thermal infrared remote sensing	5
2.1 Principles of thermal infrared remote sensing	5
2.1.1 The thermal infrared domain and atmospheric windows	5
2.1.2 The Planck's law and Stefan-Boltzmann law	5
2.2 A dual-channel method for the identification of subresolution high temperature sources	5
3 The MITIP, an atmospheric correction and image processing method	7
3.1 Data preparation and pre-processing	7
3.1.1 Data preparation	7
3.1.2 Data pre-processing	7
3.2 Procedure of the MITIP	7
3.3 Outcomes of the MITIP	7
4 Validation and improvement of the MITIP	9
4.1 Analysis of normal temperature environments	9
4.1.1 Data preparation	9
4.1.2 Results comparison with MODIS SST and calibration	9
4.1.3 transferability test (SST)	9
4.1.4 Results comparison with MODIS LST and calibration	9
4.1.5 transferability test (LST)	9
4.2 Conclusion of the comparisons and calibrations	9
5 Analysis of high-temperature events	11
5.1 High-temperature events	11
5.1.1 Volcanoes	11
5.1.2 Fire events	11
5.2 Comparison with the results of the Zhukov's algorithm	11
5.2.1 Brief description of Zhukov's algorithm	11
5.2.2 From pixel-based to cluster-based analysis	11
5.2.3 Comparison	11

6 Conclusion and outlook	13
6.1 Conclusion	13
6.2 Outlook	13
Bibliography	17

List of Figures

List of Tables

1.1	Main FireBIRD camera parameters (Altitude 510km) (Frauenberger et al., 2015)	3
-----	--	---

beginabbreviationsll
endabbreviations

Chapter 1

Introduction and motivation

1.1 Motivation

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 environmental equilibrium (Chuvieco, 2008). HTEs might bring benefits at appropriate time and places, for example by rapidly 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 role in Earth system processes in the context of global climate change and population explosion will cause a lot of problems (Bowman et al., 2009).

One significant and obvious effect of high-temperature events is the release of a host of particulates and gases, which might cause climate change 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, created unprecedented disruptions to European air traffic during 15 - 20 April, 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 events, 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, severe fires in forests stimulate vegetation regeneration, increase plant biodiversity and optimize vegetation structure (Moritz et al., 2014). On the other hand, fires, especially intense fires, can burn up vegetation and create hydrophobic layer on the soil surface or at some depth of the soil, making the soil much more prone to erosion by wind and rain (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 quantificat 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 - 4.2 μm) 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 - 0.90 μm) 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).

After the BIRD mission, DLR continues monitoring of HTE with the new Fire Recognition with Bi-spectral IntraRed 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 comprise 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 thesis.

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 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 introduced 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

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 $\mu\text{m} \times 7 \mu\text{m}$	30 $\mu\text{m} \times 30 \mu\text{m}$
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

method introduced in Chapter 2, 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 chosen 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 demonstrated 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

2.1 Principles of thermal infrared remote sensing

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 comparison with MODIS SST and calibration

4.1.3 transferability test (SST)

4.1.4 Results comparison 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

Bibliography

Bibliography

- Bond, W.J. and B.W. van Wilgen (1996). *Fire and Plants*. Doodrecht, the Netherlands: Springer Netherlands, p. 263.
- Bowman, D.M.J.S. et al. (2009). "Fire in the Earth System". In: *Science* 324, pp. 481–484.
- Carlsen, Hanne Krage et al. (2012). "Health effects following the Eyjafjallajökull volcanic eruption: a cohort study". In: *BMJ Open* 2.6, pp. 1–11.
- Chuvieco, E., ed. (2008). *Earth Observation of Global Change: The Role of Satellite Remote Sensing in Monitoring the Global Environment*. Doodrecht, the Netherlands: Springer Netherlands, p. 223.
- Frauenberger, Olaf et al. (2015). "Results on verification and validation of OOV-TET1 multi-spectral camera observations within the FireBIRD project". In: *Proc. 10th IAA Symposium Small Satellites for Earth Observation*. Ed. by Rainer Sandau, Hans-Peter Röser, and Arnoldo Valenzuela. Vol. 10. Small Satellites for Earth Observation. Wissenschaft und Technik Verlag Berlin, pp. 163–166.
- Gabet, Emmanuel J. (2003). "Post-fire thin debris flows: sediment transport and numerical modelling". In: *Earth Surface Processes and Landforms* 28.12, pp. 1341–1348.
- Gudmundsson, Magnús T. et al. (2010). "Eruptions of Eyjafjallajökull Volcano, Iceland". In: *Eos, Transactions American Geophysical Union* 91.21, pp. 190–191.
- Moritz, Max A. et al. (2014). "Learning to coexist with wildfire". In: *Nature* 515.7525, pp. 58–66.
- Rücker, Gernot et al. (2011). "High Resolution Active Fire Monitoring for Global Change Analysis: The Upcoming FireBIRD Satellite Mission". In: *Proc. 5th International Wildland Fire Conference, Sun City, South Africa, 9 - 13 May 2011*.
- Zhukov, B. et al. (2005a). *Experience of detection and quantitative characterization of fires during the experimental small satellite mission BIRD*. Tech. rep. LIDO-Berichtsjahr=2005, p. 96.
- Zhukov, Boris et al. (2005b). "Detection and analysis of high-temperature events in the BIRD mission". In: *Acta Astronautica* 56.1. 4th IAA International Symposium on Small Satellites for Earth Observation, pp. 65–71.