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Identifying burnt areas and flood monitoring based on multi-spectral passive and microwave active remote sensing in tropical peatlands.

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Introduction 1

Destabilisation of hydrological conditions and associated fire occurrence are the most significant barriers hindering degraded tropical peatland revegetation. For this reason, the monitoring of fires and hydrological conditions is crucial for guiding drained tropical peatland restoration. One of the best tools for large-scale monitoring of the natural environment, especially when access and in situ information are limited, is satellite remote sensing, and fusion of active and passive remote sensing data can provide new insights into dynamic systems such as peatlands. There is usually a relationship between automation, complexity and processing time leading to variations in the method's effectiveness, including reliability and accuracy.

Main goal: to develop a rapid method for ease of use by non-specialist users, which has capability to deliver reliable results describing the mapping of the burnt and flooded areas.

The specific objectives:

1) to present a method for identifying burnt areas based on multi-spectral passive remote sensing data
2) to present a method for flood mapping areas based on active radar remote sensing data
3) to present a combined method for burnt areas identification and flood mapping based on integrating passive and active temporal data series

Study area & datasets 2

Two types of data, from multi-spectral passive (Sentinel-2, Landsat-8) and microwave active (Sentinel-1) remote sensing sensors, were combined to monitor fires and floods in a 5,000 km² area of tropical peatland of varying land use and level of degradation in Central Kalimantan (Fig 1). Fifteen test sites were chosen to demonstrate the results (Tab 1). All processing has been done using Google Earth Engine (GEE), allowing convenient access to its data and processing functionality in the cloud.

Table 1. List of test sites

Test site	Land cover / Land cover (from MENLHK)
A	dryland agriculture
B	dryland agriculture
C	bareland
D	bareland
E	swamp/wetland
F	swamp/wetland
G	water body
H	swamp shrubland
I	swamp/wetland
J	swamp/wetland
K	swamp/wetland
L	swamp shrubland
M	swamp shrubland
N	swamp shrubland
O	swamp shrubland

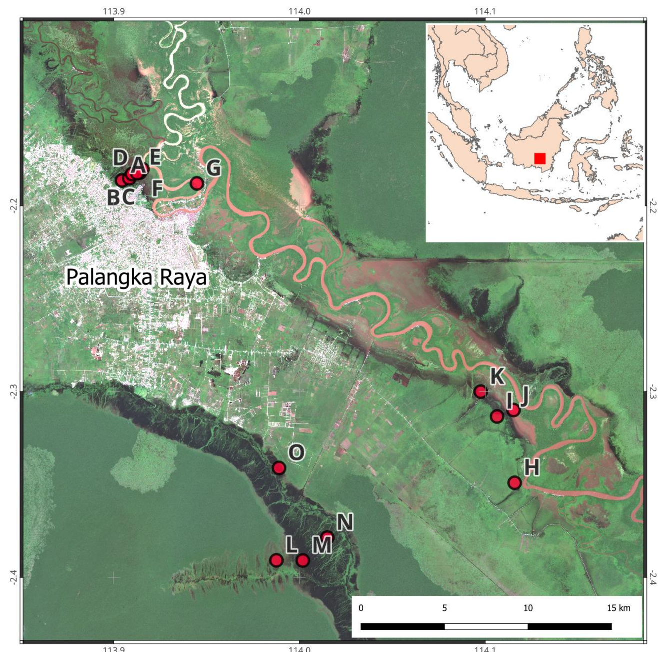

Fig 1. Location of the study area with test sites (A-O).

Methods 3

Identifying burnt areas based on multi-spectral passive remote sensing data

Burnt areas were mapped through the Normalised Burn Ratio (NBR) vegetation index. The NBR combines near-infrared (NIR) and shortwave infrared (SWIR) wavelengths and is designed to highlight burnt areas.

$$NBR = \frac{NIR - SWIR}{NIR + SWIR}$$

The difference between NBR called differenced Normalised Burn Ratio (dNBR), obtained from two images, can be used to estimate the burn severity. A higher value of dNBR indicates more severe damage, while areas with negative dNBR values may indicate regrowth following a fire. Burn severity levels obtained calculating dNBR, proposed by USGS and used in this work, are shown in a table (Tab 2).

Table 2. Burn severity levels and related dNBR ranges.

Severity level	dNBR range
Enhanced Regrowth, high (post-fire)	<-500, -249>
Enhanced Regrowth, low (post-fire)	<-250, -101>
Unburned	<-100, 99>
Low severity	<100, 269>
Moderate-low Severity	<270, 439>
Moderate-high Severity	<440, 659>
High severity	<660, 1300>

Burned area maps were generated for each pair of two consecutive images in time series using the workflow shown in Fig (2). When one image in a pair has been masked due to clouds, the image following the masked one was considered.

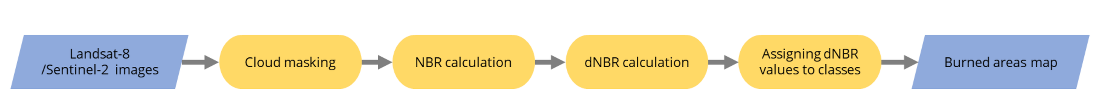

Fig 2. Flowchart of generating burnt areas map based on Sentinel-2 and Landsat 8.

Flood mapping based on active radar remote sensing data

A change detection approach with a simple and common thresholding method was chosen for flood mapping. SAR backscattering coefficient (SN) can identify permanent and ephemeral water bodies. Calm water surfaces appear smooth and cause specular reflection leading to low backscatter, while the surrounding land surface appears much rougher causing higher backscatter. Potentially flooded area maps were generated for each image in relation to the reference image using the workflow shown in Fig (3). The reference image was calculated as a percentile of 85% based on all images in the studied period and was used to generate a map of permanent water bodies. A detected reduction of backscatter calculated for each image by more than 35% was classified as a potentially flooded area.

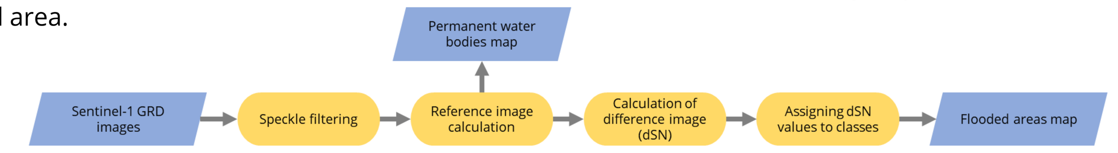

Fig 3. Flowchart of generating flooded areas and permanent water bodies map based on Sentinel-1.

A combined method for burnt areas identification and flood mapping based on integrating passive and active temporal data series

The combined method assumes the use of products from the methods discussed above and the temporal behaviour of the NBR and SN values in the nearest time range (at least two months).

- If a high dNBR index is preceded by temporary flooding, then the area initially assigned to the burnt area class is masked.
- If a decrease in the NBR value confirms the sudden drop in the SN value, the area is classified as burnt.
- High dNBR in permanent water bodies is not classified as a burnt area.

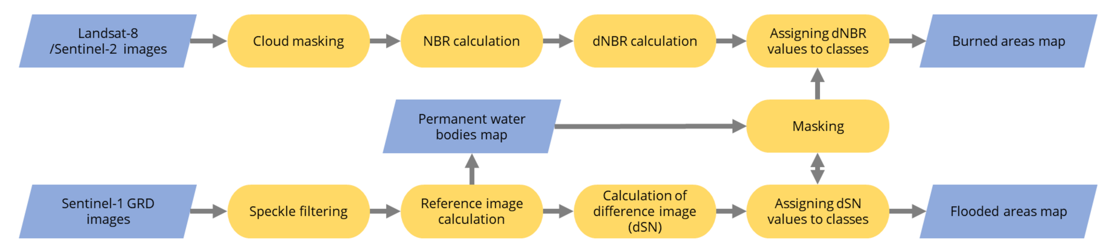

Fig 4. Flowchart for burnt areas identification and flood mapping based on integrating passive and active temporal data series.

Results 4

Identifying burnt areas based on multi-spectral passive remote sensing data

The results are maps of burnt areas for each year's fire season from 2015 to 2022. The main obstacle is frequent cloud cover affecting optical images. And thus, fire detection and monitoring of fire duration are limited. In addition, a flooded area was misclassified as a burnt area due to its high decrease in NBR value (Fig. 5 test site E). Other incorrectly assigned areas as burnt based on dNBR were observed when sandbank disclosure (Fig. 5 test site G).

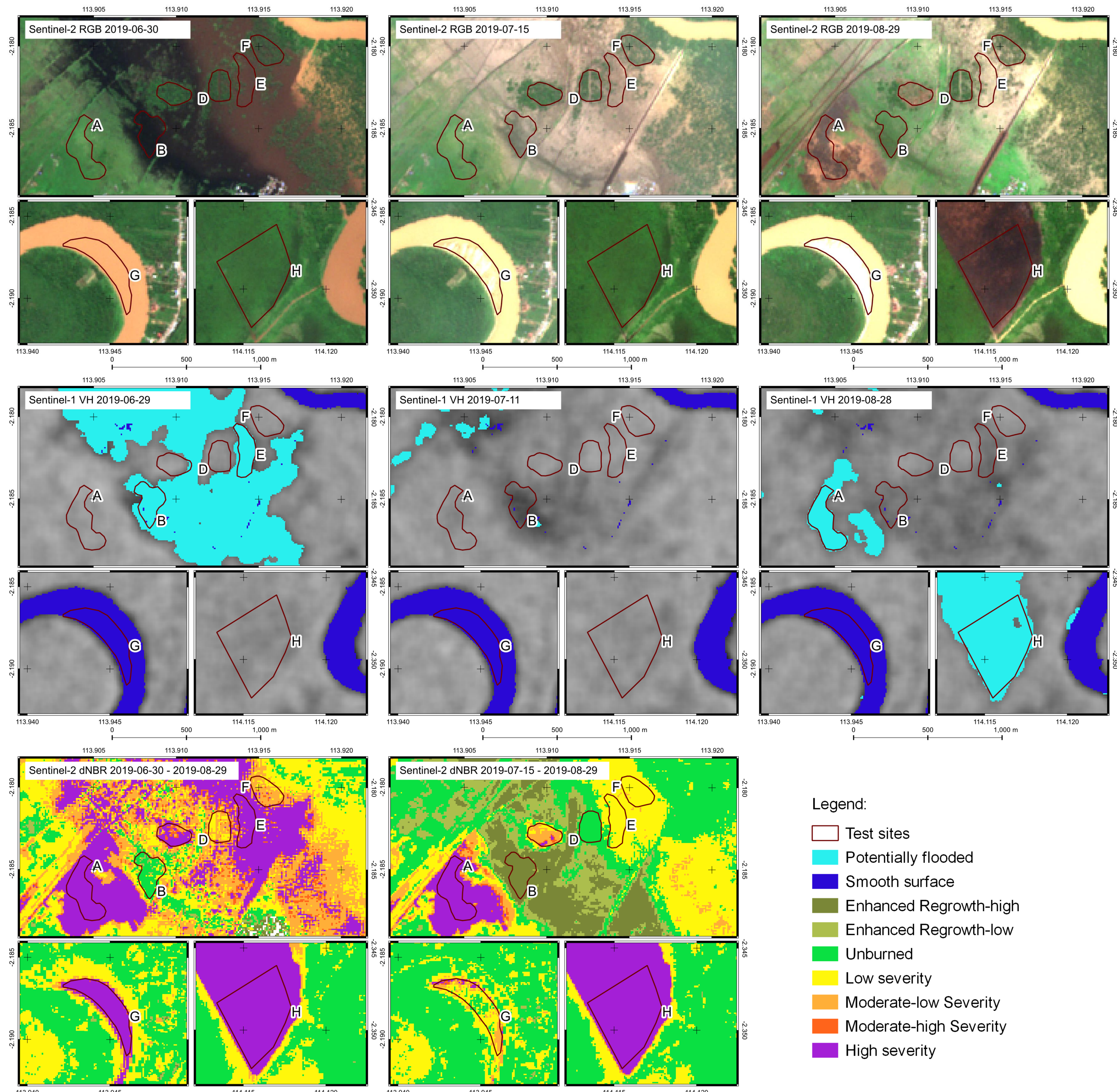

Fig.5. 1) three consecutive RGB compositions of Sentinel-2 in the summer season of 2019 with plotted test sites (upper row); the first image shows End-June conditions with ongoing seasonal flooding, the second image shows Mid-July conditions of no flooding and no fires, the third image shows End-August conditions of no flooding but after fires 2) three consecutive images of the backscattering coefficient of Sentinel-1 corresponding to the acquisition dates of Sentinel-2 overlaid by flood mapping results (middle row); 3) dNBR maps calculated for image pairs End-June 2019 - End-August 2019, Mid-July 2019 - End-August 2019 (bottom row).

Flood mapping based on active radar remote sensing data

The results are a series of maps for each year from 2015 to 2022 showing the extent of ephemeral open surface water covering the ground totally, extracted from the backscattering coefficient registered at VH polarisation. A strong backscatter decrease was found not only for the flooded area, but also for the burnt area (Fig 5. test site A and H).

An additional product is a map showing smooth surfaces, which allows the identification of permanent waters. However, a few types of objects, like calm water surfaces, sandy areas, and airport runways, are characterised similarly by the lowest backscattering coefficient. Therefore, using radar data as the only source may lead to misclassification.

Results examples of identifying burnt areas based on Sentinel-2 and flood mapping based on Sentinel-1 in the summer season of 2019 are shown in Fig 5. A summary of the classification results for the individual test areas can be found in table 3

Table 3. A summary of the classification results for the individual test areas

Test site	End-June conditions with ongoing seasonal flooding	Mid-July conditions of no flooding and no fires	End-August conditions of no flooding but after fires	dNBR between the end-June and the end-August	dNBR between the end-June and the end-August	Correctness of classification
A, H	No flood	No flood	Flood	High severity	High severity	Burnt area classified as flood
B	Flood	No flood	No flood	unburned	Enhanced regrowth-high	correct
C	No flood	No flood	No flood	High severity	Moderate low-severity	correct
D	No flood	No flood	No flood	Low severity	Unburned	correct
E	Flood	No flood	No flood	High severity	Low severity	Flood classified as burnt area
F	No flood	No flood	No flood	Moderate-low severity	Low severity	correct
G	Smooth surface	Smooth surface	Smooth surface	High severity	Low severity	Sandbank classified as burnt area

A combined method for burnt areas identification and flood mapping based on integrating passive and active temporal data series

After detecting errors related to misclassification, a time series analysis was performed for the test sites in order to find the relationship between the NBR and backscattering values and thus to develop a combined method that guarantees higher accuracy of fire and flood mapping (Fig 6).

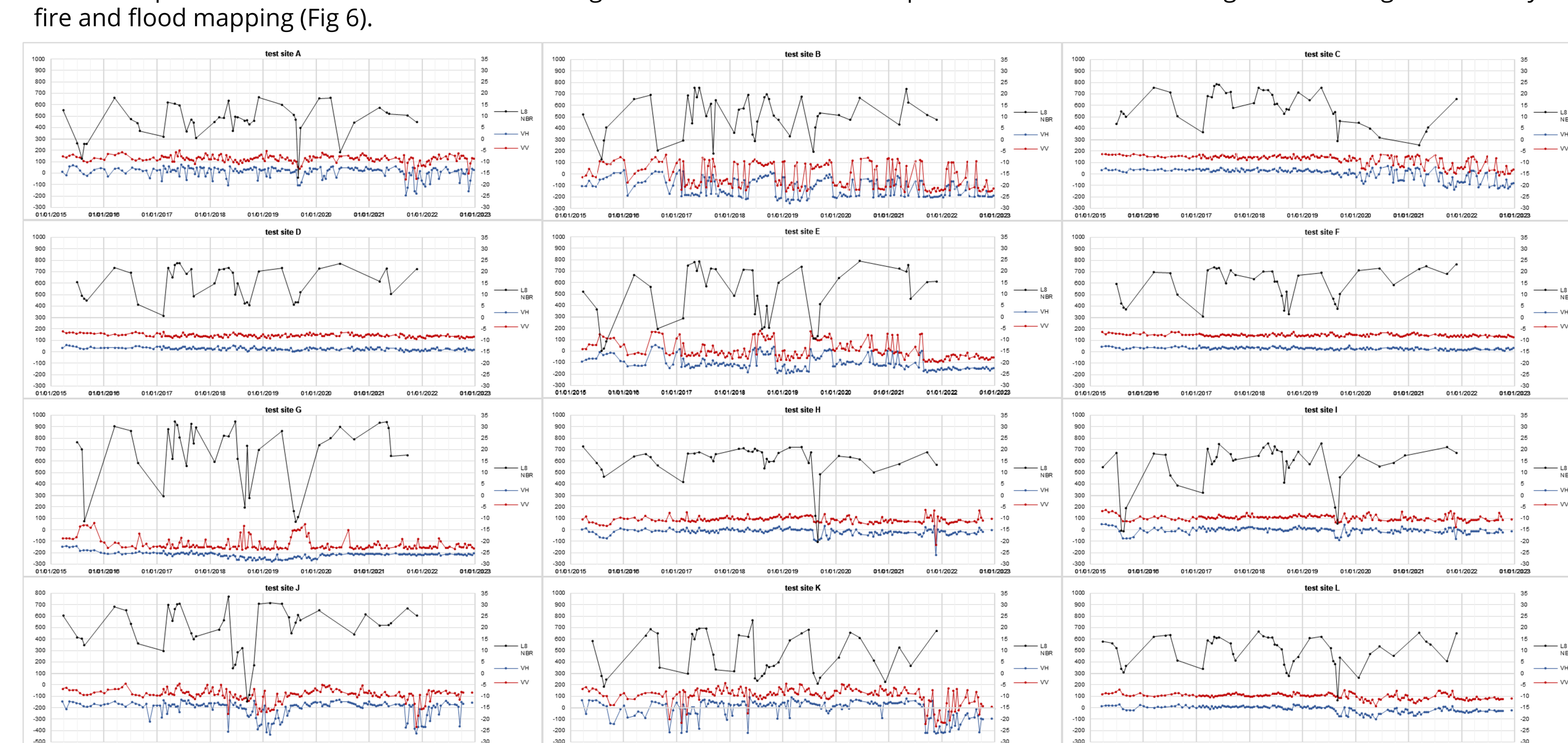

Fig 6. Temporal changes of NBR calculated based on Landsat-8, and VV and VH backscattering coefficients calculated from Sentinel-1 images for test sites

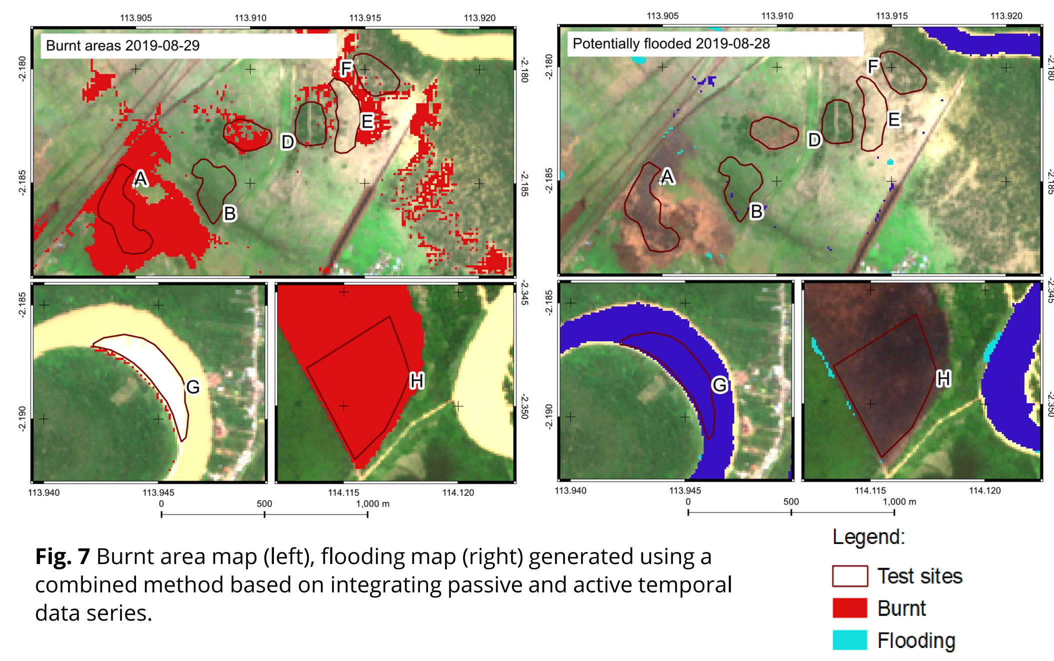

Fig. 7 Burnt area map (left), flooding map (right) generated using a combined method based on integrating passive and active temporal data series.

The results of identifying burnt areas and flood monitoring based on multi-spectral passive and microwave active remote sensing in tropical peatlands are presented in Fig 7.

Test sites previously incorrectly classified were corrected.

There are still errors in the classification of burnt areas due to the ability to detect flooded areas being limited to only open water, not vegetated areas. However, the accuracy of the burnt regions and flooding was improved.

Conclusions 5

A rapid method for ease of use by non-specialist users, which has capability to deliver reliable results describing the mapping of the burnt and flooded areas has been developed.

Using the presented methods was effective for detecting burnt areas and water bodies, but there were limitations to the passive sensors' image availability due to cloud cover.

Using dNBR and backscattering coefficient separately in some cases caused false positive results (e.g. burnt areas classified as water bodies, or burnt areas detected in the main river bed).

The fusion of two data sources increased fire and flood mapping accuracy by eliminating misclassification errors, compared to using them separately, thus indicating their strong complementarity.

Acknowledgements 6

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Contains modified Copernicus Sentinel data [2015-2022], and Landsat 8 data [2015-2022]