COMPARISON OF FIRE DETECTION AND QUANTITATIVE CHARACTERISATION BY MODIS AND BIRD

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Data of the spectroradiometers MODIS on the Terra and Aqua satellites, which are obtained on a global scale 4 times a day, are widely used for global and regional monitoring of active fires. A disadvantage of MODIS is a relatively low resolution of 1 km. We investigated the effect of the resolution on the recognition of fire fronts and on the estimation of their characteristics, as well as on the estimation of the total fire radiative power (FRP) emitted from a fire scene. For this purpose, we compared images of fire scenes in Siberia, Portugal and Australia that were obtained nearly simultaneously by MODIS and by the dedicated small satellite BIRD, which provides a resolution of 370 m in its infrared channels and allows the detection of fires with an area a factor of 7 smaller than MODIS. The results show that BIRD allows the recognition of fire fronts and the estimation of their characteristics, while in the MODIS data fire fronts are usually not clearly distinguished. On the other hand, MODIS proves to be a marginally adequate sensor for the estimation of the total FRP in fire scenes, which is related to the rates of biomass burning and of gas and aerosol emissions. Only in cases of fires with a relatively small front depth, which is typical for bush fires in Australia, MODIS may significantly underestimate the FRP by a factor of 1.8 compared to the BIRD-based FRP estimates. As a conclusion, it is recommended to combine the data of wide swath sensors, such as MODIS and of high-resolution instruments of the BIRD type for effective fire monitoring from space.

Introduction

The Moderate Resolution Imaging Spectroradiometers (MODIS) on NASA's Earth Observing System (EOS) satellites Terra and Aqua are semi-operationally used for worldwide fire detection and monitoring since 2000 and 2002, respectively. The MODIS fire products are described in detail in [1, 2]. If the day- and night-time data from the both satellites are considered, the MODIS spectroradiometers can provide coverage of the whole Earth 4 times a day. The coverage frequency increases additionally with the latitude due to overlapping of the MODIS imaging swaths.

A disadvantage of MODIS is its relatively large pixel size of 1 km (at nadir; further increasing towards the edges of the swath). In this study, we investigated the effect of the resolution on the discrimination of fire fronts and on the estimation of their characteristics as well as on the estimation of the total fire radiative power (FRP) from fire scenes. Recognition of fire fronts and estimation of their radiative intensity (FRP from 1 m of a fire front) is essential for fire fighting purposes as well as for characterising fire impact on the ecosystem. On the other hand, the FRP from a fire scene can be correlated with the rate of biomass burning and of gas and aerosol emissions from fires [3, 4, 5].

We compared the number and characteristics of fires detected by Terra/MODIS with those detected by the dedicated small satellite BIRD. The experimental Bi-spectral IR Detection (BIRD) mission of DLR operated since the end of 2001 until the beginning of 2004 and has successfully demonstrated the capability of compact IR push broom sensors for high resolution fire detection and quantitative analysis [6, 7]. The BIRD main sensors consist of the Hot Spot Recognition System (HSRS) and the Wide-Angle Optoelectronic Stereo Scanner (WAOSS-B) [6]. The BIRD / HSRS is described in detail in [8, 9]. Due to its higher resolution of 370 m in the infrared channels, BIRD allows the detection of fires with the area 7 times smaller than MODIS, however in a much narrower swath.

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

Study areas and data processing

In the time period between 12 June an 17 July 2003, BIRD acquired 9 image swaths in the area between Enisey and Baikal (between 90 and 115 °E). For each BIRD swath, Terra/MODIS swaths with the closest overpass time were selected (in case the area imaged by BIRD was located close to the edge of the MODIS swath, the neighbouring MODIS pass was used). Finally, three MODIS and BIRD image swaths were selected that were obtained in cloud-free conditions to avoid the cloud obscuration effect on the MODIS / BIRD data inter-comparison. In addition to Siberia, cloud-free MODIS and BIRD images of forest fires in Portugal and of bush fires in Australia were also compared. In all the cases, the same areas were selected in the MODIS and BIRD data. The time interval between the MODIS and BIRD data acquisitions was within a few tens of minutes.

The MOD14 product was used to identify hot pixels in the MODIS data, selecting the fires that were detected with a nominal and high confidence [2]. Fire detection in the BIRD data was performed using the BIRD hot-spot detection algorithm [10] that uses adaptive MIR, MIR/NIR and MIR/TIR tests to detect hot pixels and to separate them from false alarms (sun glints, reflections on clouds, warm surfaces).

Quantitative fire parameters were estimated from the BIRD and MODIS data using the same methodology [10] in order to provide directly comparable results. The methodology included the following steps:

- consolidation of contiguous hot pixels into hot clusters (thus a hot cluster is considered as one fire),
- retrieval of the effective fire temperature T_F and of effective fire area A_F for the hot clusters using the bi-spectral Dozier technique [11],
- estimation of the Fire Radiative Power (FRP) of hot clusters using the retrieved values of T_F and A_F,
- estimation of the error intervals for T_F, A_F and FRP with respect to the TIR background radiance variability (background clutter) and
- for pronounced fire fronts: estimation of the front length and the front radiative intensity (FRP from 1 m of the front length).

The retrieval of T_F and A_F from the MODIS and BIRD data was in most cases not reliable due to a small fractional area of the fire within the hot clusters. T_F could be estimated with an accuracy better than 100 K and A_F with an accuracy better than a factor of 2 only for ~30% of all detected fires. On the contrary, FRP could be determined in most of the cases with an accuracy better than 30% since the errors in T_F and A_F partly compensate each other during the FRP estimation.

Results

Fragments of the MODIS and BIRD fire scenes in Siberia, Portugal and Australia are shown in Fig. 1, 3 and 5. Histograms of the effective fire area and of FRP as estimated from the entire MODIS and BIRD image swaths are shown in Fig. 2, 4 and 6. The number of detected hot clusters and the total FRP in the fire scenes are compared in Table 2.

Table 2. Number of detected hot clusters and their total fire radiative power from the BIRD and MODIS data (the error intervals for FRP are indicated in brackets)

Scene	***Number of hot clusters***		***Total FRP, Gigawatt***	
	BIRD	***MODIS***	***BIRD***	***MODIS***
Angara, Russia, 12 June 2003	15	3	0.57 (0.47-0.57)	0.59 (0.37-0.59)
Angara, Russia, 10 July 2003	148	59	16.4 (15.5-16.4)	14.3 (12.3-14.3)
Baikal, Russia, 16 July 2003	162	59	11.5 (10.7-11.5)	11.9 (10.7-12.0)
Portugal, 4 August 2003	99	35	15.5 (15.0-15.8)	12.0 (10.8-12.1)
Australia, 5 January 2002	227	34	5.2 (5.1-5.3)	2.9 (2.6-3.0)

BIRD allows much more detailed fire mapping, which manifests itself in a much larger number of detected hot clusters than the number of hot clusters in the MODIS data. BIRD could detect fires with FRP starting from ~1 MW, while the detection limit for MODIS was ~10 MW – see Fig. 2, 4 and 6 (here we characterise the fire detection potential of a sensor by the minimal detectable FRP that is much less sensitive to the fire temperature than the minimal detectable fire area). In the MODIS data, some of small fires detected by BIRD are missed while others can not be separated from each other and are merged in larger clusters. Only the first effect (omission of small fires) leads to total scene FRP underestimation from the MODIS data. The magnitude of FRP underestimation by MODIS in comparison to BIRD depends on the proportion of small fires in the scene, which in turn depends both on the ecosystem and on fire intensity. The strongest FRP underestimation of a factor of 1.8 was observed for the Australian bush fires, which are characterised by a relatively small fire front depth and as a consequence by a relatively small fire proportion in the pixel signal. On the contrary, forest fires in Siberia, which are expected to have wider fronts and therefore a larger fire contribution to the pixel signal, show a relatively small underestimation by MODIS of only 4% for the three scenes. The 30 % underestimation of FRP by MODIS for the forest fires in Portugal is between the corresponding values for the Siberian and Australian fires. Accounting for weak low-confidence fires in the MODIS data had practically no effect of the scene FRP estimation by MODIS.

An essential requirement for a sensor used for operational fire detection and monitoring is the capability to recognize fire fronts and estimate their characteristics, in particular the front radiative intensity. The comparison of MODIS and BIRD fire scenes at Baikal (Fig. 1) and in Australia (Fig. 5) shows that MODIS essentially allows the detection of only separate hot pixels and does not actually reveal clear fire fronts. In contrast, the higher spatial resolution BIRD data make it possible to recognise fire fronts and to estimate their characteristics (Table 3): T_F, A_F, FRP, the front length, radiative front intensity and the effective depth (ratio of the effective fire area to the front length). The effective fire temperature was also used to determine the flaming ratio in the fire front (the ratio of the area of the flaming component to the area of the flaming and smouldering components), assuming that the flaming and smouldering components have a temperature of 1000 and 600 K respectively.

Table 3. Characteristics of selected forest fire fronts in the BIRD image of the Lake Baikal area in Siberia, Russia obtained on 16 July 2003 (the error intervals for the fire parameters are indicated in brackets)

Fire front in Fig.1	***Eff. fire temperature, K***	***Flaming ratio***	***Eff. 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

The comparison between the MODIS and BIRD data also illustrates the potential for BIRD to validate fires detected by MODIS. For example, a few weak bright spots, which are indicated with arrows in the MODIS image in Fig. 1, are recognised as nominal-confidence fires in the MODIS fire product but turn out to be false alarms after comparison with the higher-resolution BIRD image.

Conclusions

The results of this study show that the MODIS sensor, with a spatial resolution of 1 km, is marginally adequate for the estimation of the radiative power of forest fires. FRP can be related to the rates of biomass burning and of gas and aerosol emissions. Though MODIS may miss a significant portion of small fires in comparison to BIRD, it underestimated the total FRP of the fire scenes in Siberia only by ~4%. The reason is that in these scenes the major part of FRP (and consequently of the fire pollutant emissions) are produced by large fires that are reliably detectable by MODIS. In cases of fires with a relatively small front depth, which is typical for the bush fires in

Australia, MODIS may significantly underestimate the FRP by nearly 50% compared to the BIRD-based FRP estimates.

For operational fire detection and monitoring purposes, BIRD has demonstrated its significantly better capability to discriminate fire fronts and to estimate their characteristics.

However, it is difficult to combine the requirements of high spatial resolution and wide swath (which is essential for a high observation frequency) in one sensor. Therefore a reasonable strategy for development of operational space-borne fire monitoring systems can be based on combining:

- wide-swath whisk-broom moderate-resolution spectroradiometers such as MODIS for systematic global observations with a high observation frequency and
- high-resolution push-broom imagers, like the main sensors of BIRD but possibly with a still better resolution of 100-200 m for detailed monitoring of the regions where fires have already been reported.

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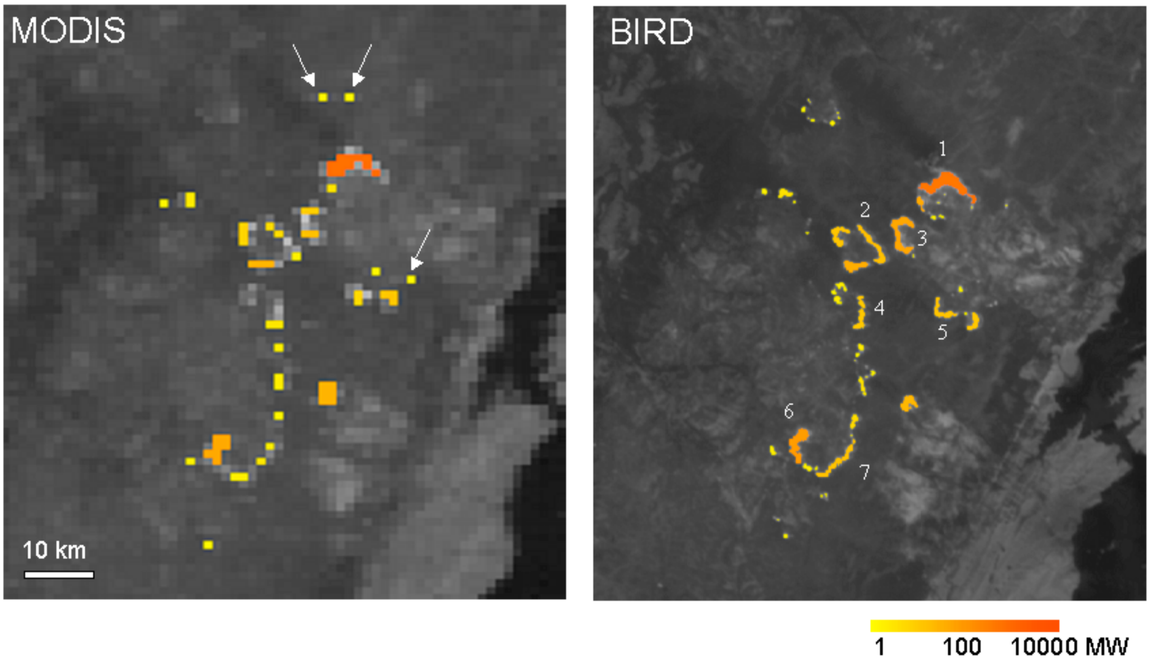

Fig. 1. Fragments of forest fire images acquired on 16 July 2003 by MODIS (4:21 GMT) and BIRD (4:46 GMT) at Lake Baikal; the detected hot clusters are colour-coded using their FRP and projected on the MIR band; the arrows indicate false alarms in the MODIS data

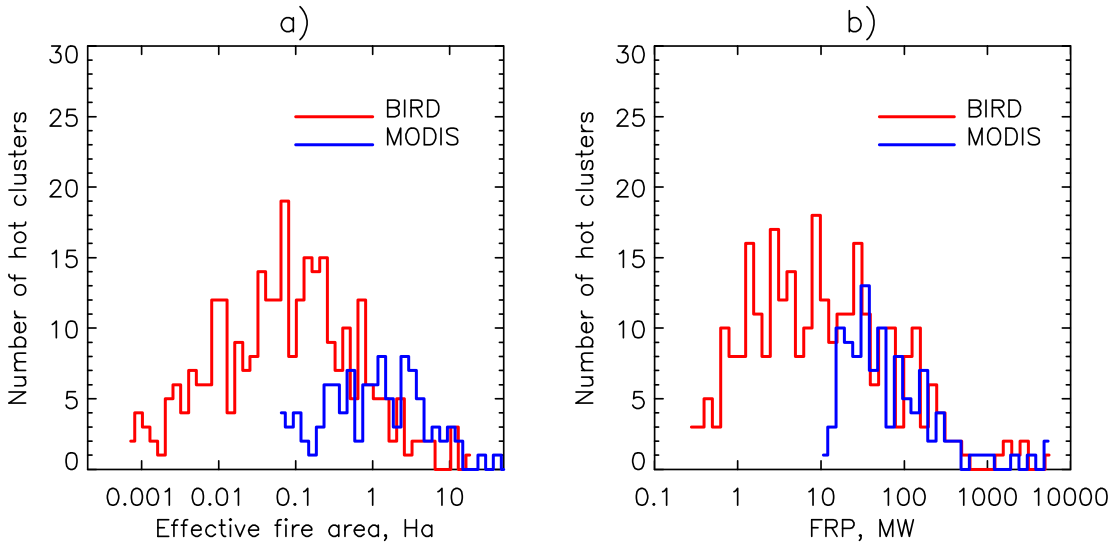

Fig. 2. Effective fire area and FRP distribution from three MODIS and BIRD image swaths acquired in Siberia

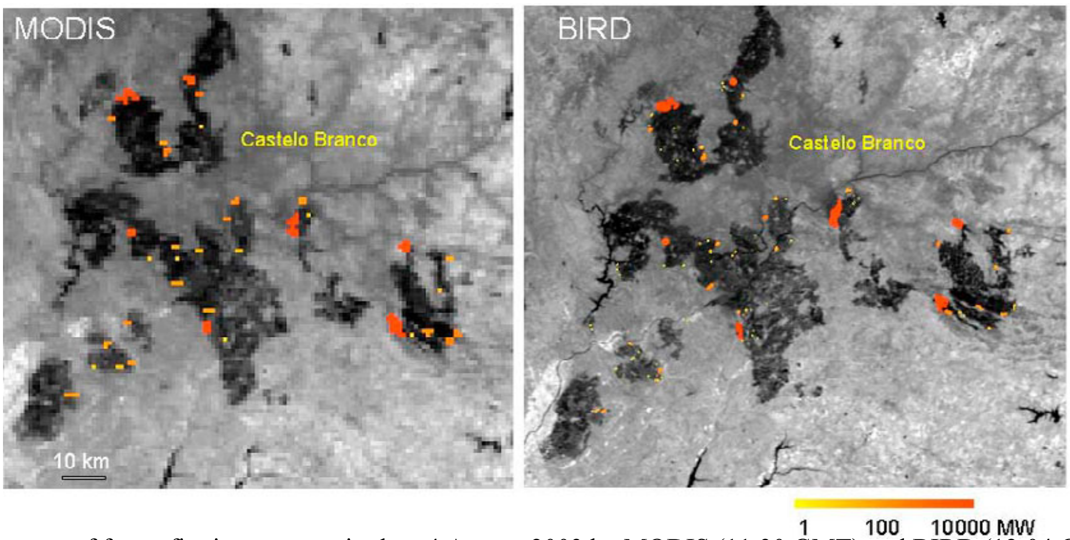

Fig. 3. Fragments of forest fire images acquired on 4 August 2003 by MODIS (11:30 GMT) and BIRD (12:04 GMT) in Portugal; the detected hot clusters are colour-coded using their FRP and projected on the NIR band

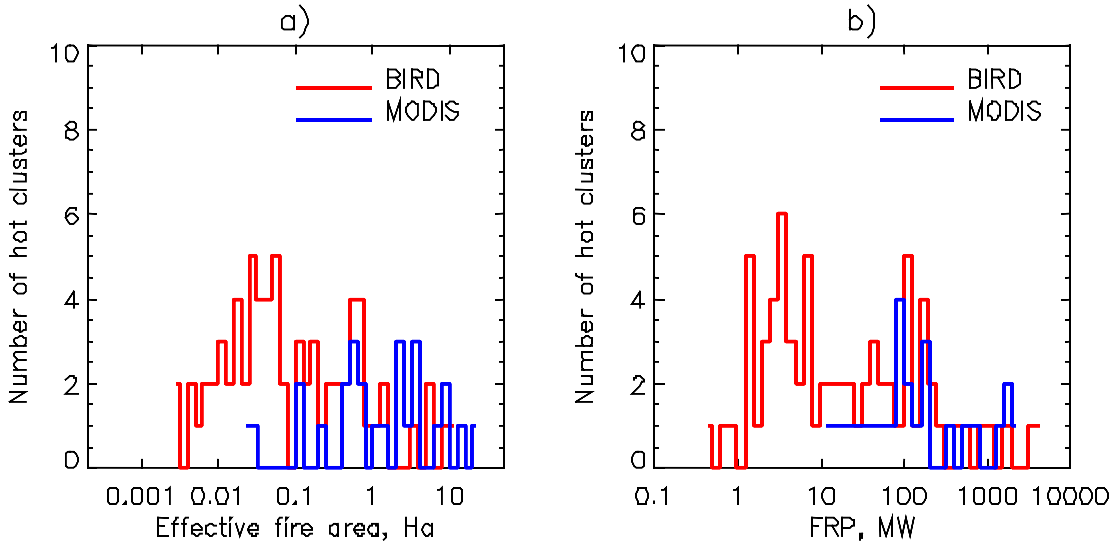

Fig. 4. Effective fire area and FRP distribution from the MODIS and BIRD image swaths acquired in Portugal

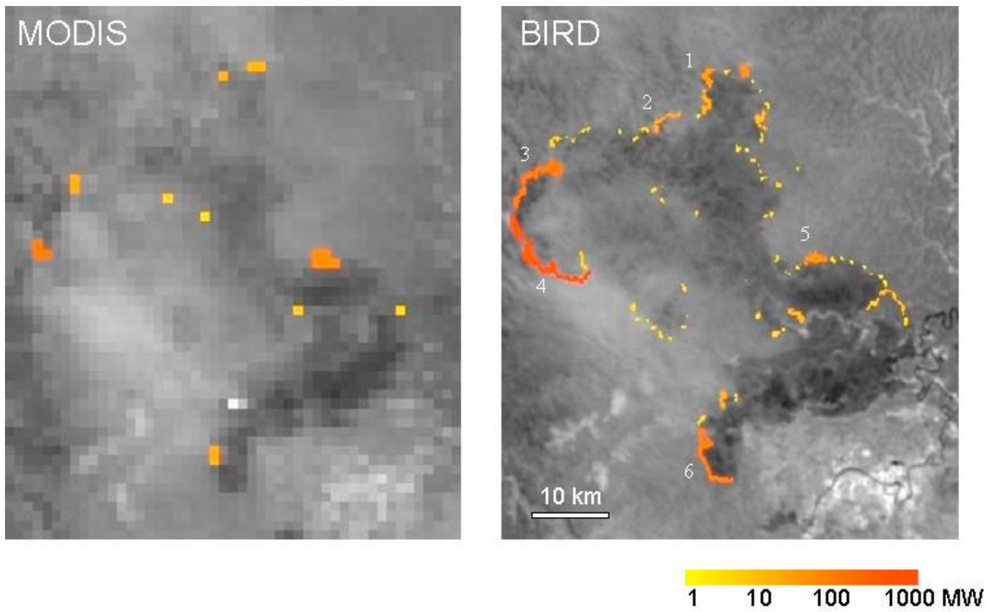

Fig. 5. Fragments of bush fire images acquired on 5 January 2002 by MODIS (0:22 GMT) and BIRD (0:08 GMT) in Australia; the detected hot clusters are colour-coded using their FRP and projected on the NIR band

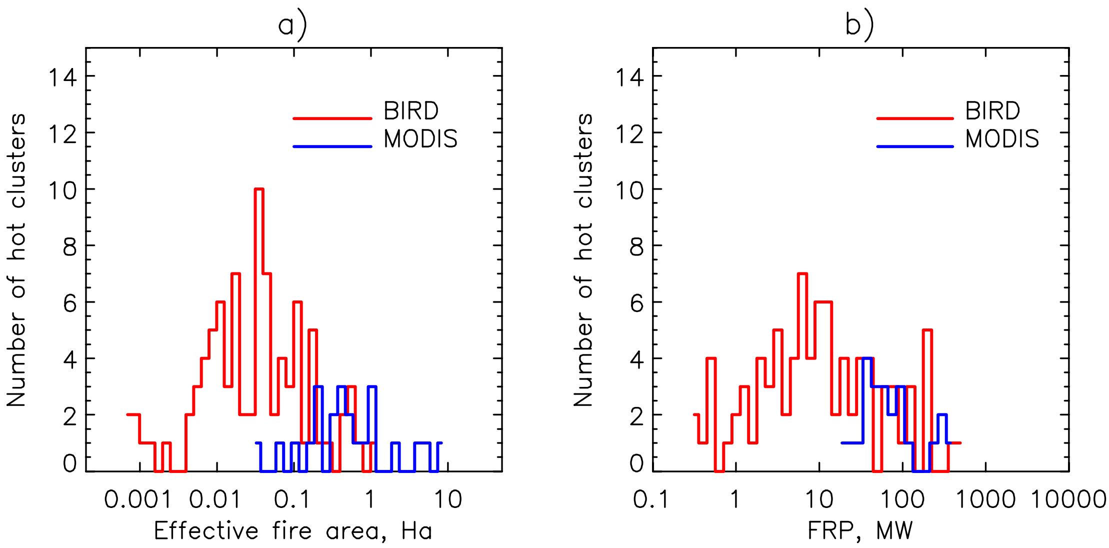

Fig. 6. Effective fire area and FRP distribution from the MODIS and BIRD image swaths acquired in Australia