Results on verification and validation of OOV-TET1 multi-spectral camera observations within the FireBIRD project

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Abstract: Since November 2014, the OOV-TET1 Satellite is operated by DLR as part of the FireBIRD mission. Within the project the multispectral camera payload (MSC) became the mainly operated experiment. Its spectral and geometrical characteristics are designed to detect and observe high temperature events, especially wildfires, active volcanoes, which require a large temporal and radiometrical dynamic range and good spatial resolution. In order to detect, to discriminate and to characterize occurrences of sides with temperatures around 1000 K, but limited spatial extend, the camera system is equipped with spectral bands in near, mid, and thermal infrared as well as in visible range, having a ground resolution of 160m. This makes the instruments sensitive for remote sensing of events with thermal features in normal temperature range. Such topics are underground coal fires, thermal anomalies, observation of sea surface temperatures etc.

1 Introduction

Permanent changes in the biosphere caused by climate change, human activities, natural incidents causing more changes to the environment affecting nature and man The increasing numbers of wildfires are one example, where climate change is one reason but also the result. Fires are also used traditionally in agriculture in many countries in order to provide the ground for new crops.

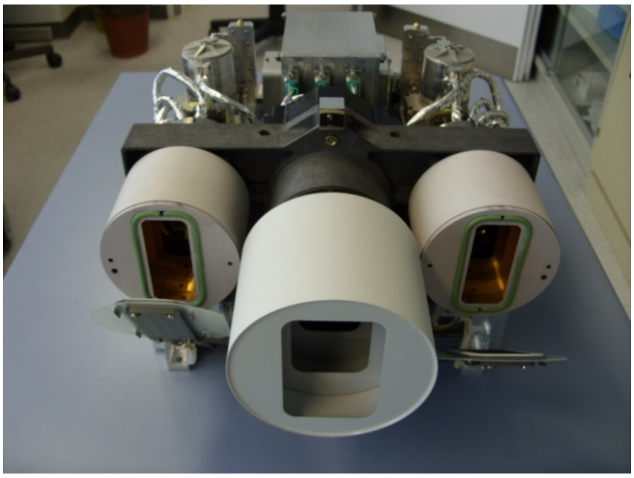

Figure 1 FireBird camera complex

Monitoring the environmental effects of wildfires, especially the release of Carbon and other aerosols in the burning process, is of global importance and a task that is also well suited to satellite remote sensing technologies such as TET-1[1].

Since wildfires have a temperature of 1000 K, observations in the atmospheric window between 3-5 micrometers are essential to detect and to discriminate wildfires from other sources of thermal emission. An additional channel in the TIR range 8-12 micrometers provides the differences in brightness temperatures for the determination of the background signal. However, such orbiters as Landsat, MODIS, VIIRS are equipped with a sensor in the TIR channel and designed to monitor effects in

	3 line-VIS Camera (3 line focal plane array)	2 Infrared-Cameras (staggered lines)
Wave length	1 460 - 560 nm 2 565 - 725 nm 3 790 - 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°
F-Number	3,8	2,0
Detector	CCD- Zeile	CdHgTe Arrays
Detector cooling	Passive, 20 ° C	Stirling, 80 - 100 K
Pixel size	7 µm x 7 µm	30 µm x 30 µm
Number of Pixel	3 x 5164	2 x 512 staggered
Quantization	14 bit	14 bit
Ground resolution	42,4 m 2)	356 m 2)
Ground sampling distance	42,4 m 2)	178 m 2)
Swath width	211 km 2)	178 km 2)
Data rate	max 44 MBit/s nom 11,2	0,35 MBit/s
Accuracy	100m on ground	100m on ground

Table 1.Main FireBird camera parameters [2)] Altitude 510km

the normal temperature range leave small fires undetected, while in case of fires with larger burning areas the senor tends to saturation, those limits the ability to quantify wild fires or other high temperature events (HTEs)[2]. Additional channels in the visible range help to discriminate sun reflections and might provide information on the type of nature. Aim of the FireBIRD camera IR-camera payload is the detection and measurement of high temperature events in sub-pixel resolution. The payload design is depicted in Figure 1, their main parameters are shown in Table 1. In order to enlarge the dynamic range, the IR-camera monitors the readout and in case of saturation initiates a second shorter integration.

The FireBIRD mission is defined as a constellation of two small satellites mainly dedicated to the investigation of high temperature events. The first satellite TET-1 was launched at 12. June 2012. The second satellite is scheduled to launch in spring 2016.

Receiving the raw data an operational processing unit generates a standard format for the raw data for archiving and reprocessing. Based on these raw data files the L1b standard products will be generated. L1b products are radiometric calibrated data with geographic annotation and related Meta Data Information. These information can be delivered in an ENVI conform format or in a HDF-EOS5 format

The combination of the IR bands with bands in visible range is also useful with respect to other areas of remote sensing. In case of the FireBIRD mission such targets with high temperatures are volcanoes and industrial sites, in the normal temperature range e. g. urban maps, underground coal fire, maritime pollution.

2 Calibration Activities

2.1 Radiometric calibration

In order to obtain scientifically usable image data a radiometric calibration of the sensor's visible and infrared bands is required. The application of corresponding calibration datasets on raw swath image data is the first step in the image processing pipeline and aims to the conversion of digital raw image data into units of mean spectral radiances related to each band's spectral band. For the visible (VIS) / near infrared (NIR) bands calibration datasets have been determined from on-ground flat-field measurements using well characterized reference radiators. These datasets are applied on currently incoming VIS/NIR swath data and still appear to be valid with respect to the sensitivity. The offsets, which means dark signal had been adjusted for data processing. For midwave (MWIR) and longwave infrared (LWIR) bands in-flight calibration data is recorded shortly after swath data is taken. This is achieved using a flap which is slowly heated, while it is temporarily placed in front of the sensor's IR optics. A contemporary redetermination of calibration data sets is necessary for infrared bands since their per-pixel sensitivities and offsets show a rapid drifting behavior [6]. However, disturbing signals remain in radiance images due to short term drift effects. In a second processing step, these deviations are reduced using advanced image processing algorithms which are improving subjective image quality and radiometric validity of image data required in context of fire detection and scientific post-processing in general. The radiometric validity can be shown from datasets determined during test fire campaigns.

2.2 Geometric Calibration

An accurate geometric calibration of satellite's cameras is essential for locating and co-align recorded images. Geometric calibration includes the calibration of single cameras' interior orientation as well as co-alignment of three cameras to each other as well as to AOCS. It is important for two parts of data processing. First, it is needed to overlay the five bands with subpixel accuracy to enable fire detection and parameter estimation. Second, the location of detected fires has to be determined via direct geo-referencing. Due to the need of online data processing indirect geo-referencing is not possible. The exact geometric calibration had to be determined during the commissioning phase. This included the calibration of interior orientation as well as co-alignment. Both were determined on ground but were not fully applicable in flight. Recalibration was performed using ground control points manually selected in the five strips in a single scene. A special camera model for line cameras was used to model interior orientation and misalignment of the cameras. Using a customized bundle adjustment this model was fitted to control points - leading to a set of geometric calibration parameters. Due to time synchronization problem a set of geometric calibration parameters was only valid within one scene and not usable for others. After fixing the synchronization problem, this issue was solved. Currently, direct geo-referencing is possible with an accuracy of 500 meters RMS if the terrain height is known. Due to the large field of view of the cameras the terrain height must be known in order to precisely determine the geographic location corresponding to an image pixel and to make an overly of the off nadir bands.

3 Application

3.1 High Temperature Events-Detection

The detection of high temperature events is one of the main features of the TET satellite. Therefore, the focus lies on the detection of fires and events with temperatures around 1000 K. In order to avoid saturation for events with high energy, two samples per ground pixel are taken, with the second sampling is performed using a shorter integration time. With TET, it is even possible to detect fires with areas much smaller than the actual ground mapped pixel size. The relationships are explained in detail by Zhukov et al [4].

To achieve this sub-pixel accuracy, it is necessary to have at least two distinct infrared bands which are provided by TET. One band is sensitive in the mid infrared range (3.4 to 4.2 µm) where typical fires have their radiative maximum. The second band required is sensitive in the thermal infrared range (8.5 to 9.3 µm), providing the background temperature. Using these two infrared bands as input data for the dual-band approach, the effective temperature and the effective sub-pixel area of a detected high temperature event can be estimated simultaneously. Additionally, the red band of TET is used for basic classification for background pixel assessment and false alarm rejection e.g. due to sun light reflections.

Before applying the dual-band approach, the three different spectral bands have to be co-registered and potential fire pixels have to be identified. The red band and the thermal infrared band are mapped to the mid infrared band by a half-automatic method. A rough manual mapping is refined by a cross-correlation approach. After this, the three bands are co-registered with a precision of less than a pixel. Then, background pixels are determined by interpreting these three bands, e.g. classify and exclude clouds, sun-glints, and hot objects. These background pixels define thresholds which are used to identify fire pixels. After clustering neighbor fire pixels, the dual-band method estimates fire temperature and area for all found fire clusters. Furthermore and finally, the fire radiative power (FRP) and geographic coordinates are calculated for every fire cluster. Since the active fire front covers often only a small fraction of a pixel less than 10% it is essential to have a good estimation of the background temperature. Canopy layers, e. g. forests and bush lands are often very heterogeneous, which can lead to larger margins in fire parameter estimations especially in the case of small fires [4].

The main difference to the precursor mission BIRD is the usage of the red band instead of near infrared band as input data for the fire processor. TET has a nadir looking red band and an off-nadir looking near infrared band in contrast to BIRD. Here the near infrared band is nadir looking. Therefore, the mapping to the nadir looking mid infrared band is much simpler for the red band. Fortunately, the red band is advantageous for sun-glint detection which improves the false alarm rejection. Unfortunately, it is almost impossible to distinct between forest and water by using the red band. This can decrease the thresholds for fire detection in proximity of water bodies and thus increase the false alarm rate.

4 Validation Activities

Figure 2 Test fire in the DEMMIN area

In order to obtain a correct interpretation of the radiances it is essential to compare the fire parameters derived from the observations with parameters obtained from ground based measurements under defined conditions.

For this a test fire design has been made and deployed at the calibration side DEMMIN® in north-east Germany. The test burn has been performed on 17. August 2013. The aim of the test was to create a fire at the low detection threshold of the sensor with a well

	Savannah Shabeni			Savannah Skukuza 6			Experimental Fire DEMMIN / Germany		
	TET-1	**Helicopter**	**Ratio**	**TET-1**	**Helicopter**	**Ratio**	**TET-1**	**Ground**	**Ratio**
T_{min}/ K	661	550		559	550		490		
T_{mean}/ K	685	668	1,02	580	595	0,97	727	940	0,77
T_{max}/ K	713	907		606	803		1500	1150	
AF_{min} / ha	0,15			0,36			0,001		
AF / ha	0,19	0,24	0,80	0,47	0,60	0,79	0,0141	0,0143	0,99
AF_{max} / ha	0,23			0,60			0,1733		
FRP / MW	23,6	35,1	0,67	30,3	25,5	1,19	2,24	1,36	1,65
FRP / MW / m^2	12,48	14,80		6,43	4,27		15,85	9,51	

Table 2 Comparison between FireBIRD results and ground based measurements, with: T - Effective fire temperature; AF - Effective Fire Area; FRP – Effective Fire Release Power. These parameters used to describe the typically inhomogeneous properties of wildfires
Note: Minimum and maximum values provided for T and A are error interval estimations.

specified dimension and a homogeneous surface temperature. The estimated FRP, an abstract parameter to describe the fire with respect to biomass consumed, was 2.24 MW compared to 1.36 MW calculated.

MW Radiance	**100**	**100**	**100**	**150**
LW Radiance	**99**	**100**	**101**	**100**
FRP / MW	2.4	2.7	3.2	4.1
T_F /K	889	744	669	942
A_F / m^2	68	158	280	92

Table 3: Effects of variations of radiance with respect to fire parameters

The results of the parameter estimation compared to the ground based parameters is shown in Table. 2 The estimated error intervals are comparable large with respect to the real fire. Since the fire covers only 0.11% of the ground pixel the influence of the estimated background temperature in the LWIR is very large. Table 3 shows the influence of the background temperature estimation (LWIR Radiance). The results of fire estimations for TET1 show as described before, that especially the background clutter in the non-fire part accounts for large error margins.

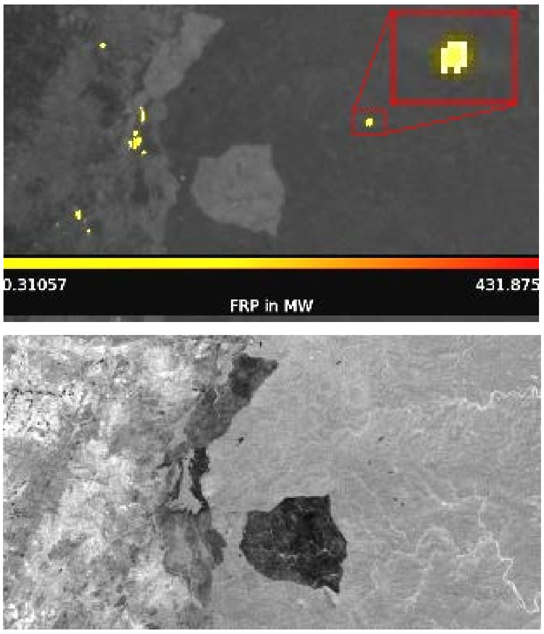

Figure 3: Fire experiment in open savannah in Kruger National Park, Republic of South Africa (26th Aug. 2014). Top: FRP on MWIR band; Bottom: NIR band

Two other in situ-measurements had been performed within an international ground calibration campaign in the savannah grass land in the Republic South Africa in August 2014, during the dry season, was aimed to investigations on fire ecology [7]. The burns have been monitored from helicopter with IR camera and from satellite. The comparison of all campaigns is shown in Table 2. The helicopter measurements show as well, that the temperatures of the active fire vary significantly. At the moment of the data take the fire burned still with low intensity with a rectangular shape of the fire front in the size of about 360m x 180m. Due to high dynamics of grass land fire the fire growth in intensity by more than 100% within 5 seconds, so possible errors might arise due to inexact timing. Cleary visible in the NIR band are burned areas in black, but also water holes (small dark spots), whereas burned areas appear brighter in the MWIR band.

5 HTE Observation, Detection and Quantification

In the time that the IR camera system aboard TET-1 has been active, approximately 1450 scenes have been captured containing wildfires and other high temperature events (HTE), which are volcanos and industrial sites, like power plants, offshore gas and oil rigs, refineries, and mine sites. HTE occur in all continents within a wide range of land cover types, from grasslands in South Africa, Eucalypt forests in Australia, Boreal forests in Canada and even volcanos in Iceland.

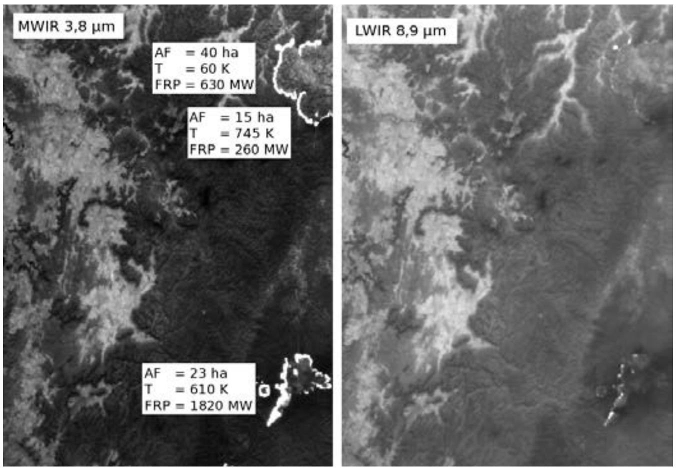

Figure 4. Detected fire fronts in Australia on 26.10.2013

5.1 Detection of Hotspots in Australia

The climate in Australia is conducive to the spread of fire across the whole continent. From the hot dry summers (November to March) in the southern temperate zones to the tropical dry season (April to September) in the north, fire events occur across the continent over the entire year (Sullivan et al., 2012). This provides an opportunity for the TET-1 satellite system and the FIREBIRD project in the future, with a target area with the potential to provide a wide range of fire types and sizes, over a wide range of surface land cover varieties.

Figure 4 shows a site west of Sydney and was the site of a catastrophic wildfire commencing between 17th and 20th October and ending on 19th November. This fire resulted in two people dying and 248 buildings destroyed, with a total cost of $94 million (Murphy, 2013). In total, all of the fire instances in this area during this time burnt over 65,000 Hectares.

5.2 *Observation of gas flaring*

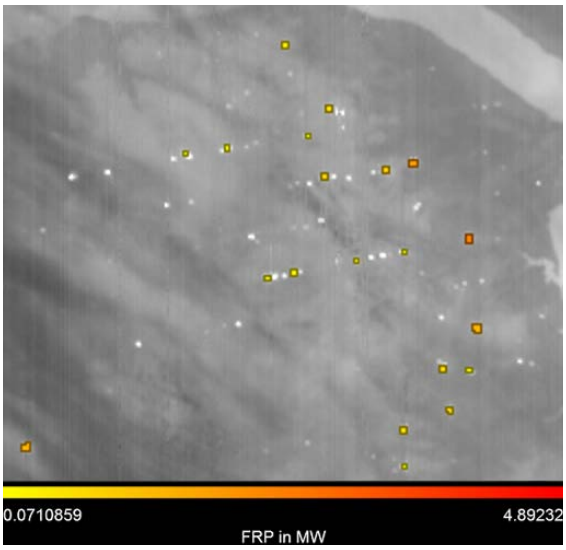

Figure 5 Energy released by gas flare in North Dakota USA in a night time image of the MWIR band on 21. Nov. 2014 (Background temperature around -8°C

Gas flares on oil wells contribute also significantly to CO_2 emission and is therefore in many countries prohibited by law. In a project to make flaring estimates using light emissions and MODIS fire products [9] the conclusion was that an estimate in quantity is not possible with this means. Target of the investigations are sites with permanent gas flaring, while in many locations gas flares occur only during pressure reliefs because the gas is nominally contained. Figure 5 shows a location with permanent flaring in North Dakota. In order to detect and make to estimate the magnitude of the gas flares the thresholds of the fire detection algorithm has been adjusted. Also visible in the image are some stripes due to insufficient calibration. The reason is that the background temperature is with 265 K below the linear response range of the detector. Still more observations under warmer ambient temperatures are needed to validate the results. One possibility to improve the detection is also to define a dedicated operational mode with longer integration times.

5.3 *Monitoring Sea Surfaces Temperatures*

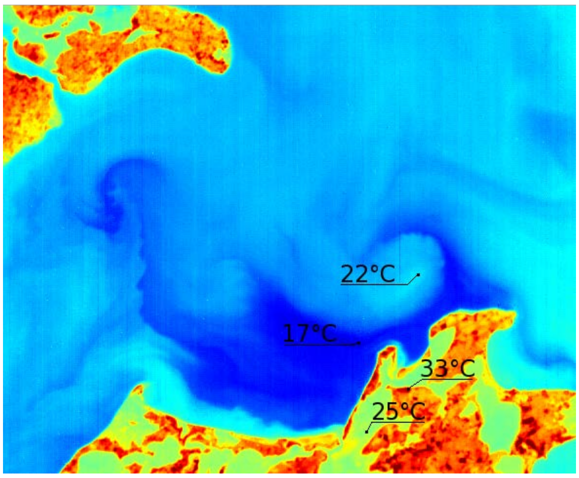

Figure 6: Sea surface temperatures on the Southern Baltic Sea, (10th July 2014)

Although monitoring of water surfaces is not the designed task of TET-1, a good example of different water brightness temperatures obtained from the LWIR band is shown in Figure 6. The dark blue areas indicate upwelling cold water in the Baltic Sea between Germany and Denmark. In order to separate flat water areas from land additional information is needed, such as a water mask obtained from the NIR band. Brightness temperatures might be also used to detect maritime pollution, e. g. oil spills since they affect the emissivity of the surface in the thermal infrared range. This subject however hasn't been investigated due to a lack of either clear scenes and, fortunately lack of polluted areas to observe.

6 Conclusion and Outlook

Already Zukov [4] could demonstrate that remote sensing sensors in the middle infrared are suitable best for fire detection. If this information is combined with information by sensors operating in VIS, NIR, and TIR, then a classification and estimation quantitative fire parameter estimation is possible. The combination of these spectral bands helps to quantify the background as a main source of uncertainty and provides also information on type and state of vegetation burned, which is needed to derive such parameters as burned biomass and CO_2. For a stable monitoring a multi-satellite configuration is necessary.

In order to circumvent limiting factors, like the amount of data that can be stored and downlinked can be counteracted by means of data reduction using, e. g. cloud screening and pre-selection of scenes suspicious to HTEs. Using on-board classification allows for a fast service of providing fire information to authorities using other communication channels than the nominal downlinks, causing a delay between data reception and data delivery.

7 Acknowledgements

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