Supporting Information for "Effects of increased drought in Amazon forests under climate change: Separating the roles of canopy responses and soil moisture"

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Introduction

Text S1. To understand how well JSBACH can reproduce the observations at the TFE experimental sites, we conduct land-only simulations at site-level. Atmospheric forcing of 3-hourly frequency representing CTR and EXP plots are used to force the model. At TAP, precipitation, temperature, specific humidity, and wind speed measured at the

nearby Km67 tower are used, with the rest of required forcing variables taken from the WATCH-WFDEI input data (Weedon et al., 2011, 2014). The humidity and temperature are applied at 2 m height, while the wind speed is applied at 10 m height. The soil depth is set to 10 m, which is the deepest available in JSBACH, and the rooting depth is set to 3 m. Soil parameters are tuned to reproduce the observed soil moisture, which are as follows: The Clapp and Hornberger (1978) exponent b is set to 1.15; the saturated hydraulic conductivity is set to 1.23×10^{-5} m/s; the saturated matrix potential is set to 0.533 m. At CAX, since no nearby measurements are available, all required forcing variables are taken from the WATCH-WFDEI input data. The soil depth is also set to 10 m, while the rooting depth is set to 6 m. The soil physics parameters (Clapp and Hornberger (1978) exponent b, saturated hydraulic conductivity, and saturated matrix potential) are set to the same values as in TAP. The simulations cover 2000 to 2006 at TAP, and 2002 to 2007 at CAX. One set of simulation is with precipitation kept unchanged (CTR), and the other with precipitation reduced to 50% of the original value (EXP; at TAP only during wet season from January to June and all-year round at CAX).

Text S2. The coupled simulations were conducted with the mpiesm-landveg_FOM_HW branch (commit a9b771ea), which is based on the mpiesm-landveg_FOM branch. The mpiesm-landveg_FOM branch is the development branch of the research group "Land Use in the Earth System" (previously "Forest Management"; hence the name FOM) in the department "The Land in the Earth System" of the Max Planck Institute for Meteorology. The mpiesm-landveg_FOM branch is in turn based on the official CMIP6 version of the MPI-ESM.

The model codes, scripts and information on how to repeat the simulations and analysis presented in this study are archived at the publication repository of the Max Planck Society (http://hdl.handle.net/21.11116/0000-0009-7975-C).

Text S3. The idea is to retain the spatial pattern and interannual variability (e.g., ENSO signals) of the observation and make use of the trend of the RCP8.5 simulation. First of all, we calculate from output of the CMIP6 version of RCP8.5 simulation the trend of both SST and SIC. At each grid point, the trend is calculated with a moving average of 20 years to remove interannual variability. The trend is then superimposed on the observations of SST and SIC from HadISST1 product.

Text S4. In JSBACH, most of the vegetation in the Amazon basin is classified as tropical evergreen trees. The maximum carboxylation rate at 25 °C (V_{cmax25}) in the model is 39.0 µmol(CO2)/m^2/s. When compared with the field measured data (Wu et al., 2017, SI), the V_{cmax25} lies within the range of mature leaves of all species, which is between 26.3 and 56.7 µmol(CO2)/m^2/s. The specific leaf area (SLA) of tropical evergreen trees in JSBACH is 0.264 m^2/molC. Compared with a site estimate from Malhado et al. (2009), the value is about 35% higher (0.196 m^2/molC). However, the value is still below the available mean value of tropical rainforest (0.329 m^2/molC; Poorter et al. (2009)).

Text S5. As can be seen from Fig. 1 and Table 1 in the main text, since the soil moisture of 21sm-20L is prescribed from the fully interactive experiment of 21sm-21L, it contains the negative feedback from the LAI under future drought. The difference in soil moisture between 20sm-20L and 21sm-20L therefore includes both (1) the pure soil moisture effects from greenhouse gas (GHG) forcing, and (2) the negative feedback from LAI. To isolate the LAI feedback, we conduct another experiment, in which the LAI is prescribed from 20sm-20L, and the soil moisture is interactive. As the soil moisture in the additional experiment include only the drought condition due to GHG forcing but does not contain the negative feedback of LAI under future drought, taking differences between the additional simulation and 20sm-20L gives the pure soil moisture effect of drought.

The followings are the comparison of the LAI feedback and the pure soil moisture effect. For soil moisture, the ratio between LAI feedback and the pure soil moisture effect is -12.1%. For GPP, the ratio is -5.9% and for NPP it is -8.1%. Finally, the ratio for NEP is -12.0%, indicating that the LAI feedback is roughly an order of magnitude smaller than the pure soil moisture effect.

Text S6. For the offline simulations at regional scale, the spatial resolution is T63 (ca. 200 km). The simulated region is limited to the Amazon region. The atmospheric output variables by MPI-ESM from the 21sm-21L experiment as described in Sec. 2.4 are used as the forcing to drive the JSBACH (the experiment with the modified JSBACH as land component is used). The pre-industrial forcing is used to drive JSBACH until the humus in the soil reaches equilibrium. Then, the model is run with historical forcing until 2014. From 2015 on, the model is forced with the climate under RCP8.5 scenario.

References

Clapp, R. B., & Hornberger, G. M. (1978). Empirical equations for some soil hydraulic properties. *Water Resources Research*, *14*(4), 601-604. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/WR014i004p00601 doi: 10.1029/WR014i004p00601

Malhado, A. C., Costa, M. H., de Lima, F. Z., Portilho, K. C., & Figueiredo, D. N. (2009, sep). Seasonal leaf dynamics in an Amazonian tropical forest. *Forest Ecology and Management*, *258*(7), 1161–1165. Retrieved from https://linkinghub.elsevier.com/retrieve/pii/S0378112709003971 doi: 10.1016/j.foreco.2009.06.002

Poorter, H., Niinemets, Ü., Poorter, L., Wright, I. J., & Villar, R. (2009, may). Causes and consequences of variation in leaf mass per area (LMA): a meta-analysis. *New Phytologist*, *182*(3), 565–588. Retrieved from https://onlinelibrary.wiley.com/doi/10.1111/j.1469-8137.2009.02830.x doi: 10.1111/j.1469-8137.2009.02830.x

Weedon, G. P., Balsamo, G., Bellouin, N., Gomes, S., Best, M. J., & Viterbo, P. (2014). The wfdei meteorological forcing data set: Watch forcing data methodology applied to era-interim reanalysis data. *Water Resources Research*, *50*(9), 7505-7514. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1002/2014WR015638 doi: https://doi.org/10.1002/2014WR015638

Weedon, G. P., Gomes, S., Viterbo, P., Shuttleworth, W. J., Blyth, E., ÖSterle, H., ... Best, M. (2011). Creation of the WATCH forcing data and its use to assess global and regional reference crop evaporation over land during the twentieth century. *Journal of Hydrometeorology*, *12*(5), 823–848. doi: 10.1175/2011JHM1369.1

Wu, J., Serbin, S. P., Xu, X., Albert, L. P., Chen, M., Meng, R., ... Rogers, A. (2017).

The phenology of leaf quality and its within-canopy variation is essential for accurate modeling of photosynthesis in tropical evergreen forests. *Global Change Biology*, *23*(11), 4814–4827. doi: 10.1111/gcb.13725

Yin, L., Fu, R., Shevliakova, E., & Dickinson, R. E. (2013). How well can CMIP5 simulate precipitation and its controlling processes over tropical South America? *Climate Dynamics*, *41*(11-12), 3127–3143. doi: 10.1007/s00382-012-1582-y

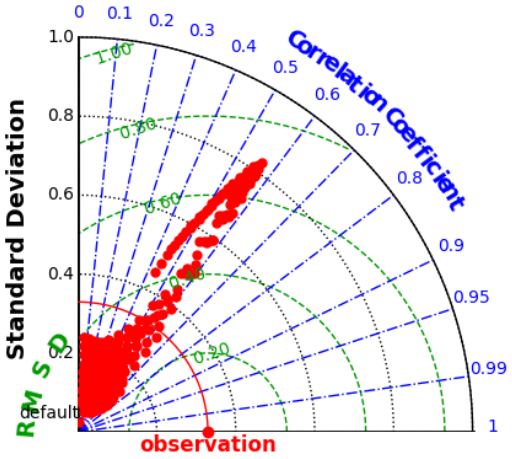

Figure S1. Taylor Diagrams of observational and simulated LAI at the experimental (drought) plot at the throughfall exclusion experimental site at Tapajós National Forest. Only the first two years of data are used. The standard JSBACH is also shown on the diagram with the label "default".

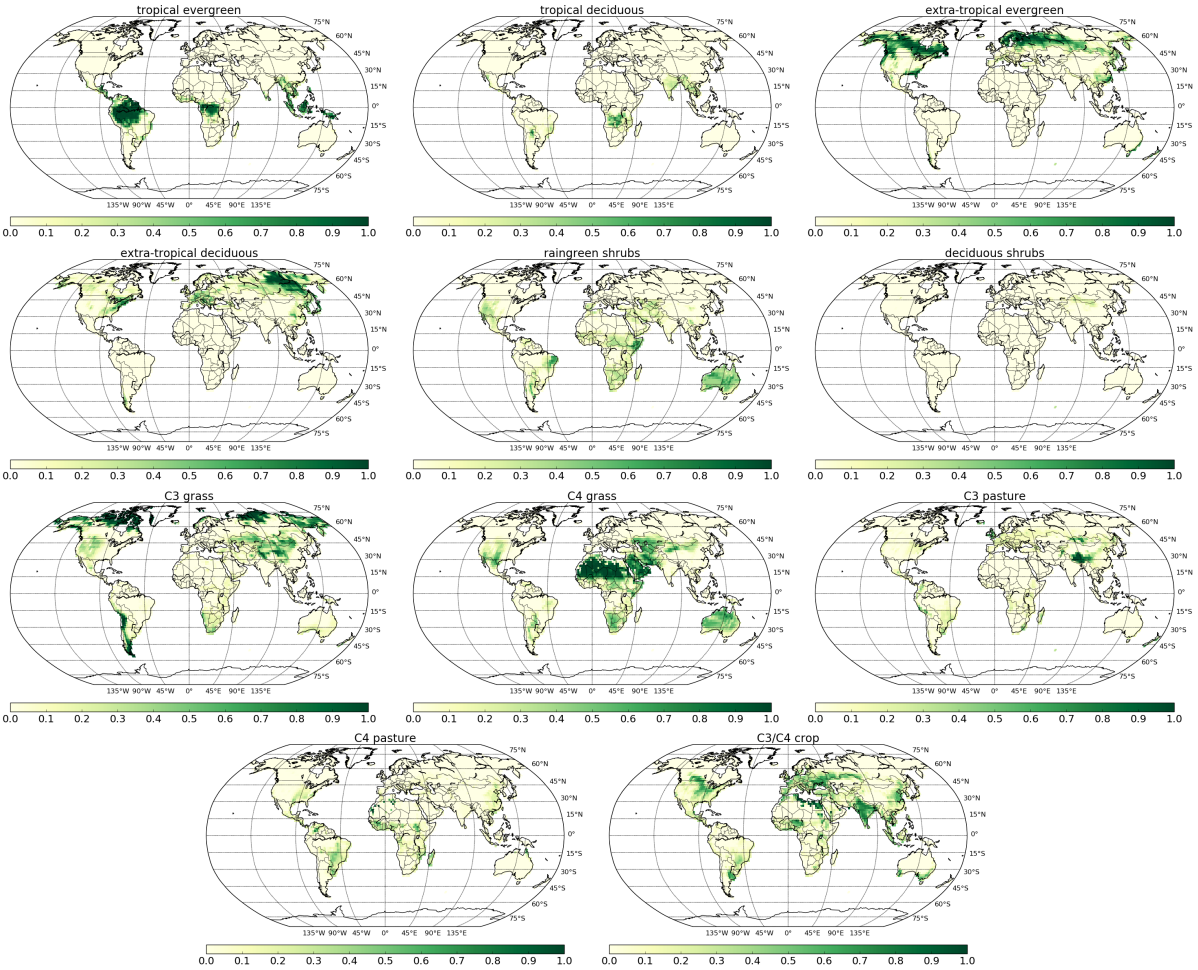

Figure S2. Cover fraction of the 11 Plant Functional Types in TRENDYv7. Note that tropical evergreen trees, tropical deciduous trees and raingreen shrubs are classified as raingreen phenological types in JSBACH.

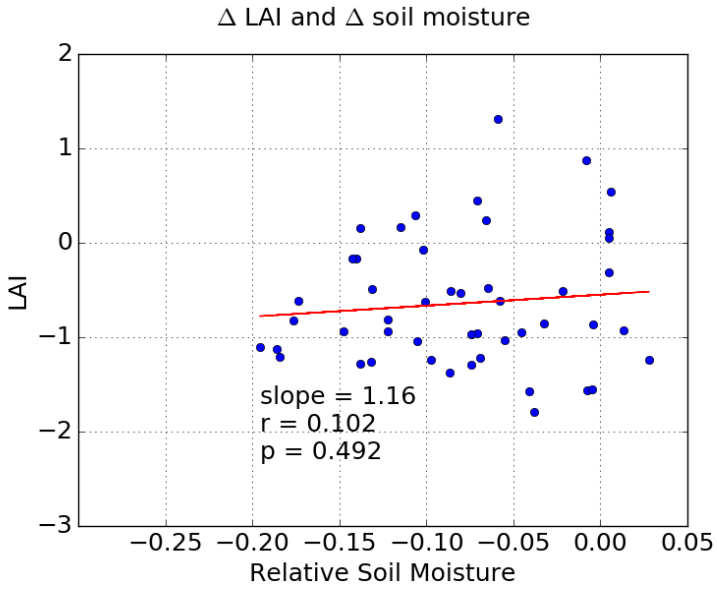

Figure S3. The differences of observations between the EXP (with throughfall exclusion) and CTR (without throughfall exclusion) plots at Tapajós National Forest. X-axis: relative soil moisture; Y-axis: LAI.

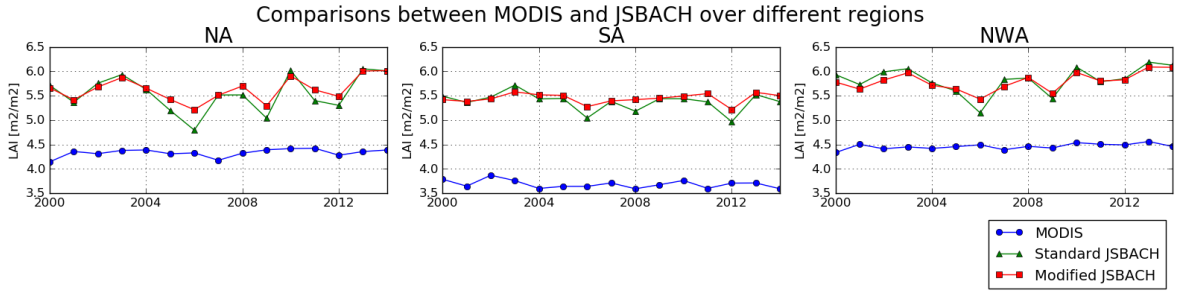

Figure S4. Comparisons of annual mean LAI from 2000 to 2014 over the three region in the Amazon basin, which are the Northern Amazon (NA, 70°W–55°W, 5°S–5°N), the Southern Amazon (SA, 70°W–50°W, 15°S–5°S), and the Northwestern Amazon (NWA, 75°W–60°W, 10°S –5°N), as defined in Yin et al. (2013).

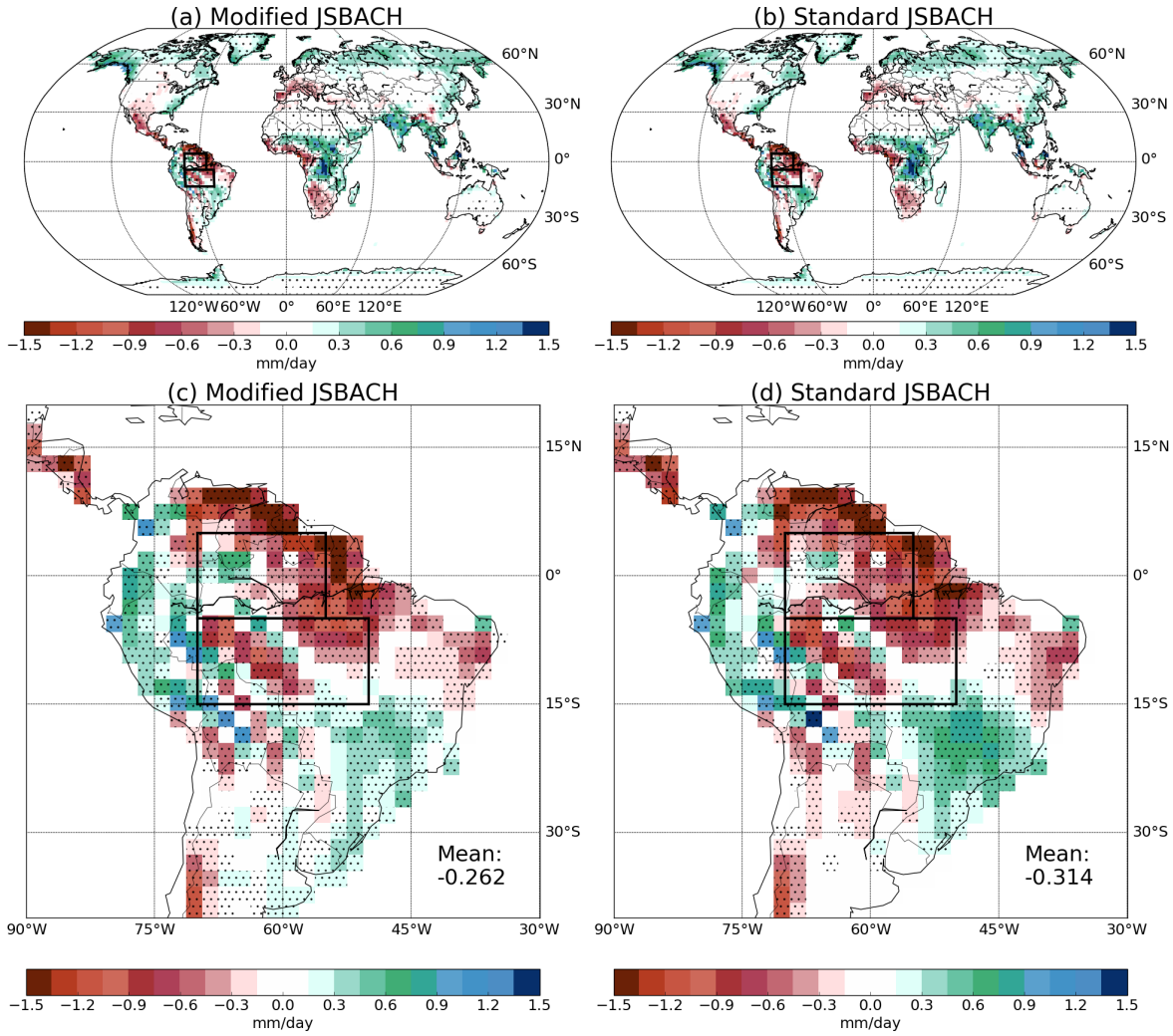

Figure S5. Simulated differences in precipitation by the MPI-ESM with the (a)(c) modified JSBACH and (b)(d) standard JSBACH as the land component. Differences are taken between the end of the 21st century (2071–2085) and the 20th century (1971–2000). (c) shows only South America from (a), and (d) shows only South America from (b).

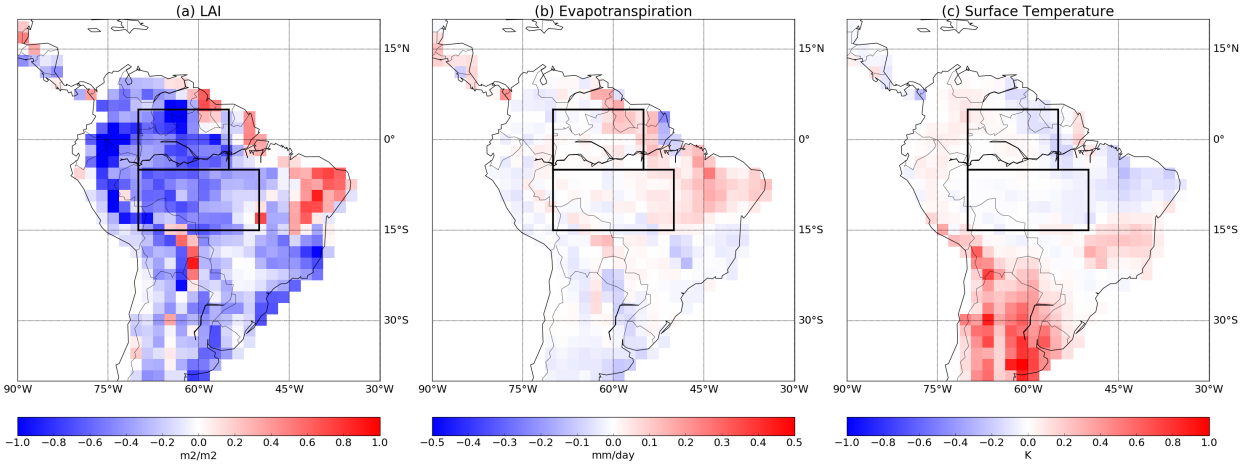

Figure S6. Differences in (a) LAI, (b) Evapotranspiration, and (c) Surface temperature simulated by MPI-ESM with different versions of JSBACH as the land component (modified minus standard). Averaged taken during the late 20th century (1971–2000)

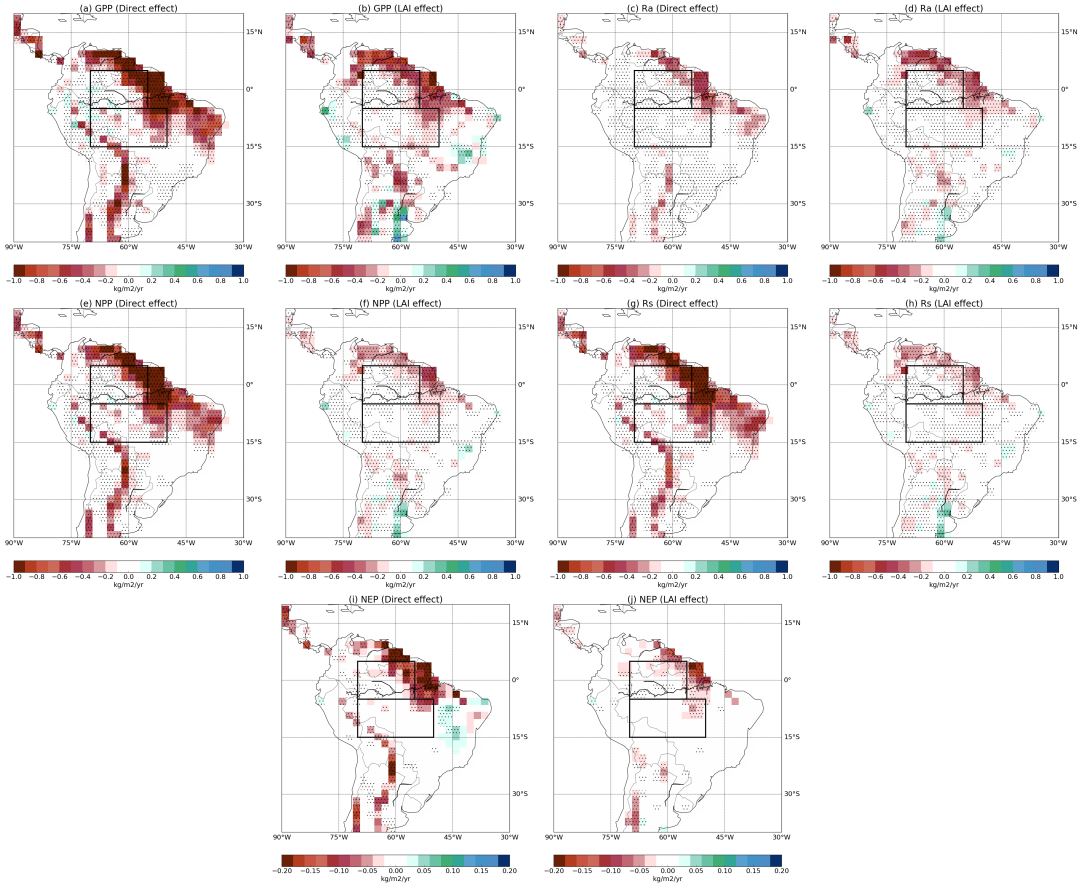

Figure S7. Spatial pattern of the direct and LAI effects on different carbon budget terms during 2071–2085. GPP: Gross primary production. Ra: Autotrophic respiration. NPP: Net primary production. Rs: Soil respiration. NEP: Net ecosystem production. Dots: All ensemble members agree on the signs of change.