Lessons Learned from Dedicated Active Fire Remote Sensing

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Abstract – Fire parameter estimation is performed using data obtained quasi-simultaneously by the Hot Spot Recognition System (HSRS) on the experimental Bi-spectral InfraRed Detection (BIRD) satellite and the MODerate resolution Imaging Spectro-radiometer (MODIS) on EOS Terra. Compared with the higher spatial resolution BIRD data, MODIS can not detect small fires, which leads in some cases to an underestimation of the cumulative Fire Radiative Power (FRP) release. FRP is a remotely sensed parameter proportional to the rate of biomass combustion. A linear relationship between FRP and the rate of vegetation combustion has been established though ground-based experiments.

Keywords: fire detection, fire characteristics retrieval, fire radiative power, combustion rate.

1. INTRODUCTION

The experimental Bi-spectral IR Detection (BIRD) mission of DLR has successfully demonstrated the capability of compact IR push broom sensors for the high spatial resolution detection and quantitative analysis of high temperature events such as active fires (Briess et al, 2003), and this work has already been reported to ISRSE in 2003 (Lorenz et al, 2003).

During the entirety of the BIRD mission, data from the Moderate resolution Imaging Spectro-radiometer (MODIS) on NASA's Earth Observing System (EOS) satellite Terra, and later also Aqua, has been used semi-operationally for worldwide fire detection and monitoring. The MODIS fire products are described in detail in (Justice et al, 2002). If the day- and night-time data from both Terra and Aqua are considered, then MODIS provides whole-Earth coverage four times per day. The coverage frequency increases further at higher latitudes due to overlaps of the MODIS imaging swaths.

MODIS and BIRD are the only sensors imaging worldwide whose Middle IR (MIR) and Thermal IR (TIR) channels do not saturate when observing major fire signals. This capability allows:

- efficient rejection of false alarms such as warm surfaces and sun-glints, that in some cases can be mistaken for fires.
- application of an innovative approach for the satellite-based assessment of the amount of fuel burned and the estimation of pyrogenic carbon release, based on the use of the fire radiative energy flux. This *Fire Radiative Power (FRP)* acts as a measure of the intensity of burning**,** whilst the time integrated FRP (or the *Fire Radiative Energy (FRE) release)* acts as a proxy for the total fuel consumed, (Wooster et al, 2003 and Kaufman et al, 1998).
- the retrieval of further quantitative fire characteristics such as the effective fire temperature T_F and effective fire area A_F, which can be used to inform the FRP retrievals and also to derived the predominant combustion characteristics (i.e. the dominance of smouldering or flaming activity, which has a bearing on the fires' chemical emissions)

Detection of individual fire fronts and estimation of their radiative intensity (FRP per unit length of the fire front) is essential for fire fighting purposes as well as for characterising the fire ecosystem impacts. Furthermore, the total FRP from a fire scene can be correlated with the rate of biomass burning and of gas and aerosol emissions from fires (Wooster et al, 2003).

2. RELATIONSHIP BETWEEN BIOMASS COMBUSTION RATE AND FRP

Wooster (2002) showed that the relationship between fire radiative energy and biomass consumed in the fire could be considered linear. However, since satellites measure instantaneous fire radiative power rather than fire radiative energy, further work is necessary. Figure 1 shows the results from a small experiment conduced in the UK, where FRP was determined at 1 second intervals from a MIR thermal imaging camera viewing vertically downwards 10 m above a fire of herbaceous fuel that was mounted atop digitally logged scales. The relationship between the FRP and the rate of combustion is seen to approximate a linear relationship, and if this holds for larger, natural wildfires then satellite-derived FRP measures can be directly converted into combustion rate estimates and, via application of the relevant emissions factors, into flux estimates of carbon, trace gases and aerosols.

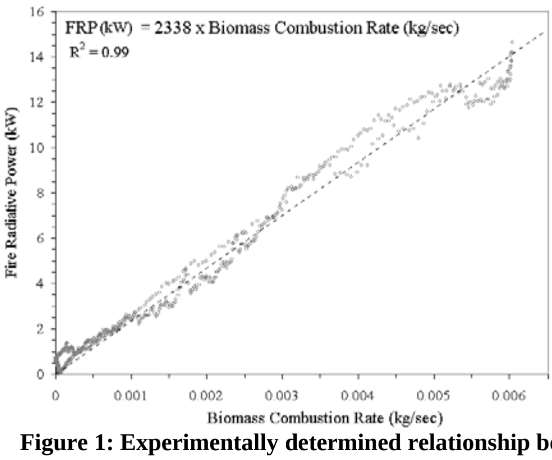

Figure 1: Experimentally determined relationship between FRP and combustion rate

3. MODIS AND BIRD FIRE OBSERVATION CHARACTRERISTICS

Table 1 shows the relevant parameters the MODIS and BIRD channels used for fire recognition.

Table 1: Main characteristics of the MODIS and BIRD channels used for fire recognition

	MODIS on EOS-Terra/ Aqua	**HSRS / WAOSS-B on BIRD**
Spectral channels for fire detection	MIR: 3.9 - 4.0 µm TIR: 10.8 - 11.3 µm RED: 0.62 - 0.67 µm NIR: 0.84 - 0.88 µm	MIR: 3.4 - 4.2 µm TIR: 8.5 - 9.3 µm NIR: 0.84 - 0.90 µm
MIR channel saturation	500 K	600 K
Spatial resolution	1 km	370 m / 185 m
Swath width	2330 km	190 km
Revisit time	4 times a day	Experimental imaging of selected areas

4. FIRE PARAMETER RETRIEVAL

In order to generate directly comparable results, in this paper the quantitative fire parameters were retrieved from BIRD and MODIS data using an identical methodology (Zhukov et al, 2003) which included the following steps:

- consolidation of spatially contiguous identified hot pixels into hot clusters.
- retrieval of the effective fire temperature, effective fire area and FRP for each hot cluster.
- estimation of the TIR background temperature variability (background clutter) and of the confidence intervals for the effective fire temperature T_F , effective fire area A_F , and FRP.
- for pronounced fire fronts: estimation of the front length and radiative intensity (ratio of FRP to the front length) in order to characterise the fire front strength).

Estimation of T_F and A_F are in the case of smaller fires sometimes unreliable, but alternative methods for the estimation of FRP, which operate without the stage of effective fire temperature and area retrieval, are discussed in (Wooster et al, 2003 and Kaufman et al, 1998).

As an example of the results generated by this process, Figure 2 shows an area to the west of Lake Baikal, Russia imaged by MODIS and BIRD on 16 July 2003 within a 30-minute interval. These fires are large, and the FRP results generated from the estimated T_F and A_F data are stable. The BIRD data allow the clear recognition of the individual fire fronts and estimation of their characteristics T_F , A_F , FRP, front length, radiative front intensity and the effective depth (ratio of the effective fire area to the front length; Table 2). Similar findings were also found in the case of intense bushfires detected previously in Australia (Wooster et al., 2003). The T_F parameter derived from BIRD was also used to determine the fire front flaming ratio (the ratio of the area of the flaming component to the area of the flaming and smouldering components). This calculation is made assuming that the flaming and smouldering components have temperatures of 1000 and 600 K respectively. In contrast to BIRD, MODIS generally makes it possible to detect only separate hot pixel clusters rather than actual fire fronts, though an exception is a very strong fire front “1” that can be recognised in both MODIS and BIRD. The capability to recognize and characterise individual fire fronts, in particular the front radiative intensity, can be considered an essential requirement for a sensor used for fire detection and monitoring to support operational fire fighting activities.

These MODIS and BIRD comparisons also illustrate the potential for BIRD to validate fires detected by MODIS. For example, a few weak bright spots in Figure 2 just north of the strongly radiant front 1, which were recognised as nominal-confidence fires in the MODIS fire product, turn out to be false alarms after comparison with the higher-resolution BIRD image. There are also clearly some fire fronts detected by BIRD that are totally missed by MODIS, for example the fire to the northwest of fire front 1 in the BIRD image.

5. CONCLUSIONS

Though MODIS misses a significant portion of small fires in comparison to BIRD, it actually underestimated the cumulative FRP of the Siberia fire scene shown in Figure 1 only by ~4%. This is because the vast majority of the scene-FRP (and consequently of the fire pollutant emissions) is being produced by the largest fires that are reliably detected by both MODIS and BIRD. Nevertheless, BIRD has demonstrated a significantly better capability to discriminate individual fire fronts and to estimate their characteristics due to its higher spatial resolution. Clearly a combination of high spatial resolution and wide swath width (which is essential for a high observation frequency) is the ideal solution for a sensor aimed at fire detection, monitoring and characterisation, but this is difficult to achieve in a single instrument. Therefore a reasonable strategy for the development of a fully operational space-borne fire monitoring system is the combination of:

- Wide-swath whisk-broom moderate-resolution spectro-radiometers, such as MODIS, in order to provide systematic global observations with a high observation frequency, with
- High-spatial resolution push-broom imagers, like the main sensors of BIRD but possibly with an further improved spatial resolution of ~100-200 m, for detailed monitoring of the regions where fires have already been reported.

The *IR Element* whose definition is planned by the European Space Agency (ESA) within the context of the *Space Component for Global Monitoring for Security and Environment (GMES)* shall be considered as a prospective European high-spatial resolution fire detection and monitoring sensor.

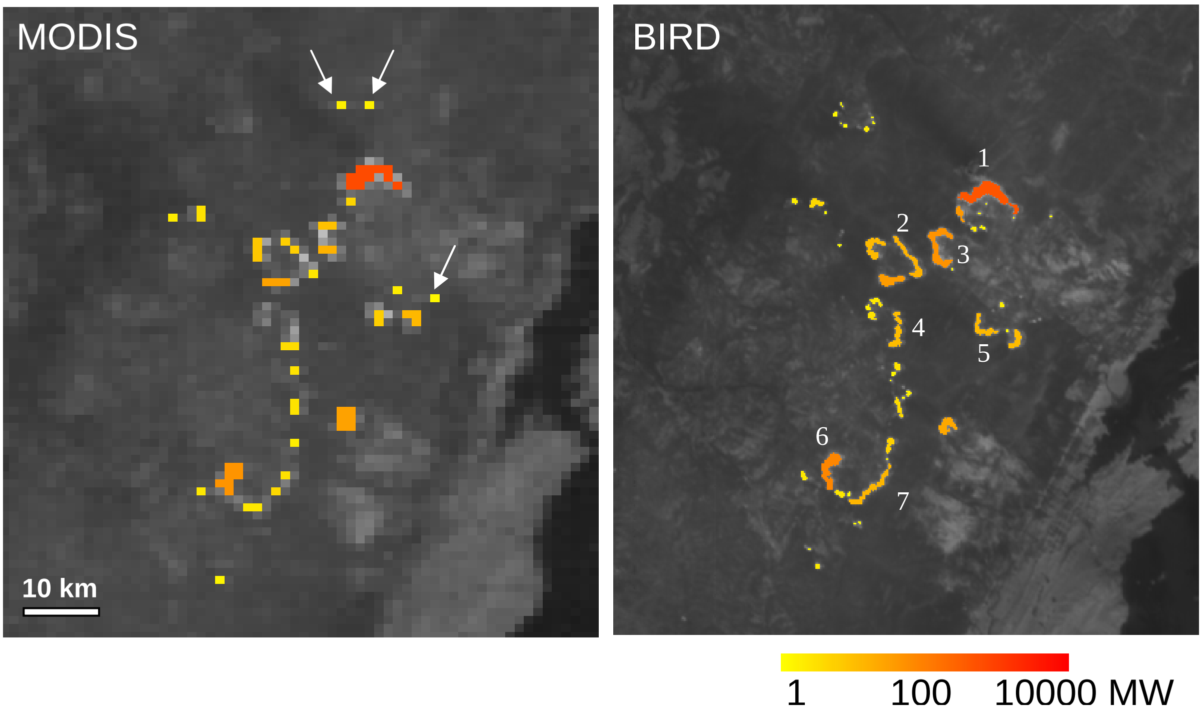

Figure 2: Fragments of forest fire images at Baikal, obtained by MODIS and BIRD on 16 July 2003. Images show the MIR image from each sensor, and detected hot clusters are colour coded according to their FRP.

Table 2 Characteristics of selected forest fire fronts in the BIRD image of the Lake Baikal area in Siberia, Russia obtained on 16 July 2003 (the confidence intervals for the fire parameters are indicated in brackets)

Hot cluster (Fig.2)	*Effective fire temperature, K*	*Flaming ratio*	*Effective fire area, Ha*	*FRP, MW*	*Front length, km*	*Front radiative intensity, kW/m*	*Front effective depth, m*
1	851 (800-920)	0.30 (0.20-0.51)	6.3 (4.4-8.4)	1829 (1771-1829)	8.2	223	7.7
2	711 (668-771)	0.08 (0.05-0.15)	1.1 (0.7-1.5)	150 (136-150)	5.8	26	1.9
3	775 (716-868)	0.16 (0.09-0.34)	2.1 (1.2-3.1)	409 (377-409)	6.5	63	3,2
4	783 (740-839)	0.17 (0.12-0.27)	0.53 (0.38-0.71)	111 (105-111)	4.8	23	1.1
5	850 (771-988)	0.30 (0.15-0.89)	0.43 (0.23-0.70)	126 (121-126)	3.4	37	1.3
6	860 (819-913)	0.32 (0.23-0.48)	1.9 (1.4-2.3)	568 (554-568)	5.0	114	3,8
7	763 (694-882)	0.14 (0.07-0.38)	0.73 (1.21-0.36)	136 (123-136)	6.3	22	1,2

6. REFERENCES

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