ASSESSING THE IMPACT OF DROUGHT AND LAND COVER ON WATER AND CARBON CYCLING USING MODELING AND REMOTE SENSING

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ABSTRACT

As drought and other extreme weather events are likely to become more common in the future, it is of paramount importance to understand how various ecosystems are impacted and respond to such events. In particular, it is necessary to be able to understand potential changes in the water and carbon cycles. Here, we investigate the impacts of the 2015 drought on the state of Mato Grosso using the NOAH-MP land surface model. Specifically, we are interested in the impacts of the drought on future recovery of the drought stricken regions. We utilized a three year simulation (2015-2017) to examine how variation in drought magnitude impacts future carbon and water cycling across the state. Emphasis was placed on the alteration of the latent heat (LE) and net ecosystem exchange (NEE) in response to changes in leaf area index (LAI) and surface temperature (T_r). We found reductions in both LAI and T_r that were highly correlated with the reductions in LE and NEE. This was particularly noticed in the reduction of NEE in savanna regions which resulted in this ecosystem becoming a slight source of carbon to the atmosphere in the year following the drought. This highlights the importance of understanding the differential responses of ecosystems to extreme events for assessing the future of carbon and water cycling in a changing climate.

Key words – *Drought, land cover, carbon cycling, land surface modeling.*

1. INTRODUCTION

As drought and other extreme weather events are likely to become more common in the future, it is of paramount importance to understand how various ecosystems are impacted and respond to such events. This is particularly true in the Amazon where future droughts are likely and the region is highly sensitive to changes in rainfall [1]. It is necessary to be able to understand how the cycling of water and carbon are altered due to the role of the land surface on moderating the impacts of climate change in the region [2]. Land surface modeling provides a valuable tool for assessing these changes across a heterogeneous landscape as well as being able to relate the alterations to perturbations of the model's state variables.

Therefore, the objective of this work is to examine the impact of a large drought on the net ecosystem exchange (NEE) and latent heat (LE) fluxes and relate these impacts to the modeled fields of surface temperature (T_r) and leaf area index (LAI).

2. MATERIAL AND METHODS

We utilized the Noah-MP model [3] to examine the impacts of drought on the water and carbon cycling in Mato Grosso. The Noah-MP model is a state of the art land surface model consisting of a dynamic vegetation model. In order to assess the ability of the Noah-MP to examine the impacts and recovery from drought, we used the 2015 Amazonian drought as a case study. The study period consists of 2015-2017 and was focused on the state of Mato Grosso at 2 km spatial resolution with hourly model output. The total model domain was 642x697 grid cells.

The Noah-MP model is forced with 3 hourly GLDAS-2 data at 0.25° resolution. Noah-MP requires gridded forcing data of incoming solar and long-wave radiation, surface pressure, rainfall and snowfall, 2m air temperature and humidity, and wind. We run the model in dynamic vegetation mode, with a Ball-Berry canopy stomatal resistance formulation. The soil moisture factor for stomatal resistance is set to the Noah option. The Monin-Obukhov formulation is utilized for the surface drag component of the model. The modeled land cover is taken from the modified IGBP MODIS dataset. The distribution of the land cover types across Mato Grosso can be seen in Figure 1(a). Here, we focus on two of the dominant land cover types in the region; forest (type 2) corresponding to 30% and savanna (type 9) consisting of 23% of the land area.

We present preliminary results here which focus solely on the difference between September of 2016 and 2015. During these two months, the Multivariate El Niño Index from NOAA was 2.256 in 2015 and was -0.363 in 2016. Given the dominance of the El Niño on drought conditions in the Amazon, these values confirm the drought conditions in 2015 and the post-drought stage of 2016. As an initial examination, we investigated the impacts of monthly averaged LAI and T_r changes from 2015 to 2016 and the associated changes on the monthly averaged latent heat LE and NEE fluxes. We focus on the changes in 2016 relative to the 2015 values and all the differences are calculated as the mean September, 2016 value minus the mean September, 2015 value. We chose to initially focus solely on these fields in order to facilitate a comparison with the MODIS land surface temperature and vegetation fields in the next stage of analysis.

3. RESULTS

The 2015 drought had lingering impacts on vegetation productivity in the following year as evidenced by changes in LAI. The mean LAI value for the model domain decreased from 3.03 m^2m^{-2} in 2015 to 2.87 m^2m^{-2} in 2016. The

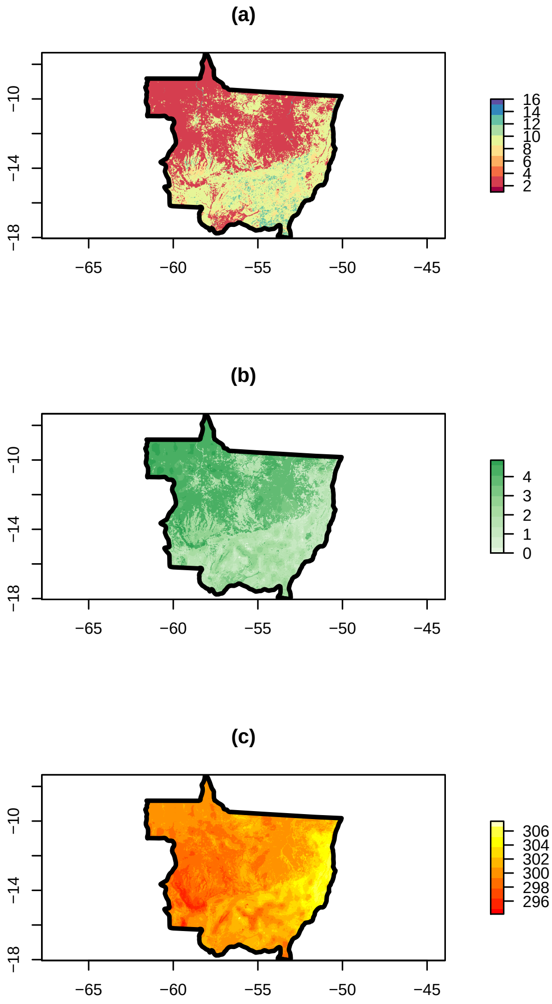

Figure 1: Maps of (a) Land cover, (b) September, 2016 LAI [m^2m^{-2}] and (c) mean September 2016 surface temperature [K].

savanna had a larger mean reduction from 1.90 to 1.70 m^2m^{-2} and the forest regions experienced a mean reduction from 4.12 to 4.04 m^2m^{-2} (Figure 1(b)). Since 2016 is not a drought year, the mean monthly surface temperatures in 2016 are slightly reduced relative to 2015 even with the reduction in LAI. The overall mean temperature in 2015 was 301.7 K while in 2016 it was 300.4 K.

From Figure 1 it is clear to see that the changes in surface temperature and leaf area index are not independent of one another. To more fully examine the covariability, we plotted the joint distribution and density plots (Figure 2) for the savanna and forest ecosystems. While the forest does experience a large reductions in LAI with a range of differences between -2.57 to 0.61 m^2m^{-2}, the majority of the forest grid cells experienced a near zero change ($d(LAI) = -0.07$ m^2m^{-2}). The same is not true for the savanna regions where the majority of the grid cells experience a reduced LAI in 2016 relative to the 2015 values (mean $d(LAI) = -0.2$ m^2m^{-2} with a range between -1.23 and 0.866 m^2m^{-2}). Of course, since the savanna generally has a lower LAI, these changes represent a much larger percentage change in this ecosystem.

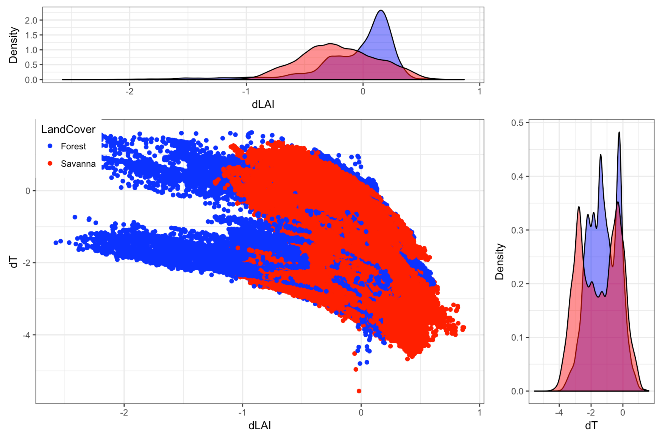

Figure 2: Density and relationships of changes (2016-2015) in leaf area index [m^2m^{-2}] and surface temperature [K] for the dominant modeled land covers of forest and savanna.

There was also a greater temperature reduction (cooler temperatures in 2016) for the savanna environment whereas the forest grid cells experienced a smaller reduction in temperature. The mean temperatures differences follow a similar range to one another with the dT in the forests having a range from -4.8 to 1.62 K with a mean of -1.22 K. The range of dT in the savanna was -5.56 to 1.34 K with a mean of -1.47 K. While the range and means are similar between the ecosystems, the actual distributions of the changes are quite different with the dT for the savanna exhibiting a more bimodal distribution relative to the changes observed in the forested regions (Figure 2).

The changes in surface temperature and leaf area index correspond to changes in the carbon and water fluxes. Figure 3 demonstrates the spatial distribution of the mean monthly LE in 2015 and 2016, as well as the difference between the two years. The overall mean LE is higher during 2015 than in 2016. Across the entire region, the LE in 2015 was 71.41 Wm^{-2} and 63.7 Wm^{-2} in 2016. The decrease was similar in both the forests (-6.97 Wm^{-2}) and savanna (-6.07 Wm^{-2}). This is consistent with the increase in solar radiation during drought conditions in the region [4].

The overall mean monthly NEE was changed from -5.98e-5 $gm^{-2}s^{-1}$ in 2015 to -5.06e-5 $gm^{-2}s^{-1}$ in 2016. Here, however, we observed a difference between the savanna and the forest regions. The forests were -1.04e-4 $gm^{-2}s^{-1}$ in 2015 and -0.996e-4 $gm^{-2}s^{-1}$ in 2016 indicating a slightly reduced sink of carbon in these regions following the drought period. The savanna regions were a sink of carbon in 2015 (-5.98e-5 $gm^{-2}s^{-1}$) and changed to a slight source of carbon in 2016 (6.73e-7 $gm^{-2}s^{-1}$).

Next, we wanted to examine how the changes in LAI and T_r are reflected in the water and carbon fluxes. The reduction in surface temperature is correlated with an increase in the latent heat flux in 2016 (Figure 5). Both ecosystems generally see the same response in the LE flux, with the correlation being -0.40 in the forests and -0.42 in grasslands. The changes in NEE are also generally the same for both ecosystems with

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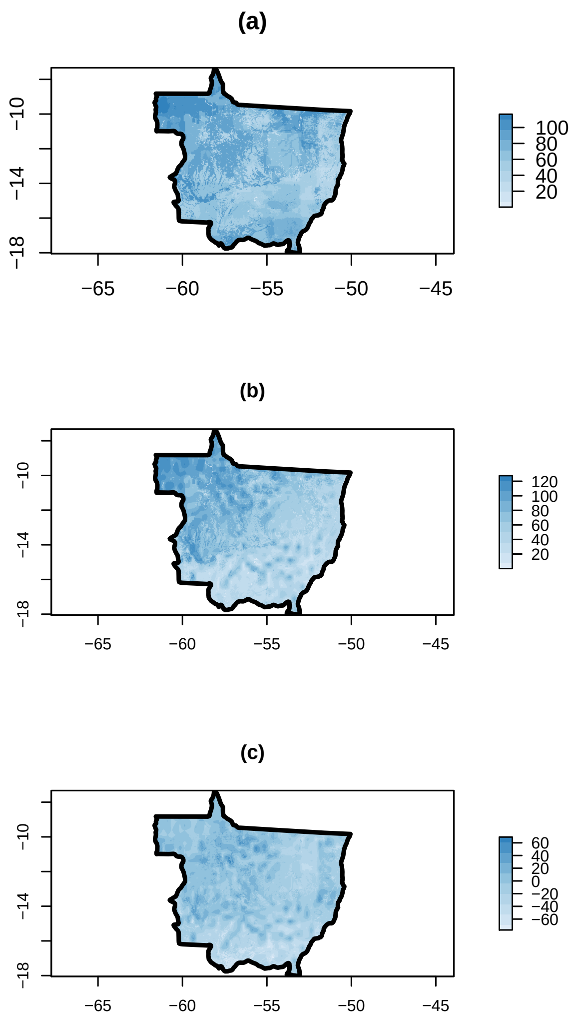

Figure 3: Modeled latent heat fluxes [Wm^{-2}] for (a) 2015 (b) 2016 and (c) the difference (2016-2015).

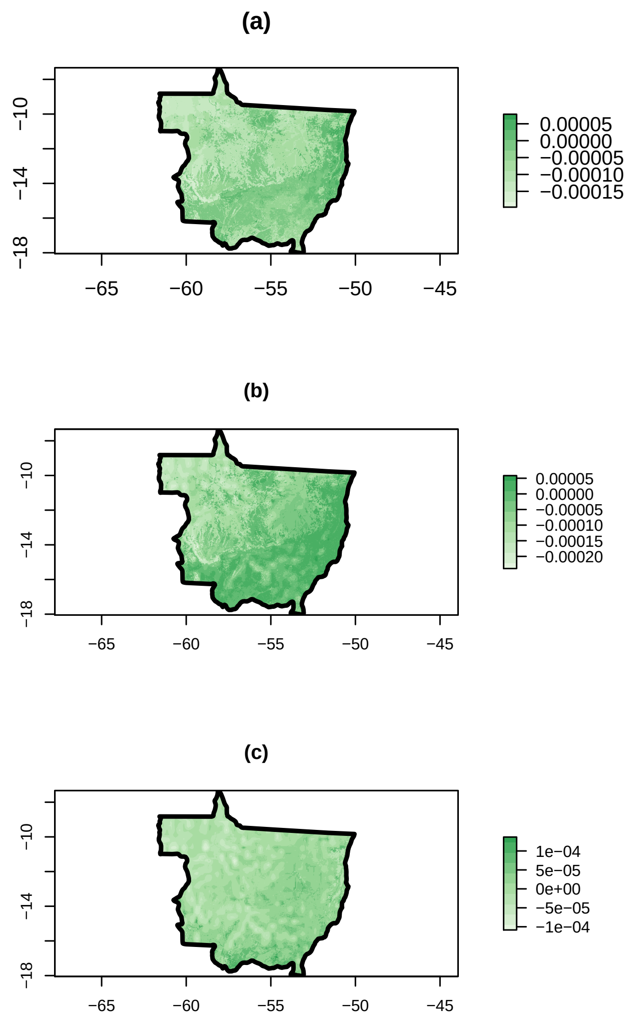

Figure 4: Modeled net ecosystem exchange [$gm^{-2}s^{-1}$] for (a) 2015 (b) 2016 and (c) the difference (2016-2015).

the reduced temperatures corresponding to a more negative NEE flux and thus a greater sink of CO_2. The relationship is stronger for the savanna ecosystem as exemplified by the strong linear density in the plot (correlation of 0.67 in grasslands compared to 0.44 in the forested regions).

The Noah-MP model exhibited a strong correlation between the changes in LAI and the impacts on the monthly water and carbon fluxes (Figure 6). The forested region had a correlation of 0.88 between the change in LAI and the change in LE. The grassland had a slightly reduced value of 0.62, but with significantly more scatter. Note that with the positive correlation, the impact of the drought in 2015 was to largely reduce LAI values and thus correspond to a reduction in the LE flux. The impact of LAI on the NEE is pronounced for both ecosystems with correlations of -0.92 and -0.87 for the forests and grasslands respectively.

4. CONCLUSIONS

The initial analysis presented here illustrates the potential impacts of drought on the savanna and forested ecosystems in Mato Grosso. Both ecosystems experienced reduced LAI and T_r values one year after the drought. These reduced values corresponded to reduced values in surface temperature which led to a reduction in the NEE in the year following the drought. This reduction in NEE was most pronounced in the savanna where the alteration was enough to shift the savanna to being a slight carbon source to the atmosphere. The impacts on the LE flux were more similar across the ecosystems with both reducing the monthly averages about 6 Wm^{-2}. For both ecosystems the reductions in carbon and water cycling are highly related with the changes in the LAI and T_r.

These preliminary results illustrate the importance of land cover type on the carbon and water cycling alterations when recovering from an extreme meteorological event such as drought. Further analysis will consist of detailing the seasonal dynamics of the carbon and water fluxes in relation to the severity of the drought and comparison of the model results with MODIS imagery of surface temperature, vegetation fields and the derived fluxes.

These results also highlight the utility of an advanced land surface model such as Noah-MP as a tool for attributing the impacts of an extreme event across model state variables. In

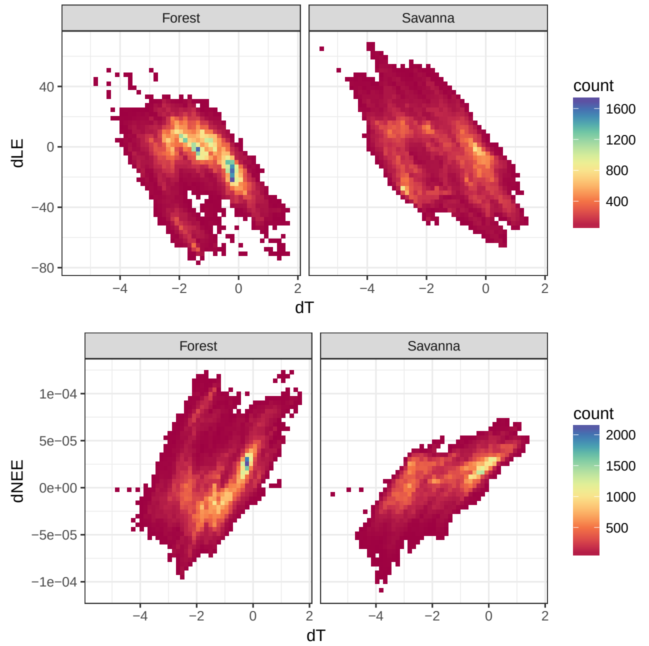

Figure 5: Impact of changes in surface temperature [K] (2016-2015) on the (top) change in latent heat flux [Wm^{-2}] and (bottom) change in net ecosystem exchange [$gm^{-2}s^{-1}$] for (left) forested and (right) savanna ecosystems.

particular, we can assess how ecosystems exhibit differential sensitivity to similar forcing events. This will become essential knowledge as we attempt to respond to the stresses induced by future climate change in these ecosystems.

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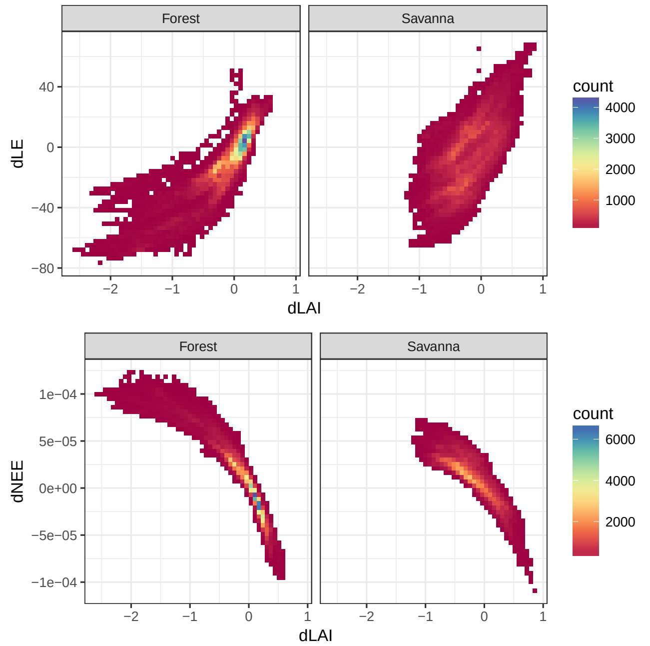

Figure 6: Impact of changes in leaf area index [m^2m^{-2}] (2016-2015) on the (top) change in latent heat flux [Wm^{-2}] and (bottom) change in net ecosystem exchange [$gm^{-2}s^{-1}$] for (left) forested and (right) savanna ecosystems.