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QUANTIFICATION AND CHARACTERIZATION OF PEAT FIRES AND RELATED FIRE-EMISSION FACTORS FROM TROPICAL PEATLANDS

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SUMMARY

Peatland fires are a major contributor to Indonesia‘s greenhouse gas emissions in recent decades, particularly in previously drained and burnt areas during El Niño events, as witnessed in 2015. Despite the estimated magnitude of these emissions, peat and peatland fires still lack verified field data, methods and models. Peat fire emissions are still not fully incorporated within the Indonesian National Carbon Accounting System (INCAS) as part of its carbon Monitoring, Reporting and Verification (MRV). This NASA-funded joint Indonesia and USA project is based in the Ex-Mega-Rice Project, within the BOS-Mawas Area in Central Kalimantan. It builds upon the extensive investments and research of the previous Kalimantan Forests and Climate Partnership (KFCP) REDD+ demonstration project. The current project is developing the necessary fire emissions factors and expertise to implement operational annual peatland fire emission quantification capabilities to complement the existing peat decomposition-related emissions monitoring capacity for the area. The project has developed improved fire evaluation methods and information, and ground-to-remote calibrations for detecting fires, determining what can burn, mapping burned areas, quantifying relevant emission factors and estimating the volume and mass of consumed biomass. The project will through field data collection integrate fire-related human actions with fire scene analyses to ascertain when, where, how, and under what surface fuel load conditions are likely for initiating peat fires. The project is working directly with villages, district, provincial and national governments, Central Kalimantan‘s Environmental Agency and INCAS to ensure the methods, data and applications of the analyzed results are quickly and appropriately integrated into carbon models and fire management activities in Indonesia.

Keywords: *Peat fires, peat emission factors, tropical peat land, MRV, peat fire evaluation*

INTRODUCTION

Peatland fires are a major contributor to Indonesia‘s greenhouse gas (GHG) emissions, particularly in drained areas, and in first and second burn areas during El Niño–Southern Oscillation ENSO events. Despite the volume of these GHG emissions, peatland fires emission factor are not currently incorporated accurately within the Indonesian National Carbon Accounting System (INCAS), implemented by the Indonesian Government‘s carbon Monitoring, Reporting and Verification (MRV).

This NASA-funded project is a partnership between Bogor Agriculture University or *Institut Pertanian* Bogor and South Dakota State University, with a number of Indonesian collaborating institutions and builds upon extensive investments in peat and fire research, since 2009, developing technical capacity, data collection, and site infrastructure development, completed as part of the Kalimantan Forests and Climate Partnership (KFCP) REDD+ demonstration project, which concluded in June 2014. The NASA project is conducting the necessary fire research and expertise to implement operational annual peatland fire emission quantification capabilities within INCAS to complement the existing decomposition-related emissions monitoring capacity for the BOS-Mawas Area in Kapuas District in Central Kalimantan, Indonesia.

Quantification of the amounts of GHGs, aerosols and smoke particulates emitted in peat fires are critical elements for properly assessing their global climate effects and impacts upon local health. However, the IPCC GHG accounting guidelines (IPCC 2006; 2014) provide very little guidance for estimating such emissions from peat fires. Few studies have quantified the chemistry and climate relevant emissions from burning tropical peat and, have all been conducted in laboratory settings. In undisturbed tropical peat forests, peat carbon stocks are relatively stable, protected by anaerobic conditions underground. However, disturbance, especially drainage, even in the absence of fire, leads peat soils to suffer from compaction and aerobic conditions, allowing bacterial decomposition that emits an estimated 86 Mg/ha/yr of CO_2 (Hooijer *et al.,* 2009); or roughly 26 Mg/ha/yr of soil carbon. Although episodic, and varying in area each year (Ballhorn *et al*., 2009), peat fires are estimated to oxidise between 100 and 600 Mg ha^{-1} of carbon from peatlands (Konecny *et al.,* 2016). Monitoring fires that penetrate into the peat is of particular interest and difficult because of the quantity and form of emissions that result from these burns, yielding disproportionate impacts on human health and global climate. The purpose of this paper is to provide an overview of the project and present some initial outputs although, detailed results and subsequent discussions are not presented.

OBJECTIVES

Peat fires require sustained high temperatures and fuel moisture levels below 130% at the fire front (Usup *et al.,* 2004) to be maintained. Factors controlling peat burning are the moisture level, mineral content of the fuels, organic composition, bulk density, flow permeability, and the presence of sufficient cracks or channels for sufficient oxygen flow. While the basic characteristics and processes of peat fires and emissions have been documented, much of the human influences and quantification of emissions are still to be determined.

The Project which spans three years from 2013 to the end of 2016 is located in the BOSF–Mawas Area in Kapuas District, Central Kalimantan, Indonesia and has the following objectives:

- To work with trained field teams to regularly monitor the vegetation, fuel loads and hydrology and to also investigate actual fires by recording biophysical characteristics and social aspects of surface and peat fires supported by remotely sensed data, to provide essential details that could indicate what relevance, if any, they had for explaining the ignition of episodic deep-peat fires.
- Investigate and document causal connections between biophysical and social elements of the fire dynamic and the chains of bio-physical events leading to deep-peat fires.
- To quantify the chemistry and climate-relevant emissions from burning peat and develop fire emission factors for the various vegetation types on peatlands using in-situ whole air sampling and filter collections. These will be used to support laboratory analyses of smoldering peat and burning vegetation that have quantified CO_2, CH_4, and many other important gases.
- To determine fuel loads for the various peatland vegetation types, changes in land cover and number of surface fires based on burn scar maps using Landsat Imagery from 1990-2015.
- To develop models that will provide estimates of the changes in peat elevation and volume in degraded peatlands using field based plot measurements, along with Landsat Imagery and LIDAR to determine changes in peat elevation (building on methods and measurements developed during the KFCP Project) along with ground water hydrology.
- To socialize the results and to provide outreach material for stakeholders, including establishment of appropriate links to INCAS for integration of project findings into Indonesia‘s MRV process.
- To strengthen Indonesian ability to accurately estimate GHG emissions from peatlands as a significant factor in Indonesia‘s overall emissions from the forests and land sectors.

METHODOLOGY

Vegetation Monitoring

This work is designed to facilitate estimation and description of biomass, forest structure, composition, type of vegetation and rates of regeneration, by monitoring a series of Forest Monitoring Plots (FMP) established by KFCP in 2009 across a range of locations in the study site (Graham *et al*., 2014a). There are eight locations representative of the range of forest types spread throughout the study site, with five locations associated with a canal and three locations in relatively undisturbed, closed-forest, both logged and unlogged. Each location contains three rows of plots perpendicular to the canal and parallel to the hydrology transects. Along each row, four plots were established, at 50 m, 100 m, 400 m and 700 m from the canal, making a total of 96 plots. The plots in each location comprise a set of ‗nested quadrats of different sizes to facilitate the monitoring of seedlings, saplings, poles and trees. There are also heavy fuel load (Graham *et al.,* 2014b), hydrology and peat depth data for each location.

Hydrology Monitoring

The hydrology monitoring follows the methodology and protocols developed in KFCP (Ichsan *et al.,* 2014) and focuses on the 60 km of transects and the monitoring of over 300 dipwells (on the peat dome) and 31 staff gauges located in the canals and rivers where they intersect with the transects. The transects are monitored twice per year; at the peak of the dry season when water levels are lowest and at the peak of the wet season when water levels are highest. Monitoring is concentrated on transects in the highly degraded part of the peat dome (Block A) and around the large east-west canal (SP1 canal). Subsidence data, is not monitored as there is already an extensive set of analysed subsidence data from KFCP.

Fire Monitoring

The Fire Scene Evaluation Form (FSE) and accompanying Manual, is a scientific field-practice that has been developed for the Project by experienced fire and social scientists to ensure consistency and accuracy. The Form and its 79 questions and measurements involves the recording of biophysical data (including field weather and environmental conditions, measurements of basic fire characteristics, area burnt, fuel and peat characteristics with a focus on peat fires) and social data (land tenure and related governance, human actions and causal mechanisms of fire ignitions). When coupled with landscape scale GIS data and more detailed human actions data, this information then enables evaluators to create models of area-specific peatland and peat fire dynamics, and related carbon emissions. The Form is designed to be completed by those with competent field skills to undertake a replicable evaluation of different fires and locations. In some instances, the evaluators need to make some decisions, judgements and interpret the environmental conditions.

In order to obtain accurate and consistent results, a Manual has been developed which provides the necessary methodologies and descriptions to undertake the FSE. In some cases where questions are not ‗quantifiable', possible answers are provided in the form of photos or illustrations. Since the field conditions during or after the fires are not always easy to characterise, the Form is designed with a ‗Confident, Quite Confident, Some Confidence' rating that the evaluators can use to enable all questions to be answered with a proviso from the evaluators that some questions can only be answered based on a ‗best guess' rather than certain data. Furthermore, many questions are accompanied with a request for a photograph (the photo code written on the form) so that those with more experience can later cross-reference visual evidence and answers on the Form.

Human Actions

This activity was designed to utilise interdisciplinary research techniques involving both the biophysical and social science disciplines to better understand the causal connections between human actions and biophysical characteristics of surface fires which transitions from surface to peat fires in tropical peatlands. The methodology involves village interviews and obtaining observational data to identify causal linkages between anthropogenic ignitions and the establishment of peat fires. In contrast to other interdisciplinary wildfire research projects (Vayda 2013), the social data obtained has been designed to be specific enough to be combined with bio-physical evidence from fire scenes for descriptions of when, where, how, and under what conditions fires have occurred and, critically, whether or not they have ignited large fuels like logs and stumps or light fuels such as ferns. From these descriptions, conclusions will be drawn about the likelihood of different fires or types of fires causing subsequent peat fires.

A Project database is being developed (SDSU-IPB Peat Fire Database) in Access, building upon the KFCP vegetation database. The database holds the hydrology, vegetation, FSE, fuel and social data. All data locations are uniquely coded, with GPS data recorded, so that spatial cross-analysis across the data subsets is possible, allowing for landscape, interdisciplinary results and models.

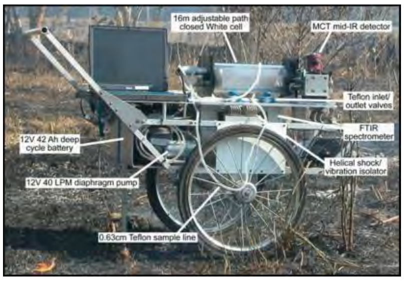

Figure 1: UM off-road FTIR, flask, filter lab.

Quantification of Emissions from Peat and Peat Swamp Forest Fires

A battery-powered, off-road Fourier Transform Infrared Spectrometer (FTIR) and Whole Air Sampling (WAS) system with an on-board filter collection laboratory was used along with two photoacoustic extinction meters (at 405 and 870 nm) in the 2015 fire season for field measurements of the trace gas and aerosol emissions from smouldering peat (Figure 1; Akagi *et al.,* 2013). The instrument suite can accurately measure and analyse ~90 gas species and aerosol mass, chemistry, and optical properties. Many of the dominant emissions are reactive species that could only be measured accurately in-situ by the FTIR. These field samples will allow comprehensive field/laboratory comparisons and the development of reliable algorithms to derive quantitative estimates for real fires of the numerous chemical species that are currently only measureable in the laboratory. Based on these results, comprehensive field-derived emission factors for peat burning under ambient conditions will be determined. This will better constrain the quantity of carbon emissions by chemical species, allowing better estimates of the global warming potential (GWP), health effects and atmospheric chemistry and climate impacts.

Notably, the filter collection and PAX systems allow the determination of emission factors (g/kg fuel burned) for concomitant scattering/cooling aerosols at the same time as the warming greenhouse gases. Among the gases measured in the laboratory and field were many precursors for secondary formation of more scattering aerosols and ozone, which is another powerful GHG formed in smoke plumes after emission. A key product of this research will be the comprehensive emission factors that will be calculated for surface and subsurface peat burning to specify the amount of compound per kg peat burned (dry mass basis) for all the chemical compounds measured using the carbon mass balance method.

Peat Fire Research & Modelling Annual Emissions

Quantifying peat-fire carbon emissions is challenging due to their location, depth of burning and rate of spread which results from the interplay with climate, weather, land use (human actions), land cover, drainage, disturbance history, fire type, peat depth and composition. Hence, the answer lies in determining the surface area burned, available fuel fraction at a given location through time and the amount of fuel consumed per unit area. Peatlands are extensive, remote, and are difficult landscapes to navigate, so remotely sensed data is used for modelling regional fire dynamic in the project area and annual emissions. Modelling of annual emissions will be based on a probabilistic model based upon satellites, existing Landsat-based annual land use and fire history data sets from 1990-2010 (Ballhorn *et al.,* 2009), fire history data from 2010-2016 and on peat fire measurements for MC%, rate of spread and volume of peat consumed (Graham *et al.,* 2016).

Tropical Rainfall Measuring Mission (TRMM) data has been found to be highly accurate for drought detection in Indonesian lowlands (Vernimmen *et al.,* 2011). Although the scale of the data do not allow for detailed rainfall measurements within project area, the data provide excellent coverage and estimation of precipitation across the entire basin, thereby driving the depth of the water table that largely controls peat flammability. TRMM data will be used to calibrate the hydrological field data and monitor peat flammability.

The MODIS active fire product is a useful tool for monitoring fire, but there are additional challenges for detection of fires in tropical regions that result from gaps in orbital overpasses in equatorial regions, low intensity nature of many surface and peat fires, and general masking issues related to clouds and smoke (Cochrane 2013). The Terra morning overpass MODIS satellite will mainly be used for monitoring fires but will also use the proximity and persistence of fire detections on the ground to parameterize the vulnerability of mapped surface fires to potential peat fires burning into the ground surface.

Land cover change and burn scar mapping with Landsat has long been used for land cover change mapping. Spectral Mixture Analyses (SMA) techniques using Landsat imagery have been shown capable of mapping understory fires in tropical closed canopy forests (Cochrane and Souza 1998). The project will use similar techniques to develop the land cover and fire scar mapping through to 2016.

In parts of the project area, a limited Lidar dataset was collected in 2007 along several transects using a small footprint (0.25m) pulse system and used to provide an initial estimation of burn depths (average 0.33 +/- 0.18 m) within the peatlands (Ballhorn *et al.,* 2009). A second full waveform, dataset for the same areas was collected in the 2011 season by KFCP and a third Lidar data collection was undertaken in 2014 by the Project on the same transects as used previously, greatly facilitating comparability within the dataset. Changes to the elevation of the peat and volumes from differential Lidar data will be estimated using these data sets.

Data from current Peat Moisture Content determined at the peat fire front undertaken in the Project along with water table depths, will be used to determine when peat fire ignitions are likely to occur. Peat-fire spread will be modelled using current measurements being undertaken by the project (Graham *et al.,* 2016), with rate of spread of deep peat fires based on results by Usup *et al.* (2004) and Graham *et al.* (2016). Hence using field based plot measurements, along with Landsat Imagery and LIDAR changes in peat elevation and volume along with ground water hydrology will be used in the model (based also on methods and measurements developed within the BOSF-Mawas Area (Ballhorn *et al.,* 2009).

Improved emissions estimates will be made based on comprehensive emission factors derived from integration of field and laboratory based emissions analyses. Once validated, the ignition/spread/emissions model will be used to provide annual emissions estimates for the 1997-2016 time periods.

Strengthening Capacity, Socialisation and Integration into Indonesia's MRV

The Project involves many scientists from Indonesia to promote capacity building, training, sharing data for INCAS and to facilitate collaboration with other Indonesian institutions. The Project plans to present methods and initial results at two Workshops each year; one in the District and another in the Provincial capital. The Workshops provide the opportunity for presentations by the Project as well as researchers undertaking studies in similar topics. In association with the Workshops, the project has held ‗hands on" field days, for water table depth determination, peat sampling, vegetation monitoring. These have been well attended with positive feedback.

In 2012, the Indonesian National Carbon Accounting System (INCAS) implemented the Indonesian Carbon Accounting and Reporting Model (ICARM) for Kalimantan. As the initial estimates of GHGs modelled for peatlands was limited, the project collaborated with INCAS to develop recording system to incorporate fire-related carbon emissions based upon the project's modelled and validated peat consumption amounts and the field and laboratory verified emission factors for in-situ peat combustion. To ensure this will be possible, the output formats have been designed in association with INCAS staff so data produced by the Project can be readily used by INCAS for its peat fire emissions estimates.

CONCLUSION

The Project is in its third year, and has been able to monitor three fire seasons, the last one in 2015, being the longest and driest during the period of the Project. In addition, the 96 vegetation plots were able to be remeasured and water table and ground water measured across the area in the middle of each dry and wet season for the past three years. In 2015, the battery-powered, off-road Fourier Transform Infrared Spectrometer (FTIR) for sampling gasses from peat fires along with a Whole Air Sampling (WAS) system, filters and PAX for particulate was deployed with results to be published in mid-2016 and presented at the mid-year Workshop. The emission modelling is on-going and the human actions component has completed the field based interviews with results being available in mid-2016. It is anticipated that the 2016 fire season will also be monitored using the FSE Forms and a pre fire season workshop held in the District in mid-2016.

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