Final report

Proposal title: Collaborative Research on Ecophysiological Controls on Amazonian Precipitation Seasonality and Variability

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Report period: January 2014 - March 2018

Abstract

The principal objective of our project is to address how vegetation influences climate variability and precipitation over Amazonian rainforests, with an emphasis on plant physiological controls on deep convection triggering along a geographical water stress gradient. Using a new tool of sun-induced chlorophyll fluorescence (SIF), our study integrates plant physiological observations and climate modeling and aims to decrease the gap between field ecology and climate modeling. We have installed sensors at Manaus site (K34) and at Rebio Jaru (Ji-Paraná, Rondonia).

From field observations, we found a diversity of hydraulic functioning, indicating that within the same forest we will find different responses to the predicted climatic changes. The hydraulic strategies varied through a continuum of hydraulic security and water transport efficiency, which can be related to a long process of taxa evolution. The fact that taller trees are more hydraulically vulnerable indicates that if these forests go through higher drought conditions and temperature increase, they could experience a massive tree mortality that will promote changes on forest structure, changing the ecosystem functions, such as water fluxes and carbon storage.

To investigate the role of water stress on the onset of the rainy season, we have developed high-resolution cloud resolving model (CRM) simulations using a new strategy coupling convective and large-scales. The first results show that the presence of early morning fog reduces the wet season transpiration and carbon uptake over the everwet regions of Amazonia. We have incorporated SIF into CLM to constrain energy, carbon and water flux of tropical forests.

By using CloudSat-observed cloud vertical structure, we show an empirical relationship between atmospheric energetics and convective clouds in Amazonia, in comparison with the savanna/shrubland and tropical West Pacific, emphasizing predominant deep convection during the early wet season when Bowen ratio and convective available potential energy (CAPE) increase. Although on average the deep convections are prominent only during the short dry-to-wet transition while shallow/congestus clouds dominate the rest of the year in Amazonia, there is a clear cloud regime shift when CAPE grows beyond a threshold value.

Our project helped initiate and maintain collaboration between US and Brazilian scientists. We have been collaborating through yearly field campaigns, weekly international research meetings, and ongoing other collaborative projects. Through these activities, we helped our students and postdocs fill their knowledge gaps and learn new research techniques.

1. Soil and plant measurements

The principal objectives of our field campaigns were i) install high-resolution sensors, ii) perform measurements on plant-hydraulic traits, and iii) collect soil, water and plant samples for laboratory analysis. The main goal behind these field campaigns was to feed earth-system computational models with data and processes of plant response to seasonal water stress and severe droughts. The field works were performed in the 2015, 2016 and 2017 years in the following LBA (Large-scale Biosphere-Atmosphere Experiment) sites:

Manaus (K34), Rebio Jaru (RBJ) and Bananal (BAN). They comprise a range of possible biophysical drivers of plant-drought response, including length of the dry season, water table depths, and soil properties.

1.1. Manaus site (K34)

In Manaus, our field site was a plateau forest at ZF-2, Km 34 site, one of the main sites of the LBA project. We first identified and mapped 200 individual trees to the level of species with the aid of a taxonomist. We selected 17 species that are abundant both in terms of species abundance and basal area. In this site, we installed point dendrometers (ZN12-T-2IP, Natkon.ch, Switzerland) at 1.5 m above ground level on a total of 40 trees, representing 2 - 4 individuals of each specie, to monitor long term three growth and daily trends in sugar and water relations. Two potentiometers measured the thickness of the bark and the xylem every 10 minutes. Changes in thickness are measured by the compression or relaxation of the spring of the potentiometers. For each specie we also evaluated key plant hydraulic traits, i.e. xylem vulnerability to embolism, leaf water homeostasis parameters, wood density, wood anatomy, and minimum leaf water potential, all of which are associated with species drought resistance and water use strategies. We recovered the existing soil moisture measurements, installed a new data logger and soil moisture measurements were done at the following depths: 80 cm, 160 cm, 240 cm, 320 cm, 480 cm, 640 cm and 1430 cm, using the same sensors previously installed. The data were collected from October 2015 to December 2017. Besides monitor soil moisture variability, we used the shaft to collect in situ soil samples for soil-physics (soil-water characteristic curve, texture, porosity and density), chemical (cations, organic matter and cation exchange capacity), mineralogical (X-Ray) and isotopic (^{18}O and ^{2}H) analysis. For the isotopes, we also collected plant (the same species monitored by the dendrometers) and water (rainfall, groundwater and soil water at various depths) during 4 field campaigns along 2015-2016 (Jul/Ago, 2016; Oct/2016; Feb/2016 and Aug/2016).
Ecophysiological analysis suggest a wide range of hydraulic strategies across Amazonian forest trees. For example, high wood density species such as *Dypterix odorata* are cavitation resistant (P_{50} = -4.46 MPa), while other species such as *Eschweilera coriaceae* show more vulnerability to embolism formation (P_{50} = -1.57 MPa). We also found evidence that deciduous species, like *Lecythis prancei*, are more vulnerable to drought (P_{50} = -1.80 MPa). Differencial xylem vulnerability across species appear to influence the species stomata control, as our finding indicate correlation between the minimum water potential and P_{50}. The dendrometers data also point a diversity of behavior between species. While some species show daytime shrinkage of the xylem and expansion of the phloem, others unexpected show the opposite behavior. Changes in the tree diameter over diurnal cycle are clear and further reflect changes in stomatal and canopy conductance. Our data highlight diversity in water transport strategies not only due to regulation of water loss but also control of the stem tissue water and phloem conductance, possibly arising from osmotic adjustment and radial osmolite transport.
Chemical soil analysis shows that organic matter content (OMC) values vary of 1.92 dag/kg at the surface (20 cm) until zero at the 880 cm depth. The soil-water characteristic curves show that at the wilting point (- 1.5 MPa) the soil layers still retain 35 - 45% of moisture. Comparing these values with the ones at which plants lose 50% of their

hydraulic conductivity (P_{50}), we can see that the plants at this site seems to able to get the water stored in the soil, even with the high pressure exerted by the soil microporosity. The isotopic composition of soil, water and plant are under analysis. However, the data reveals that plants are using water mainly from the first layers of the soil profile – 1 to 2 m – even during the strong El Nino event.
From field observations, we found a diversity of hydraulic functioning, indicating that within the same forest we will find different responses to the predicted climatic changes. The hydraulic strategies varied through a continuum of hydraulic security and water transport efficiency, which can be related to a long process of taxa evolution. The fact that taller trees are more hydraulically vulnerable indicates that if these forests go through higher drought conditions and temperature increase, they could experience a massive tree mortality that will promote changes on forest structure, changing the ecosystem functions, such as water fluxes and carbon storage.
A major part of the ecophysiological studies performed at the K34 site was presented in the Fernanda Barros Ph.D. thesis. In this thesis, two chapters' address ecophysiological K34 results (Barros et al., 2018a; Barros et al., 2018b). This paper was submitted to the New Phytologist and are under analysis. Another 2 papers were published with the results of K34 dendrometers: Emmerick et al (2017a,b).

1.2. Rebio Jaru site (RBJ)

This study site is located at Jaru Biological Reserve (Rebio Jaru), a national conservation area of the Rondônia state, at around 290 km far from Porto Velho, the capital. For the present work, field data were collected from September 2015 to November 2017.
For ecophysiological studies, we first identified and mapped more than 400 individual trees to the level of species, with the aid with a taxonomist. After that, we select 31 individuals from 23 different species to install point dendrometers. Also, plant hydraulic traits measurements – TLP, P_{50}, P_{88}, and daily plant water potential) were done in 23, 10, 5 and 20 individuals, respectively. By these results we can see that the *Dypterix cf odorata* presented the greatest P_{50} value (-5.08 MPa), while the lowest one (P_{50} = -0.84) were obtained by *Sagotia Guianensis*. However, during the experiments, we saw that the number of observations was not enough to guarantee good representativeness of the data. In other words, the type of test could not be applied for all the species studied in this site. On the other hand, TLP values were more stable and replicable measurements. For the 23 individuals analyzed, TLP values varied between the range of -1.10 MPa and -2.91 MPa, with the lowest values observed for the *Protium n*., -1.10 MPa and *Pouteria e*., -1.15 MPa.
The greatest values were found for the species *Pouteria d.*, -2.91 MPa and *Licania s*., 2.49 MPa, being the maximum ones. For the daily curves, we observed 3 different behaviors: a group of species (n = 2) showed strong decrease in the water potential at noon, slight recover at 14h and another decrease at 16h. Another group (n = 6) present a constant decreasing in the daily potential from the predawn until 16h. And the last group (n = 9) we observed decreasing potential at the 12h - 14h, with recovering only at 16h. Important to mention that for all of the species, the daily values of potential were not greater than 2.5 MPa.

1.3. Bananal site (BAN)

This study site is located at the Cantão State Park (PEC), a conservation area located in Tocantins state, at around 250 km far from Palmas, the capital (BAN site). During our GoAmazon project, we identified the species with dendrometers in each plot and monitored their growing along the 2016/2017 years. We found, in total, 46 species, from which the more common are *Moraceae*, *Sapotaceae* and *Chrysobalanaceae*, respectively with 30, 22 and 17 individuals, considering both plots. The four-dominant species (n >10) in the plots are *Brosimum gaudichaudii*, *Discocarpus brasiliensis*, *Duroia genipoides* and *Micropholis guyanensis*. Except for the *Brosimum gaudichaudii*, they are species normally found in the seasonal flooding environments (ref). The total number of species we monitored are 27 in the FP, and 28 in NFP. Only 9 species were common for the 2 environments: *Brosimum gaudichaudii*, *Cynometra bauhiniifolia*, *Discocarpus brasiliensis*, *Duroia genipoides*, *Handroanthus serratifolius*, *Licania egleri*, *Licania hypoleuca*, *Mouriri ficoides*, and *Pouteria ramiflora*. We can see that 44% of the species in the both plots occur in seasonally flooded environments of another region - Amazon, Brazilian savanna, Atlantic Forest and Pantanal. These results show the existence of flooding tolerant species in both, flooded and non-flooded plots. For some species inside the plots, we also measure xylem vulnerability to embolism (P_{50}), TLP (turgor loss point) and plant water potential daily curves. We also installed point dendrometers (ZN12-T-2IP, Natkon.ch, Switzerland) in 6 individuals. For the soil parameters, we collected disturbed and undisturbed soil samples for physical, chemical and isotopic analysis in three different soil profiles: one besides the flux tower (seasonally flooded area), one inside the FP (flooded plot) and another inside the non-flooded plot (N-FP). Physical parameters involved texture, density, porosity and SWCC (soil-water characteristic curve), the last one being done only for the soil profile besides the flux tower, the same place where are installed the soil moisture sensors. Soil moisture measurements were done in the following depths: 10 cm, 20 cm, 70 cm, 80 cm, 150 cm , 220 cm and 290 cm. Undisturbed soil samples were collected in the following depths. Chemical analysis involved organic matter content (OMC), main cations (K, Ca, Na, Mg), aluminum (Al), phosphorus (P), pH and CCE (cation exchange capacity) in the three soil profiles. In this site we also collected soil, plant and water samples for isotopic analysis. The period of data collection was from October/2015 to September/2017.

1.4. Anatomical and physiological characteristics of tropical tree species in the Amazon

S. Ingrid Coughlin, under guidance of co-PI Domingues, studied the anatomical and physiological characteristics of tropical tree species in the Amazon. To estimate the magnitude of the impact that drought could have on the tropics, it is important to have a clear understanding of current tropical tree physiology and the extent to which trees can acclimate or resist water-stress. They explored the acclimatability of tree leaf anatomy under a 13-year through-fall exclusion experiment (TFE). Large trees (dbh>30cm) presented with thinner leaves, due to shrinkage of spongy parenchyma, which may have implications for reducing boundary layer resistance. Additionally, there was a decoupling between minimum stomatal conductance (g_{smin}) and leaf anatomical features in trees on the TFE, which could be explained by changes in water- use strategies. They also present baseline tropical physiological measurements of mesophyll conductance (g_m) and CO_2

photocompensation point in the absence of light respiration (Γ^*). Granted current limitations to accurately measure g_m and Γ^*in the tropics, our results indicate that tropical species had low Γ^* values in comparison to other warm- climate trees and that determinations of g_m were highly sensitive to variations in Γ^*. These combined results improve our knowledge and predictive power of the tropical ecosystem response to climate change.

2. Fluorescence measurements

Dr. Ari Kornfeld in Joe Berry's lab has focused on developing the instrumentation to measure chlorophyll fluorescence from flux towers in the Amazon.

Hardware: Instrumentation for measurement of the emission of solar induced chlorophyll fluorescence (SIF) was designed and installed at the K34 tower near Manaus. The design phase of this effort resulted in a complete revision of the instrumentation approach that had been used in previous measurement of canopy-scale SIF. The central element of this approach is the "RotoPrism". In this device a prism is used to "switch" the view of a single fiber optic between upward facing or downward facing diffuser disks. These provide cosine corrected hemispheric samples of the upwelling or downwelling light fluxes. A pneumatic controlled rotary actuator is used to switch the prism between the two configurations on demand. The light is collected by a lens and transmitted via an 80 m fiber optic to a spectrometer located in a temperature controlled container in the air conditioned instrument shed at the base of the tower. The RotoPrism is hermetically sealed to protect the prism and actuator from the hot and humid climate. The device is fitted to the end of a 6 meter length of 50 mm aluminum pipe that is supported by guy wires at the 60 m level on the north side of the tower. The fiber optic is protected from exposure to sun light and weather by the aluminum tube and electrical conduit that extended from where the pipe is attached to the tower to the instrument shed. Two 3mm PVC tubes conduct compressed gas to drive the rotary actuator permitting the position of the prism to be controlled from the shed. Compressed gas is provided by a standard cylinder of commercial grade N2. A laptop computer with custom software written in MatLab is used to control the RotoPrism and acquire data from the spectrometer. The spectrometer chosen for this application is an Ocean Optics QE-Pro with a 25 micron slit and a Shott RG695 order-blocking filter. The grating was adjusted to monitor the 730-785 nm range with a spectral resolution of approximately 0.18 nm FWHH.

Software: We have developed software for acquisition and analysis of canopy and reference spectra. The program controls the spectrometer adjusting integrations time to optimize S/N ratio given the available lighting. Automated collection of reference spectra sunlight is also accomplished under program control. These spectra are archived and can be used to de-convolve the light collected above the canopy into reflected sunlight and light emitted as fluorescence using a singular value decomposition approach.

<u>Current status</u>: The equipment was installed at the K34 tower on June 22, 2016, and the RotoPrism device has worked perfectly since then. However, we have had problems with the infrastructure at the site. Data was lost for about 6 weeks beginning in September 2016 and then we experienced complete failure from Jan 15, 2017 on. These are due to failure of the air conditioning in the instrument shed at the base of the tower causing our spectrometer to overheat and shut down.

Analysis of data: SIF observations taken over an interval of several months shows a strong linear correlation with measured photosynthetically active radiation (data not shown). We anticipate that SIF should be proportional to the product of PAR, the fractional absorbance of PAR (fPar), the fluorescence yield ψ_F, and the probability that a fluorescent photons will escape the canopy (Ω_C), SIF=PAR * fPAR * ψ_F * Ω_C. The fact that we observe little variation in SIF plotted against PAR indicates that the other terms of this equation have remained about constant over the period of these measurements. We have also analyzed the correlation seen in other studies between SIF and the NIR reflected light from the canopy. We would have expected the presence of stress to result in changes in the relative level of SIF to NIR over the day. This also showed little change over the time of the measurements. Satellite observations of SIF over the Amazon basin show a significant seasonal pattern with SIF increasing over the dry season. The fact that we did not observe this at the canopy scale may be related to the fact that the hemispheric measurement perspective used in our measurements is likely to be less sensitive to seasonal changes in the phase angle (sun angle - view angle difference) than the satellite measurements that are from a nadir view. However, we should caution that this conclusion applies only to the limited time that we were able to get good measurements due to infrastructure failure. Nevertheless, we are confident that our equipment and the analytical approached we have developed would enable us to resolve small changes in canopy structure or fluorescence yield over seasonal and diurnal time frames. We are especially encouraged by the fact that the RotoPrism system functioned without difficulty through the year. We plan to move the existing setup to a tower at the ATTO site where there is much better infrastructure and support for the measurements than at K34.

3. Process based modeling

3.1 Fluorescence modeling

Several studies have shown that sun-induced fluorescence (SIF) is sensitive to photosynthesis rates, thus providing useful information for studying terrestrial gross primary production (GPP). We have incorporated equations for SIF into a land surface model, the National Center for Atmospheric Research Community Land Model version 4 (NCAR CLM4), to better estimate terrestrial GPP. First, we use existing theory and data to explain how SIF was incorporated into CLM4. We then demonstrate that our simulated fluorescence values are reasonable when compared with satellite (Greenhouse gases Observing SATellite; GOSAT) and *in situ* flux-tower measurements. Our results overestimate GPP in tropical forests and thus indicate that maximum carboxylation rate

(V_{max}) in CLM4 may be too high in tropical forests. Photosynthesis influences energy, water and carbon cycles, and we expect that the incorporation of SIF, along with satellite and in situ measurements, will improve estimates for GPP and thereby play a critical role in improving land surface models. This paper is a collaborative effort between the Brown and Carnegie teams, with Lee, Berry, and Yang participating, and is published in *Global Change Biology* (Lee et al., 2015).

3.2. High-resolution cloud-resolving model

We recently published a manuscript in the Proceeding of the National Academy of Science (PNAS), entitled Fog and Rain in the Amazon: by Anber, Gentine, Wang and Sobel. In this paper we demonstrate that we can for the first time correctly reproduce both the diurnal and seasonal cycle of the hydrologic cycle in the Amazon using a strategy opposite to climate models, which typically fail to represent those diurnal and seasonal cycles. Indeed climate models tend to exhibit rain too early in the day and generally have peak evapotranspiration in the wet season and not in the dry season as observed with eddy covariance towers. We used high-resolution cloud-resolving models (1km), which can explicitly represent convection, with a parameterized large-scale circulation, using the Weak Temperature Approximation (Sobel and Bretherton 2001). Using this strategy we can correctly reproduce all the surface fluxes (precipitation, radiation, evapotranspiration and sensible heat flux) and their seasonality as well as their diurnal cycle

In addition we showed that the main cause of the wet season is the presence of an early morning fog, which insulate the surface from top of the atmosphere shortwave radiation. In essence this fog makes the day shorter because radiation cannot penetrate to the surface in the early morning. This is why all fluxes are reduced in the wet season compared to the dry season. We believe that those are important results to better comprehend the switch from the dry to wet season, and we are now continuing the work in that direction to investigate the transition.

4. Satellite and radar data analysis

4.1. SIF observations: Analysis of biosphere-atmosphere interactions globally and in the Amazon rainforest

Co-PI Gentine, and PhD student (Julia Green) at Columbia assessed the causal link between the terrestrial biosphere and atmosphere globally and in the Amazon using observations from remote sensing data. The study was published this past year in Nature Geoscience. In this work, Julia used solar-induced fluorescence as a proxy for vegetation productivity to assess its feedbacks with the atmosphere using a Granger causality analysis. This study led to the first global long-term assessment of feedbacks between the biosphere and the atmosphere, and reinforced the hypothesis that large sections of the Amazon are light-limited (although vegetation productivity does not have feedback with consequent changes in radiation). This work demonstrated the importance of water stress (and precipitation) and light-limitation for the feedbacks. It also highlighted, the oftenoverlooked role of cloud feedback on radiation on biosphere productivity and the coupling of the surface on cloud cover generation through boundary layer processes.

4.2. Analysis of radiosondes and Amazonian Global Navigation Satellite System (GNSS) dense network data sets

Co-PI Lintner, a programmer analyst (Dr. Bryan Raney), and two undergraduate research assistants (Andrew Rohrman and Alyssa Stansfield) at Rutgers have been analyzing available radiosonde profiles of temperature and moisture from ARM mobile facility radiosondes as well as existing Brazilian radiosondes and column water vapor (cwv) from the ARM passive radiometer and Amazon GNSS dense network (Adams et al. 2011), in collaboration with David Neelin and Kathleen Schiro (UCLA) [also funded under GO Amazon] and David Adams (Universidad Nacional Autónoma de México). Efforts are underway to use these data to explore the relationships between the statistics of precipitation and the thermodynamic profiles, building on similar prior work for sites over tropical ocean regions; to investigate the spatiotemporal heterogeneity in cwv in order to assess the scales represented by point measurements; and to validate climate model simulations and explore sources of the well-known dry bias in CMIP5 simulations of Amazonian hydroclimate.

4.3. CloudSat Observations of cloud water

The Amazon rainforest is known as the “Green Ocean” for its maritime-like congestus clouds during the rainy season, and the convective available potential energy (CAPE) is reported to help regulate the convective regimes. By using CloudSat-observed cloud vertical structure, Mengxi Wu and PI Lee show an empirical relationship between atmospheric energetics and convective clouds in Amazonia, in comparison with the savanna/shrubland and tropical West Pacific, emphasizing predominant deep convection during the early wet season when Bowen ratio CAPE increase. Although on average the deep convections are prominent only during the short dry-to-wet transition while shallow/congestus clouds dominate the rest of the year in Amazonia, there is a clear cloud regime shift when CAPE grows beyond a threshold value. This critical value is a common feature shared by the terrestrial surface types but not the ocean. A possible reason for this land-ocean difference is the size of liquid cloud droplets in the low level and increasing CAPE in tropical rainforests due to an increase in Bowen ratio from the late dry season toward the transition season.

5. International collaboration

Our project is interdisciplinary in scope with 7 PIs: 3 climate modelers, 3 plant physiologists, and 1 hydrologist. As a result, we need to establish a baseline of knowledge and “common language” for our research. We have therefore organized an international online group meeting to get familiar with each other’s work, to provide feedback on ongoing studies, and to educate our students and postdocs.

We meet once a week, and our activities include giving lectures on the topics on each PI's expertise, reading important papers for our study, and presenting our results. Currently 28 researchers are participating from Brown, Columbia, Rutgers, Carnegie/Stanford, UCLA, UC Merced, INPE, U. Sao Paulo, and U. Campinas. Brown provides online access through the conference tool WebEx.

Table 1. Example of a group meeting topics

Date	**Discussion leader**	**Topics**
10/20	Joe Berry	Photosynthesis: a primer
10/27	Wu Sun	Soil Carbonyl Sulfide observations and modeling
11/10	Tomas Domingues	Leaf photosynthesis measurements
11/24	GOAmazon	Fieldwork discussion
12/1	Paolo Bittencourt	Leaf water stress
12/8	Julia Green	AGU presentation prep talks
2015		
1/26	Ari Kornfeld	Photosynthesis GUI
2/2	Ben Lintner	Developing a minimalist model of vegetation-precipitation coupling over the Amazon
2/9	Xi Yang	Journal reading: Schimel 2014 PNAS
2/23	Elliot Campbell	MIPAS Remote Sensing of OCS: GPP and Ensemble Convection Signature
3/23	Pierre Gentine	Equilibrium and weak temperature gradient: Role of cloud albedo
3/30	Laura Borma	Soil Moisture measurements
4/20	Kaiyu Guan	Photosynthesis and water availability
4/27	Jin Wu	how leaves at different ages affect the photosynthetic activities of the whole canopy.
9/23	Pierre Gentine	
10/05	Fernanda Barros/Paulo Bittencourt/Rafael Oliveira/Laura Borma	Fieldwork report 2015

Started from the GoAmazon/FAPESP grants, our project led to more collaboration among the team members. Co-PIs Oliveira, Gentine, and Domingues have an ongoing PEER-USAid project (Functional diversity of interrelated photosynthesis and water use of Central Amazonian trees - US$270k from Oct/2015 until Oct2018).

THESES:

Barros, F., Hydraulic functioning and drought vulnerability of two tropical Forests, Universidade Estadual de Campinas, Ph.D Thesis (Advisor: R. Oliveira), 2017.
Coughlin, S. I., Anatomical and physiological characteristics of tropical tree species in the Amazon. Universidade de São Paulo, M. S. Thesis (Advisor: T. Domingues), 2017.

Stansfield, A.M., Comparison of Observed and Model-simulated Atmospheric Moisture Vertical Structure Over the Amazon Rainforest, George H. Cook Undergraduate Honors Thesis, Rutgers University (Advisor: B.R. Lintner).

PEER-REVIEWED PUBLICATIONS:

Published:

Lee, J.-E., **J. Berry**, C., van der Tol, C., **X.** [+]**Yang**, L. Guanter, A. Damm, I. Baker, and C. Frankenberg, Calculations for chlorophyll fluorescence incorporated into the Community Land Model version 4. *Global Change Biology*, 9, 3469-3477, doi: 10.1111/gcb.12948 (2015).

Anber U., **Gentine P**, Wang S., Sobel A.H., Fog and rain in the Amazon, PNAS, 2015.

Green J., Konings, A. G., S. H Alemohammad, **J. Berry**, D. Entekhabi, J. Kolassa, **J.-E. Lee**, P. Gentine, Regionally strong feedbacks between the atmosphere and terrestrial biosphere, *Nature Geoscience*, **10**, 410-414 (2017).

Schiro, K.A., J.D. Neelin, D.K. Adams, and **B.R. Lintner**, Deep Convection and Column Water Vapor over Tropical Land vs. Tropical Ocean: A comparison between the Amazon and the Tropical Western Pacific. *J. Atmos. Sci. 73*, 4043—4063, doi: 10.1175/JAS-D-16-0119.1, 2016.

Lintner, B.R., D.K. Adams, K.A. Schiro, A.M. Stansfield*, A. Amorim Rocha, and J.D. Neelin, Relationships among climatological vertical moisture structure, column water vapor, and precipitation over the central Amazon in observations and CMIP5 models, *Geophys. Res. Lett., 44*, 1981–1989, doi:10.1002/2016GL071923.

Gentine P., Garelli A., Park S., Nie J. ,Torri G., Kuang Z., Role of surface heat fluxes underneath cold pools, 43, 874–883, doi:10.1002/2015GL067262.

T. van Emmerik, S. Steele-Dunne, A. Paget, R.S. Oliveira, P.R.L. Bittencourt, F.V. Barros and N. van de Giesen "Water stress detection in Amazon using radar" Geophysical Research Letter, 2017

F.V.Barros, P.L. Bittencourt, P. Gentine, N.R.-Coupe, L.S.Borma, A. Araujo and R.S. Oliveira (2018a) "Growth and drought vulnerability of big trees in Central Amazon – Fernanda Barros Thesis Chapter

T. van Emmerik, S. C. Steele-Dunne, R. Hut, P. Gentine, M. Guerin, R. S. Oliveira, J.Wagner, J. Selker, and N. van de Giesen, “Measuring Tree Properties and Responses Using Low-Cost Accelerometers," Sensors, vol. 17. no. 5, pp. 1098, 2017.

Submitted or revised:

Stark, S.C., Breshears, D.D., Garcia, E., Law D.J., Minor, D., Saleska, S.R., Swann, A.L.S., Villegas, J.C., Aragão, L.E.O.C., Bella, E.M., **Borma, L.S.**, Cobb, N.S., Litvak, M.E., Magnuson, W., Morton, J.M., Redmond, M.D. (2015) Toward accounting for ecoclimate teleconnections: intra- and inter-continental consequences of altered energy balance after vegetation change. Landscape Ecology (in revision).

Mateus, P.J.B., **Borma, L.S.,** Nico, G.; Silva, R. and Catalão, J. Assessment of two data assimilation methods to merge ground-based and satellite rainfall measurements: a case study for Brazilian Amazon Rainforest. Submitted in August, 2015 to Giscience & Remote Sensing

Robinson, E., X. +Yang, **J-E. Lee**, "Ecosystem productivity and water stress in tropical East Africa: A Case Study of the 2010-11 drought," *J. Geophys. Res*., submitted.

Yang, X. and **J. -E. Lee**, The changing seasonality of productivity in California, *Global Change Biology*, submitted.

Gentine, P., A. Massmann, **B.R. Lintner**, S.H. Alemohammad, R. Fu, J. K. Green, D. Kennedy, and J. Vila-Guereau de Aranello, Land-atmosphere interactions in the tropics, *Advances in Water Resources*, revised.

F.V.Barros, P.R. Bittencourt, M. Brum, N.R.-Coupe, L. Pereira, G.S. Teodoro, S. Saleska, L.S. Borma, B.O. Christo_ersen, D. Penha, L.F. Alves, A.J.N. Lima, V.M.C. Carneiro, P.Gentine, J-E Lee, L.E.O.C. Aragão,V.Ivanov, L.S.M. Leal, A.C. Araujo and R.S. Oliveira (2018b) "Diferential responses of Amazonian forests to El-Nino- induced drought are explained by hydraulic traits" - Fernanda Barros Thesis Chapter. Submitted to New Phytologist

In preparation:

Wu, M. and J.-E. Lee, Energetic thresholds of convection in the tropical rainforests from CloudSat Observations, in prep.

Brunnquell, D. K., **B. R. Lintner**, and B. K. Raney, Application of linear unidimensional scaling to CMIP5 model simulation of tropical South American rainfall, *Geophysical Research Letters*, in preparation.

PRESENTATIONS:

Borma, L.S., The challenge in determining the spatial and temporal variability of soil moisture in the Amazon basin. GoAmazon 2014/15 Science Conference, May, 18-19, Harvard University, Cambridge, MA.

Lee, J.-E., DOE PI meeting, Will forests grow back after deforestation?, 2015.

Lee, J.-E., Association for Tropical Biology and Conservation meeting, "Will forests grow back after deforestation?"

Lee, J.-E., CalTech Ronald and Maxine Linde Center workshop on Monsoons, "Will forests grow back after deforestation?"

Lee, J.-E., Department of Energy, Biological and Environmental Research Principal Investigators' Meeting, "Will forests grow back after deforestation?"

Lee, J.-E., AGU Fall meeting, "The role of transpiration on the hydrological cycle;"

Lee, J.-E., MIT, "Will forests grow back after deforestation?"

Lee, J.-E., Berry J., Yang, X et al. AGU Fall meeting, Calculations for chlorophyll fluorescence incorporated in the Community Land Model

Lee, J.-E., Boston University, Sun-induced chlorophyll fluorescence: modeling and applications

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