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SURFACE-ATMOSPHERE EXCHANGE IN TROPICAL PEAT FORESTS *VERSUS* OTHER TROPICAL FORESTS: A FLUXNET SYNTHESIS

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SUMMARY

Tropical peat forests are largely found in Southeast Asia and - like tropical forests globally - are subject to multiple threats including deforestation and hydrologic disturbances. How might these changes impact the globally important exchanges of carbon, water, and energy between the land surface and the atmosphere? A comparative study of tropical peat forests *versus* other tropical forests has not been undertaken to date. Here, I conduct a synthesis of surface-atmosphere exchange observations from tropical forests in the FLUXNET database. Available observations – of which there are few – indicate that tropical forests are usually carbon sinks, but tropical peat forests tend to be carbon sources. This discrepancy can be explained by differences in ecosystem respiration (carbon loss) rather than gross primary productivity (carbon uptake). Tropical peat forests have higher gross primary productivity than most other tropical forests measured to date, but ecosystem respiration is among the highest of any global ecosystem. The causes for this discrepancy are unclear. Tropical peat forests must have been long-term carbon sinks to accumulate carbon in peat, yet this peat is also likely the source of carbon losses to the atmosphere. Observations of carbon losses from tropical peat forests are often attributed to hydrological disturbances, but it is unclear how widespread this phenomenon is and if even relatively undisturbed tropical peat forests are now carbon sources. Tropical peat forests also differ from most other tropical forests in the surface-atmosphere exchange of water and energy. For example, the ratio of sensible to latent heat flux (the Bowen ratio) tends to increase as a function of net radiation in tropical forests, but the response of the Bowen ratio to net radiation in tropical peat forests is more muted. Such responses of ecosystem water and energy flux to available energy have implications for convective precipitation dynamics and ecosystem hydrology. By placing tropical peat forests in the context of other tropical forests, we can gain a richer understanding of their unique function and gain a stronger appreciation of their role in providing critical ecosystem services.

Keywords:-

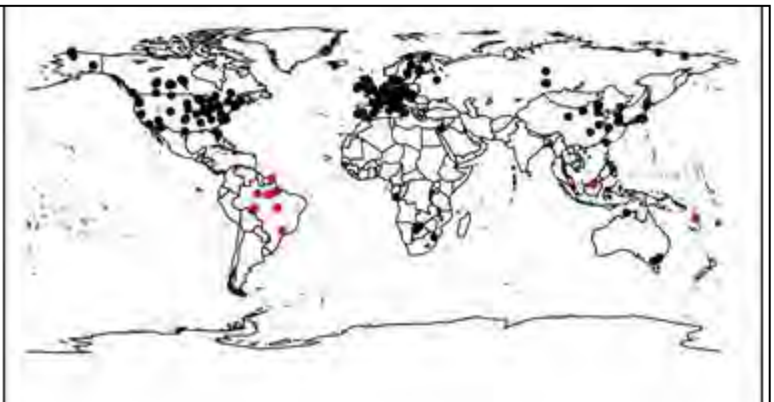

Figure 1: A global map of eddy covariance towers in the LaThuille FLUXNET database with tropical forest ecosystems in red.

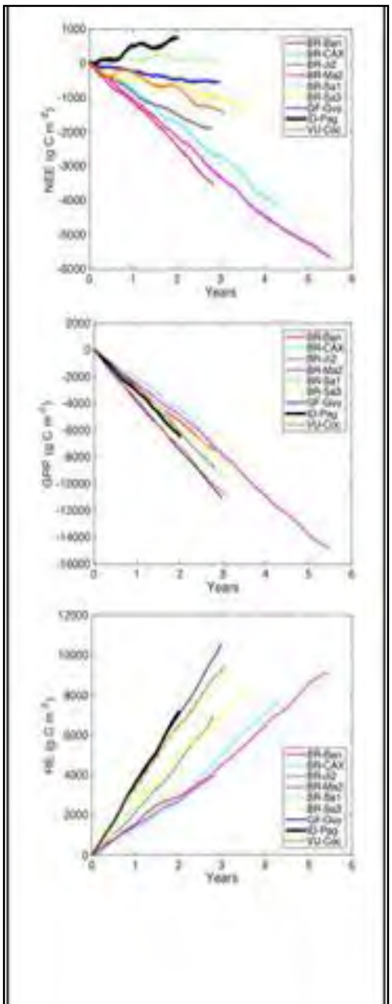

Figure 2: The cumulative sum net ecosystem exchange of CO2 (NEE, top), gross ecosystem productivity (GPP, middle), and ecosystem respiration (RE, bottom) across different tropical ecosystems of differing measurement length.

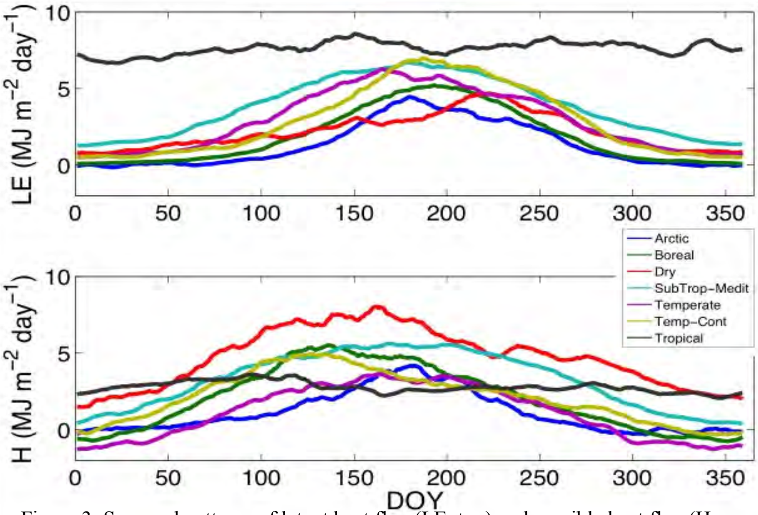

Figure 3: Seasonal patterns of latent heat flux (LE, top) and sensible heat flux (H, bottom) from different climate zones from eddy covariance observations in the LaThuille FLUXNET database. The day of year (DOY) was adjusted by half a year for ecosystems in the Southern Hemisphere to match their Northern Hemisphere counterparts.

RESEARCH RESULTS

Eddy covariance observations in the LaThuille FLUXNET datasbase (Figure 1) are publically open for analyses, but only contain ten tropical forest sites of which only one, Palangkaraya in Indonesia (ID-Pag), is a tropical peat forest (Hirano *et al*., 2012). This limits our ability to compare tropical forest and tropical peat forest ecosystems against other global ecosystems, but important insights can still be gained.

First and foremost, ID-Pag is the only tropical forest in the FLUXNET database with positive net ecosystem exchange of CO2 NEE, indicating a net carbon loss to the atmosphere (Figure 2). The reason for this difference is that the rate of ecosystem respiration (RE) is highest at ID-Pag (alongside a tropical rainforest in Guyana, Gf-Guy), but carbon uptake via gross ecosystem productivity (GPP) at ID-Pag is similar to the mean GPP of other ecosystems. In other words, GPP rates that are characteristic of other tropical forests and RE rates that are amongst the highest of any global ecosystem are the reason for the positive NEE over the two years of available measurements at ID-Pag. These observations are cause for alarm given the substantial C stocks of this and other tropical peat forests (Hirano *et al*., 2007; Hirano *et al*., 2008; Hirano *et al.,* 2012).

The effects of the biosphere on the climate system are not of course limited to CO_2 exchange. Ecosystems influence atmospheric processes and *vice versa*, and connections between the two are changing as a result of anthropogenic influences (Luyssaert *et al.,* 2014). Energy exchange between the biosphere and atmosphere via latent heat (LE, *i.e.* evapotranspiration in energy flux units) and sensible heat (H) are critical for determining atmospheric moisture content and boundary layer development, and thereby precipitation processes.

Tropical ecosystems are characterized by the highest LE of any global ecosystem (Figure 3), although temperate forests have similar LE during their peak growing season on average. The lack of seasonality in tropical ecosystems – at least compared to most non-tropical ecosystems – results in a situation where H can be relatively high (during the non-growing season in ecosystems with greater seasonality of net radiation) or low (Figure 3). How might these energy fluxes influence precipitation?

Precipitation processes in tropical ecosystems are often limited by vertical atmospheric motions that bring moisture-rich air from the surface to the top of the atmospheric boundary layer (Badiya Roy and Avissar 2002). These vertical motions are driven largely by H in areas with limited topography. A simple analysis of the Bowen ration (, simply the ration between H and LE) and available energy (via the net radiation, Rn) reveals that ID-Pag partitions relatively less energy into H than most other tropical ecosystems during the mid-day conditions that are characterized by higher Rn (Figure 4), suggesting potentially that water vapor flux from peat ecosystems limits H under high radiation loads.

To begin progress on understanding the role of the biosphere to atmospheric processes across different tropical forest ecosystems, we can apply techniques from information theory (Ruddell *et al.,* 2013). Namely, the transfer entropy (T‘) - the amount of information passed from one time series to another as inferred by a process network (Ruddell and Kumar 2009a; Ruddell and Kumar 2009b) - can quantify the importance of H to precipitation across different tropical ecosystems (Figure 5). T‘ between H and precipitation decreases across all tropical forest ecosystems during the (typical) dry season, indicating a potential shift between H and LE in determining precipitation dynamics, and interestingly H at ID-Pag has a smaller influence on precipitation than most other tropical forest ecosystems. A number of mechanisms may underlie these findings, which require additional research attention. Fortunately, new releases of eddy covariance data via the worldwide consortium of researchers in FLUXNET provide further opportunity to place tropical forest ecosystems in a global context in order to better-appreciate their critical role in the Earth system.

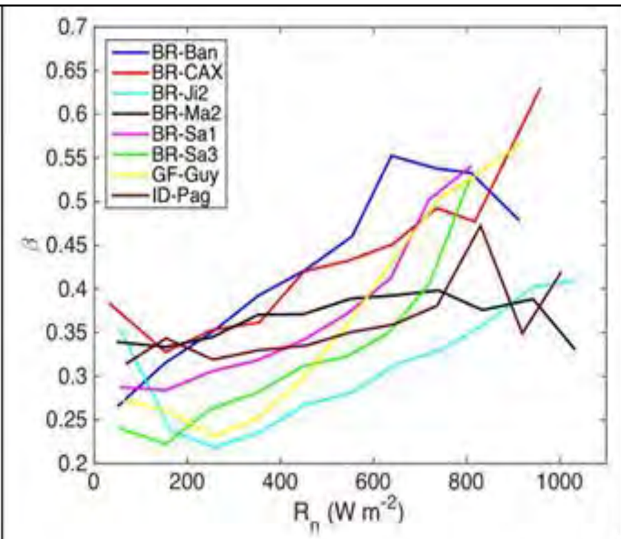

Figure 4: The response of the Bowen ration (the ration between sensible and latent heat flux) as a function of net radiation (R_n) for different R_n bins across eight tropical forest ecosystems in the LaThuille FLUXNET database.

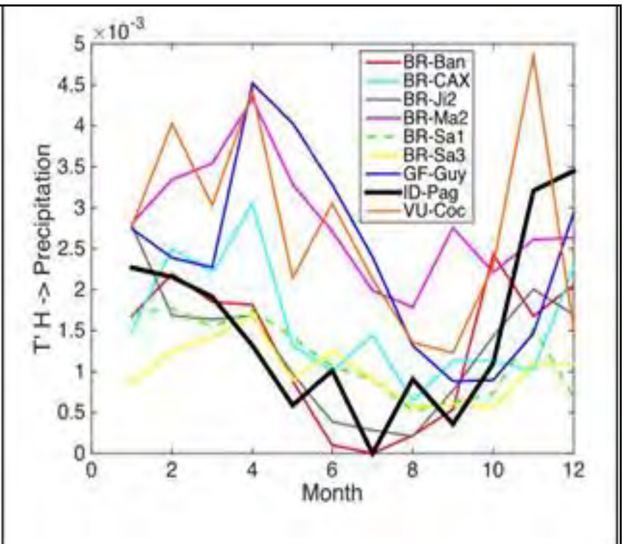

Figure 5: The transfer entropy (T‘) between sensible heat flux (H) and precipitation for monthly time steps calculated following Ruddell and Kumar (2009a) across tropical forest ecosystems in the LaThuille FLUXNET database.

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