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# DETECTION AND CHARACTERIZATION OF LOW TEMPERATURE PEAT FIRES DURING THE 2015 FIRE CATASTROPHE IN INDONESIA USING A NEW HIGH-SENSTITIVITY FIRE MONITORING SATELLITE SENSOR (FIREBIRD)

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## SUMMARY

Vast and disastrous fires occurred on Sumatra and Borneo during the 2015 dry season, pushing Indonesia into the top 5 carbon emitting countries. The region was affected by a very strong El Niño-Southern Oscillation (ENSO), similar to or even stronger compared with the last severe event in 1997/98. Fire dynamics in Central Kalimantan, Borneo, were investigated using an innovative sensor offering higher sensitivity at a finer spatial resolution (160 m) than previously available. The sensor is onboard the TET-1 satellite, which together with a second satellite (BIROS, planned launched May 2016) form the German Aerospace Center (DLR) FireBird mission. TET-1 images (acquired every 2-3 days) were used to detect fires continuously burning for almost three weeks in the protected peatlands of Sebangau National Park and surrounding areas with active logging and oil palm concessions. TET-1 detection capabilities were compared with MODIS active fire and Landsat burned area algorithms. Fire dynamics, including propagation speed and area burned, were investigated and possible causes for fires were explored. We show that TET-1 has improved detection capabilities over MODIS in monitoring small, low intensity peatland fire fronts through thick smoke and haze. Analysis of fire dynamics revealed that the largest burned areas resulted from fire front lines started from multiple locations. The highest propagation speeds measured, in excess of 200 m/day, were over peat deeper than 2 m. Fires were found to occur most often in concessions that contained drainage infrastructure but had not yet been cleared. Benefits of implementing this sensor system to improve current fire management techniques are discussed. Near real-time fire detection together with enhanced fire behavior monitoring capabilities will also advance analysis of fire impact on tropical peatlands, greenhouse gas emission estimations as well as design of measures to prevent and mitigate severe fire events in the future.

***Keywords:*** *peat fires, high sensitivity fire monitoring, fire dynamics, FireBird, Sebangau*

## INTRODUCTION

The fires that swept across Indonesia during the latter half of 2015 were catastrophic on many levels. Costs incurred from the fires to the Indonesian government are estimated to be in excess of USD $16 billion (World Bank 2015), signifying 1.9% of the national gross domestic product. Greatly reduced air quality in Southeast Asia is a consequence of major forest fires (Hyer & Chew 2010), and the resulting smoke cloud, coined the 2015 Southeast Asian Haze, spread across several countries. The islands of Sumatra and Borneo were especially heavily impacted, with poor air quality causing a state of emergency to be declared in six Indonesian provinces. Initial emission estimates from the 2015 fires amount to 1.75 billion metric tons of CO2 equivalents (World Bank 2015), pushing Indonesia into the world‘s top 5 CO2 emitting countries (www.globalfiredata.org).

The peatlands on Borneo, covering 16-27 million ha, constitute more than half of all tropical peatlands worldwide (Page *et al.,* 2009). In recent decades, these peat swamp forests have been degraded through both industrial and illegal logging, industrial plantation activities and infrastructure from development projects such as the Mega Rice Project (Miettinen *et al.,* 2012). Drainage infrastructure, such as canals, contribute to lowering the water table (Konecny *et al.,* 2016), which is then compounded by drought periods coinciding with climatological events such as El Niño-Southern Oscillation (ENSO) (Page *et al.,* 2009). On Borneo, slash-and-burn techniques often result in fires spreading into surrounding un-slashed peat swamp forests. Peatland fires are characterized by low intensity burning, which can spread into peat deposits up to 0.5 m below the surface. Combined with slow propagation speeds of less than 2 m/day, peatland fires can burn for long periods of time, are very difficult to extinguish and produce large amounts of particulate matter, CO and other gas compounds (Usup *et al.,* 2004). Peatland and forest fires in Indonesia during the 1997/98 ENSO event are estimated to have produced 0.2-0.4 Pg C, accounting for at least 10%

of the global total carbon production due to forest fires (Taylor 2010).

Many questions remain regarding better fire management practices to help avoid catastrophic fire events in Indonesia such as those in 1982/83, 1997/98 and recently in 2015. Remote sensing systems have been utilized for over three decades to support monitoring efforts, which include NOAA-AVHRR, GOES-VAS, ERS-ATSR, TRMM-VIIRS, and MODIS on the EOS Terra and Aqua satellites. Most sensors saturate between 300-340 K, the exception being one MODIS band (4-µm low-gain) which saturates at 500 K. Low sensor saturation inhibits detection of very large fire events (Zhukov *et al.,* 2006). While MODIS was to date best able to overcome this limitation, its 1-km pixel resolution hinders detection of initial fire fronts or multiple small fires.

The sensor onboard the Technology Experiment Carrier (TET-1) saturates at 900 K, improving detection of smoldering to intense large-area fires (Zhukov *et al.,* 2006). This, together with the sensor‘s 160-m spatial resolution, could improve active fire monitoring and allow measurement of fire dynamic behavior previously not possible.

We explore whether TET-1 can provide improved fire detection capabilities than hereto existing systems, thus offering the basis for an improved early-detection fire management system. Focus is paid to fire dynamics (propagation speed, area burned) over different ground and vegetation types, as well as fire occurrence in and around concession areas.

## METHODS

The study area covered the Sebangau National Park as well as neighboring oil palm concessions and degraded areas. Datasets for peat depth, primary forest cover and concessions were accessed from Global Forest Watch. Oil palm plantation concession extent was updated based on Landsat-8 imagery and classified as “Plantation”, “Small-plot agriculture”, “Recently cleared”, “Drained not cleared” or “Concession area not converted”.

TET-1 images were provided by the DLR Institute of Optical Sensor Systems in Berlin. MODIS hotspot data (MCD14) were accessed through the Fire Information for Resource Management System (FIRMS). Detection of large fire events is hindered by a low sensor saturation temperature (Zhukov *et al.,* 2006), and while MODIS has until now offered the highest sensor saturation range, the 1-km pixel resolution limits detection capabilities of small fires and fire dynamics. An initial comparison with the MODIS hotspots product suggests that TET-1 can provide improved detection of small fire fronts through thick smoke and haze (Fig 1). Landsat-7 and -8 images from June-Dec. 2015 were accessed from GloVis and atmospherically corrected.

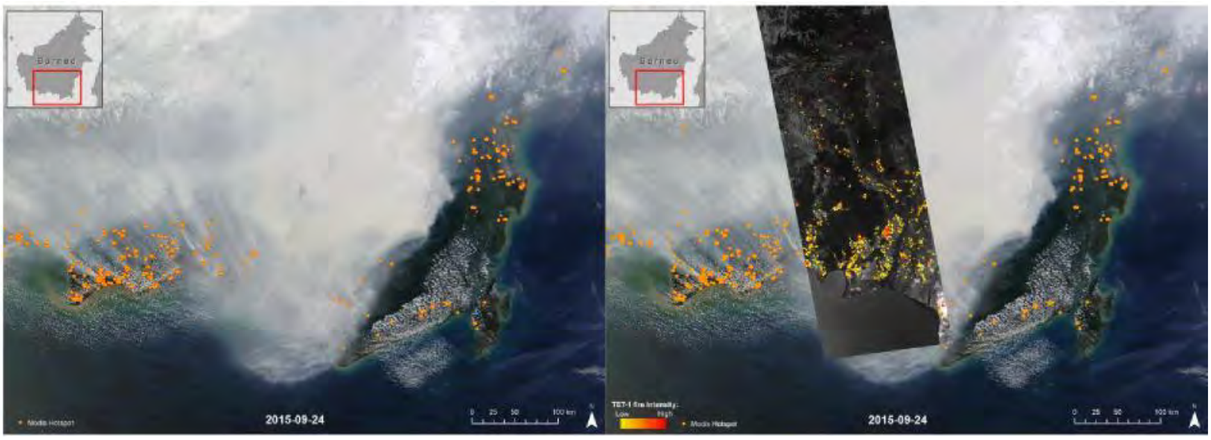


Figure 1: MODIS imagery and hotspot data compared with TET-1 imagery overlay.

MODIS Aqua true color (RGB: 1, 4, 3) images from Sept 24th, superimposed with same day MODIS hotspot data (MCD14, red dots) and TET1 gray-scale midwave infrared (MWIR) acquisition. MODIS hotspot data are under-detecting low intensity fire fronts visible in TET-1 imagery (fire intensity indicated by yellow gradient).

### *Classification of active fires and burned areas*

Hierarchical object-based image analysis (OBIA) is a recently developed technique that evaluates spectral band information combined with spatial context and pattern recognition algorithms. Both TET-1 and Landsat images were classified with eCognition software (Trimble Navigation Ltd.).

### *Comparison TET-1 and MODIS active burning fire detection capabilities*

MODIS hotspot data were controlled for temporally as well as spatially, since TET-1 acquisitions did not consistently cover the study area. *Areas of Interest (AOI) selection and measuring fire dynamics*: Fire AOI‘s were selected dependent upon a series of TET-1 detected active burning fire pixels covering at least three separate dates. For each AOI, fire front propagation speed was measured by comparing the location of a fire front from one date to the next. Area burned within each fire AOI was quantified from the TET-1 and Landsat classification results.

**RESULTS**

*TET-1 comparison with MODIS*: Hotspots data were clearly outperformed by the TET-1 data (Table 1). From Sept. 24th to Oct. 23rd , MODIS detected less than half of that by TET-1 (resp., 109,000 ha and 225, 469 ha) because thick haze hampers the detection of active fires.

Table 1: Comparison MODIS and TET-1 Active Burning Fire Detection Capabilities.

| **Sensor** | **Revisit time (days)** | **Spatial resolution (m)** | **Detected fire pixels** | **Estimated area (ha)** |
|---|---|---|---|---|
| **MODIS hotspots** | 0.5 | 1,000 x 1,000 | 1,090 | 109,000.00 |
| **TET-1** | 2-3 | 160 x 160 | 88,074 | 225,469.44 |

*Fire front analysis and area burned*:

Comparing TET-1 active burning fire pixels over successive dates revealed interesting fire propagation dynamics (Fig 2). Previous fire scars (purplish areas) and changes in logging infrastructure (rails and canals) are evident from the Landsat imagery from 1991 and 2015 (Figure 2a, b). The outer fire front from each TET-1 image is displayed as a colored fire isochrome with the respective image acquisition date indicated (Figure 2b). TET-1 MWIR data from different points within the series are also presented. One can observe fire propagation speed over previous fire scar areas being either greatly slowed (along the northern border) or the fire becoming no longer detectable (along the western and southern borders).

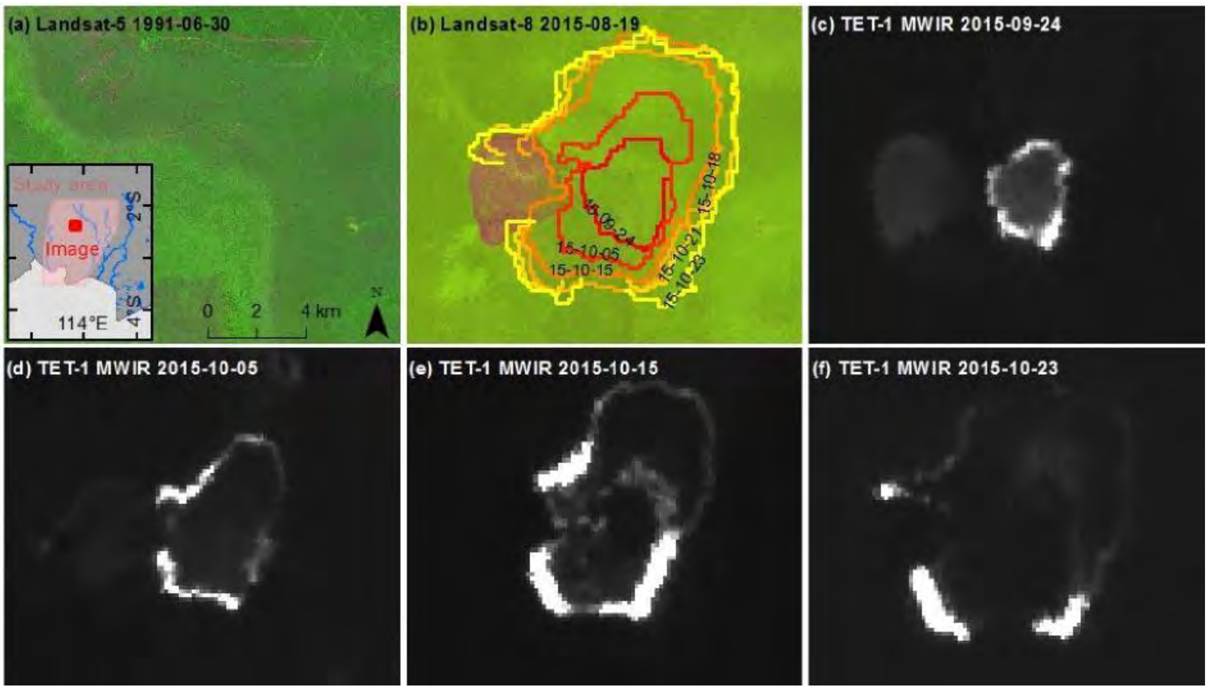


Figure 2: Fire ring front time series.

(a) Landsat-5 imagery (false color: 5, 4, 3) from June 30th, 1991, showing historical logging railway infrastructure and burn scars (purple color).
(b) Landsat-8 imagery (false color: 9, 5, 4) from Aug. 19th, 2015, overlain with TET-1 detected isochromes. Recently burned area prior to fire event is located along the western fire edge. Original TET-1 midwave infrared (MWIR) imagery is shown for Sept. 24th (c), Oct. 5th (d), Oct. 15th (e), and Oct. 23rd, 2015 (f).

*Fire dynamic measurements:*

The most common fire form observed was a long fire line discerned to have started from either a single or multiple points (resp., 6 and 7 AOIs), the other form was a fire ring spreading from a central location (3 AOIs). Highest fire propagation speeds (> 200 m/day) occurred over peat > 2 m deep. Average propagation speed reduced with decreasing peat layer depth. AOIs with the heaviest fire damage (representing burned areas from 9,948-23,367 ha) resulted from fire lines started from multiple sources. *Fire prevalence in relation to different levels of concession usage*: By normalizing by area, we observed that fires occurred most frequently in concession areas that are “Drained not cleared” (13.5%). Fires were found to occur least often in “Small-plot agriculture” (3.2%) and “Plantation” areas (4.1%).

## DISCUSSION

TET-1 detection of burning fire pixels consistently outperformed the MODIS hotspot algorithm (Table 1). While MODIS, with saturation at 500 K and daily global coverage, has been and continues to be a workhorse of global fire detection, the coarse 1-km spatial resolution detracts from the sensor‘s capability to capture fine fire structures (Zhukov *et al.,* 2006). The ability of the TET-1 sensor to measure these dynamics is demonstrated well in Fig 1, where multiple smaller fire fronts were not being detected by the MODIS hotspot algorithm.

Analysis of fire occurrence in different concession usage areas revealed that fires occur most often in plots with installed drainage infrastructure but have not yet been cleared. Since fire is the technique of choice to quickly and cheaply clear slashed areas, the frequent occurrence of fire within the “Drained, not cleared” areas is not surprising. Fires were often first detected in previously burned areas which then spread into surrounding primary forest.

Previous disturbance increases the susceptibility to fire. For instance, many fires have started in logged over areas. Logging creates gaps in the canopy, which dries out the forest microclimate and thus increases the temperature of the peat surface. Whereas drainage causes a decrease in the water table which can result in shrinkage and irreversible drying out of the peat. This study shows that peatland fires in the study area follow drainage, selective logging and old burn scars.

Efficient and effective fire management is difficult on many levels, and a key component for improvement will depend upon the best fire monitoring system possible. Early detection of small fires, before they become fire fronts many kilometers long, will greatly improve firefighting response efficiency. Fig 3 shows how fires first detected in September then, over 2 weeks, spread and connect with one another to form fire fronts over 10 km long. The MODIS hotspot algorithm failed to detect fires over the image extent on both days. The estimated burned area within Fig 3 is 15,992 ha (from Landsat). The most common fire form observed over the study were fire lines, emphasizing how early detection of small fires, before they have the chance to expand, is essential to improving fire management as it is impossible to fight the fires once they have grown to a huge fire front.

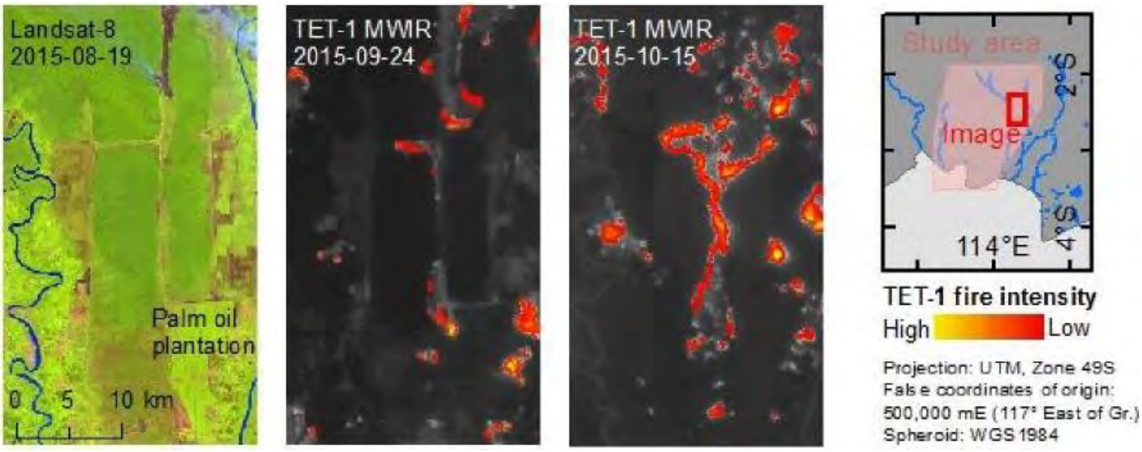


Figure 3: Comparing MODIS and TET-1 fire detection capabilities during rapid fire front expansion over 2 weeks.

Landsat-8 (false color: 6,5,4) image from Aug. 19th, and TET-1 midwave infrared (MWIR) images from Sept. 24th and Oct. 15th, 2015, with TET-1 detected active fire pixels overlaid in red-yellow gradient. Location of image within study area indicated in the inset, no MODIS hotspots were detected within image extent on either day.

## CONCLUSION

This study demonstrates the improved fire detection capabilities of TET-1 compared to existing systems. Given the sensor‘s high saturation (900 K) and finer spatial resolution (160 m), TET-1 fire detection capabilities proved double that of MODIS. The FireBird mission offers an opportunity to build upon existing sensors with a system capable of providing more detailed information on fire occurrence and previously not possible fire dynamic measurements. Monitoring of fire damage extent using sensors working in the VNIR, such as Landsat and Sentinel-2, provide estimates of burned area at even finer spatial resolution (down to 10 m) but are limited by waiting for relatively cloud and haze free images (Hoscilo *et al.,* 2011). Early fire detection through smoke and haze provides valuable information for fire control management, and the financial as well as social costs incurred by the fall 2015 fires present clear motives for improving current fire control management strategies.

Fire dynamic measurements revealed that fires tended to spread most quickly over peat > 2m deep. Fire front lines many kilometers long were the most common form observed. We found that fires occurred with the highest frequency in concession areas containing drainage infrastructure but had not been cleared prior to the fire event. Fires were observed to often begin in areas previous burned and then spread into neighboring primary forest.

TET-1 will be joined this year by BIROS, expanding the FireBird constellation and thus reducing time between acquisition dates. Expansion of the FireBird fleet is in discussion, which would enable near real-time fire detection and support improved organization of firefighting activity by enabling efforts to be focused on fires while they are still small and easily contained. We have here demonstrated not only how a FireBird sensor can improve hereto existing monitoring systems, but also how detected fire dynamic data can be used to help design measures to reduce risk of fire. This information will be useful for government agencies, fire managers and monitoring groups concerned with preventing such catastrophes in the future.

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