Impact of Inland Deforestation on Rainfall Extremes: Amplifying the Role of Cold Pool Interactions in Organizing Convection

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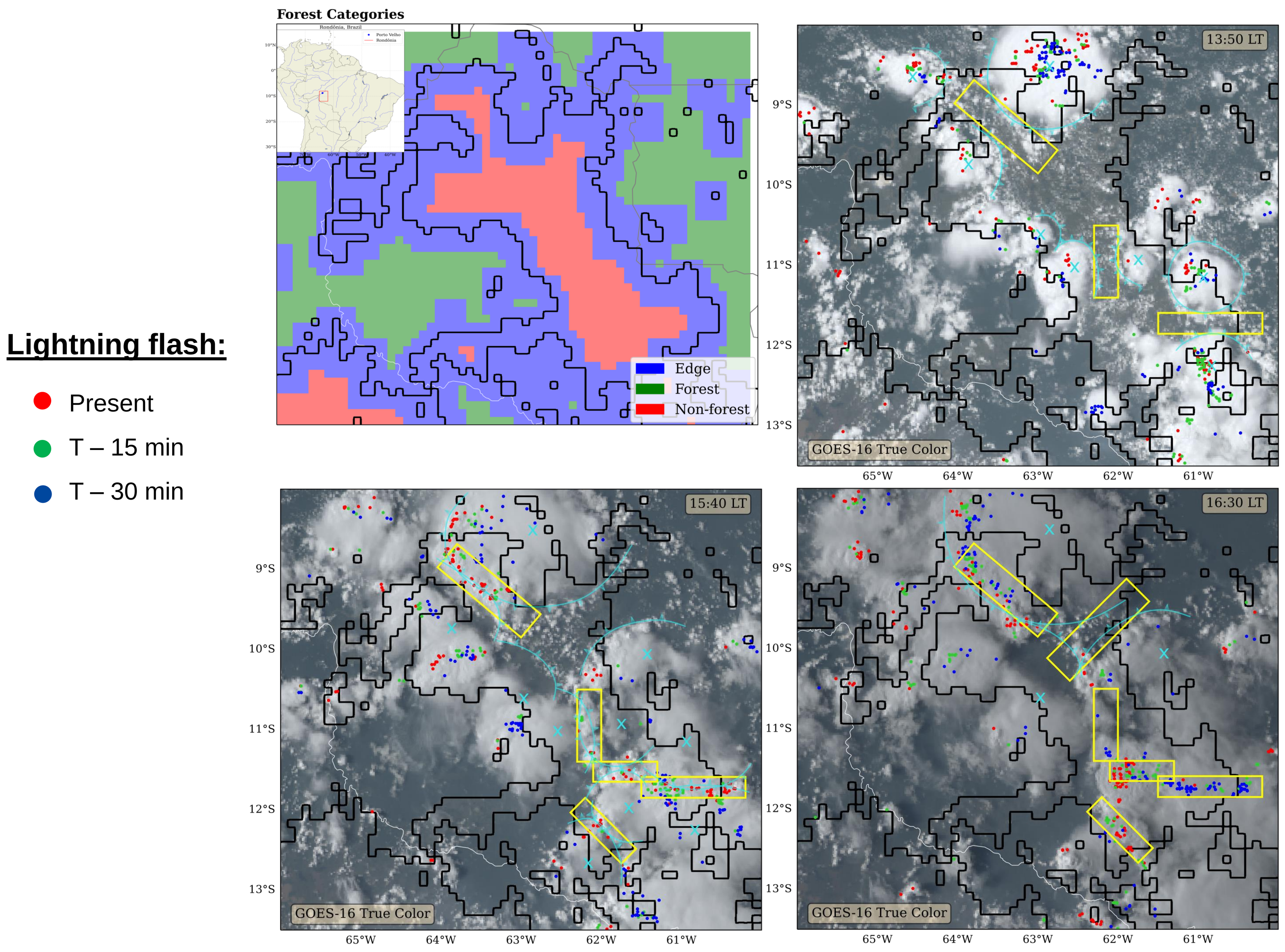
Motivation

Under weak large-scale forcing, thermally induced mesoscale circulations are well known to focus moist convection along sharp gradients in land surface properties [1]. Anthropogenic deforestation changes these land surface properties, and although a number of previous studies found an average decrease in rainfall brought about by deforestation [2], questions regarding rainfall extremes over these areas and possible mechanisms resulting in the extremes remain largely unanswered.

From initial investigations((image below) we observe numerous cold pools (CP) that collide near the centre of a deforested region in the Amazon, resulting in deep convection with dens lightning activity. A number of questions arise from this behaviour. Is it coincidence or is there a persistent pattern of deep convection? What role does the deforested land surface play? Is the deforestation size and pattern a factor in determining the probability of cold pool collisions? And how well do we expect NWP models to resolve this phenomena?

Objective:

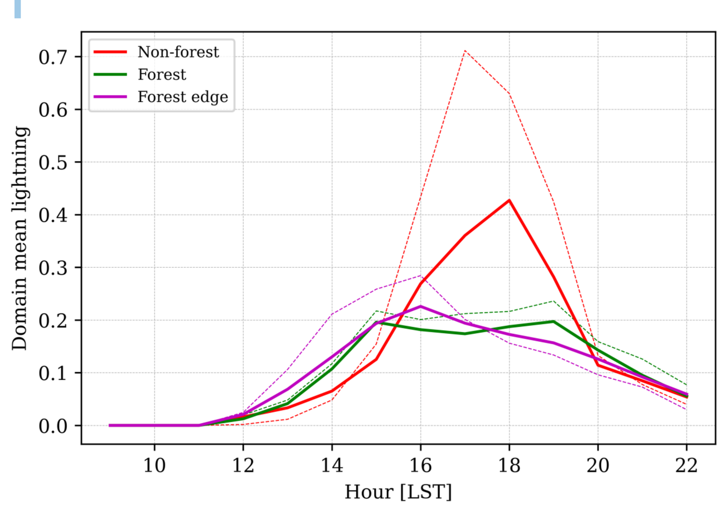
(I) Model the behaviour of inland deforestation on afternoon rainfall in a simplified way by employing a checkerboard pattern of alternating dry vs. wet soil moisture patches inside an idealized, relatively high-resolution, cloud resolving model, with patch sizes comparable to the deforestation found in Rondônia (~100km).

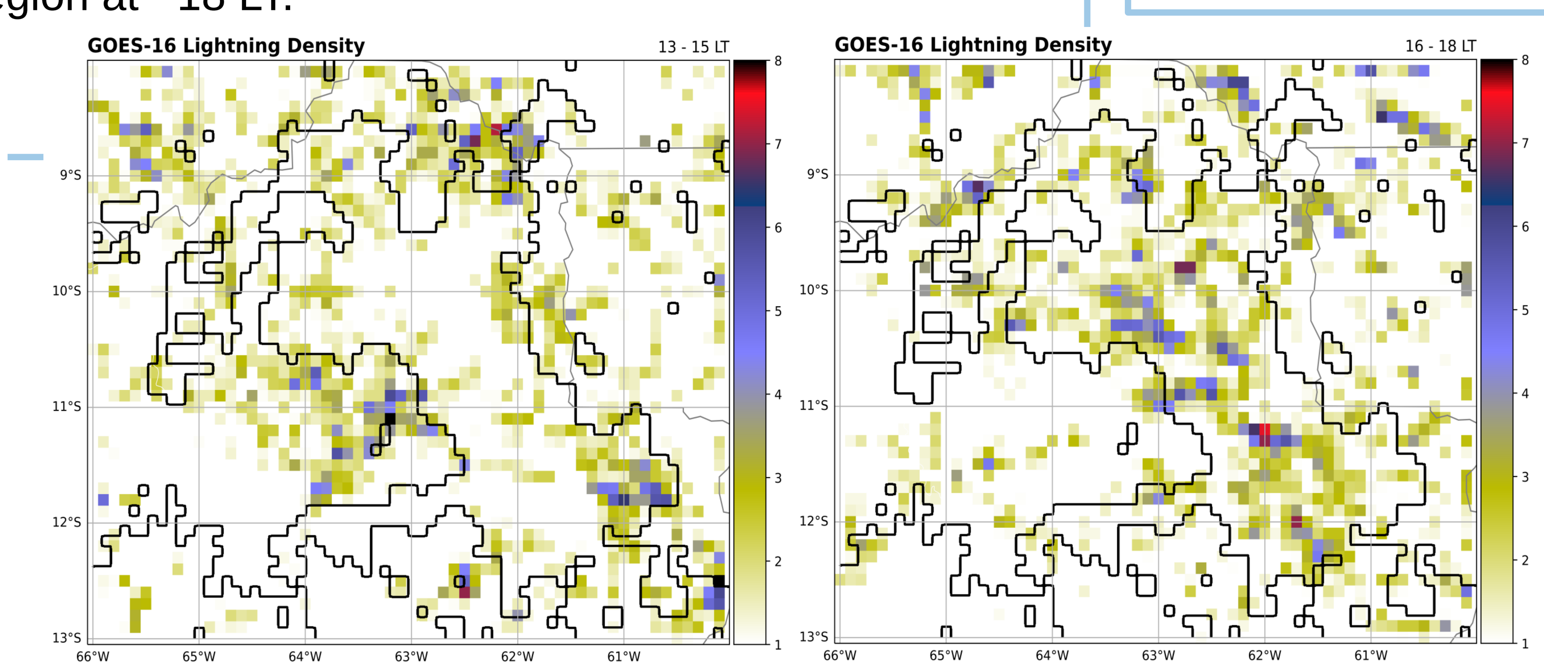


Observations | Satellite

GOES lightning observations, Rondônia. Using 4 years of lighting flash data sourced from the GOES-16 satellite over Rondônia and conditioning the lightning on days dominated by warm, synoptically weak weather (using ERA5 reanalysis), similar lightning patterns emerge when compared to the convection patterns seen in the idealized simulations (see time series plots on the right).

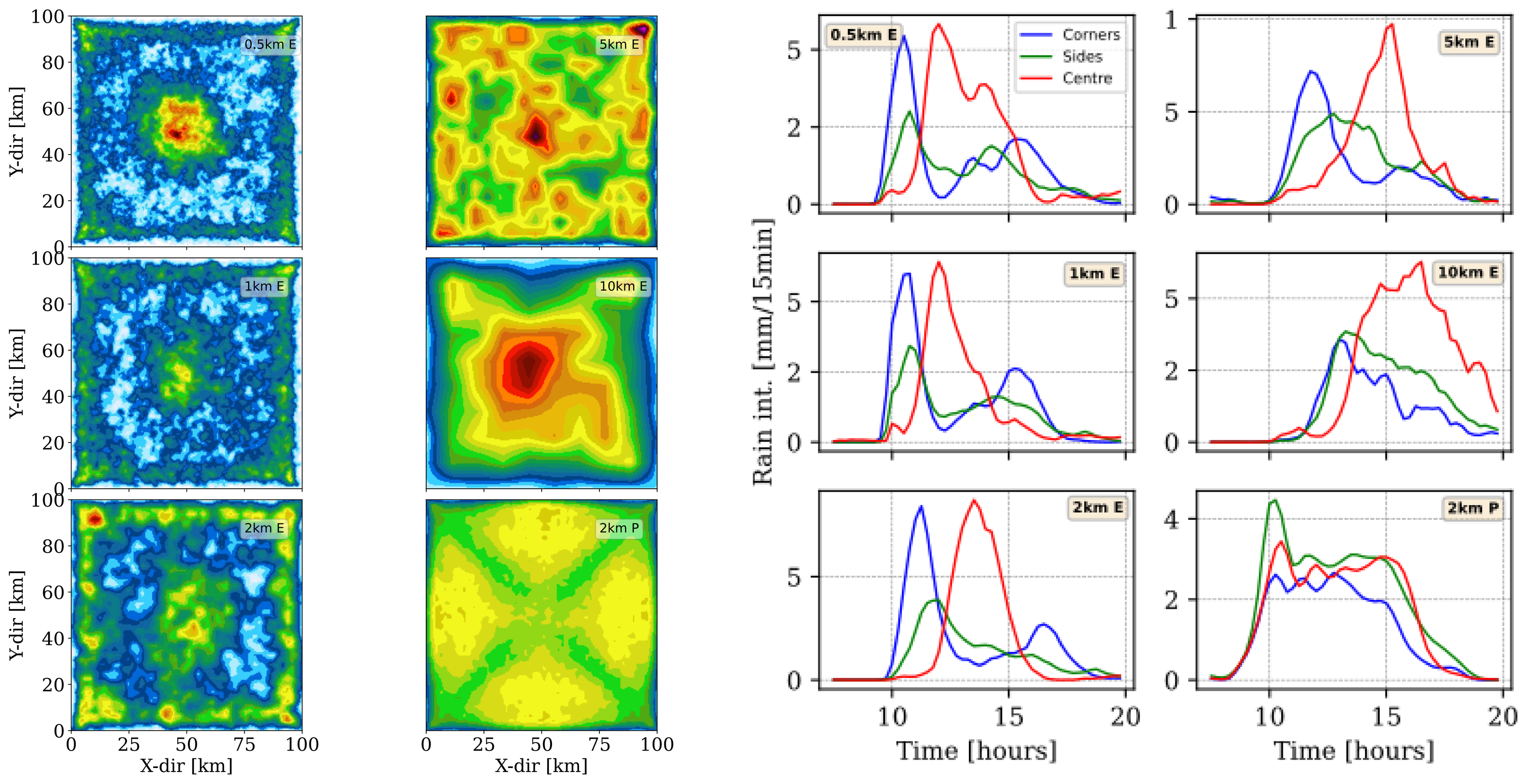
Lightning (lower right) is typically concentrated along the forest edge in the early to mid-afternoon. As the afternoon progresses, lightning migrates to the inner regions of the deforested site, where local maxima of lightning density occurs. The timeseries of lightning (lower left) shows two notable peaks; first on the edges at ~16 LT, followed by a large peak in the non-forested region at ~18 LT.





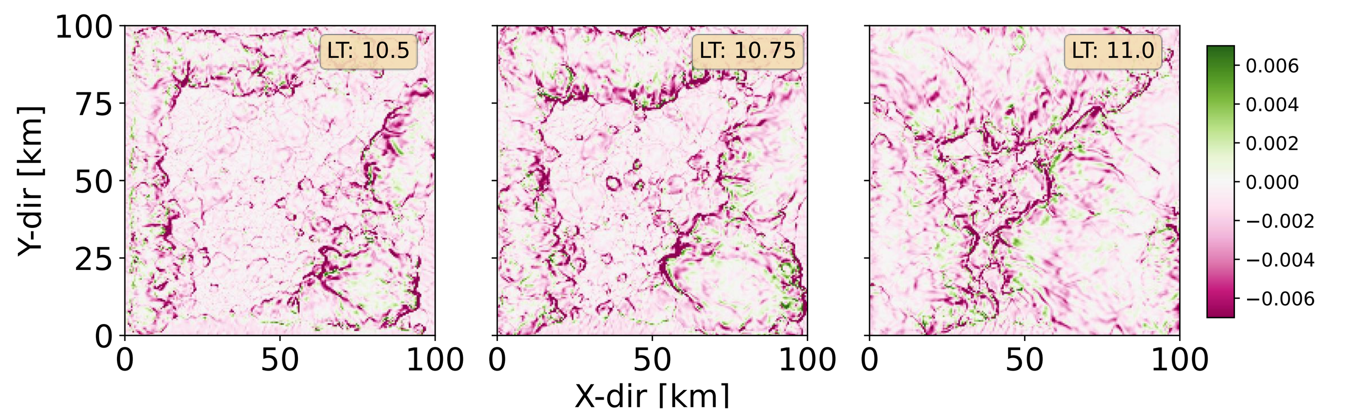
Idealized simulations | rainfall patterns

Sensitivity to model resolution. We use idealized simulations with a checkerboard pattern of dry and wet soils to answer questions related to rainfall extremes that may be relevant to deforestation. This may help better interpret past rainfall studies over Rondônia and guide future studies, particularly as it relates to model resolution. Over dry patches 100 x 100 km in size the model (WRFV4) simulates rainfall patterns that are strikingly similar to those we find in the GOES-16 lightning data. This is true for horizontal grid resolutions (with explicit convection) ranging from 500m to 5km, with the biggest difference being a shift in timing of peak rainfall to later in the day. This holds true even at 10km, though the temporal peak of rainfall in the centre is less pronounced. With convective parameterized switched on (2km P) the model fails to resolve the pattern we observe in the lightning data, both spatial and temporally.



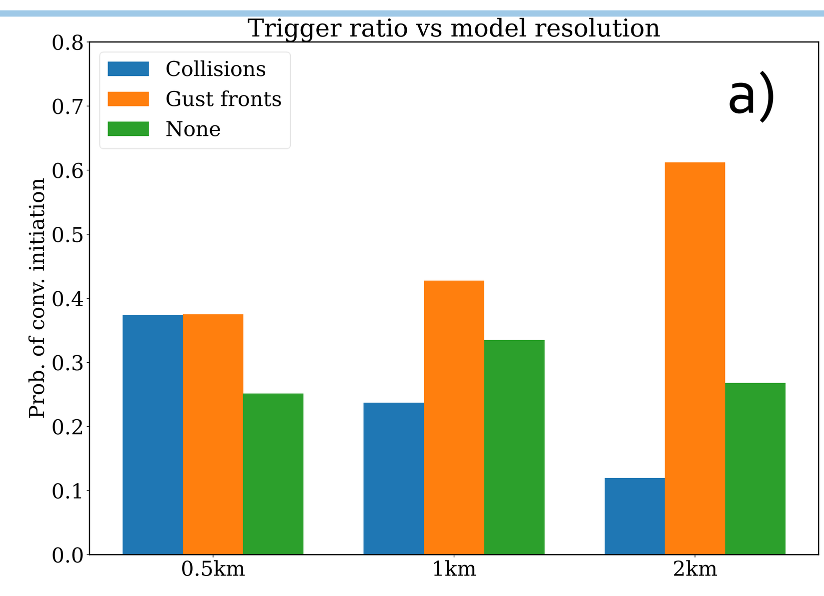
Idealized simulations | CP detection

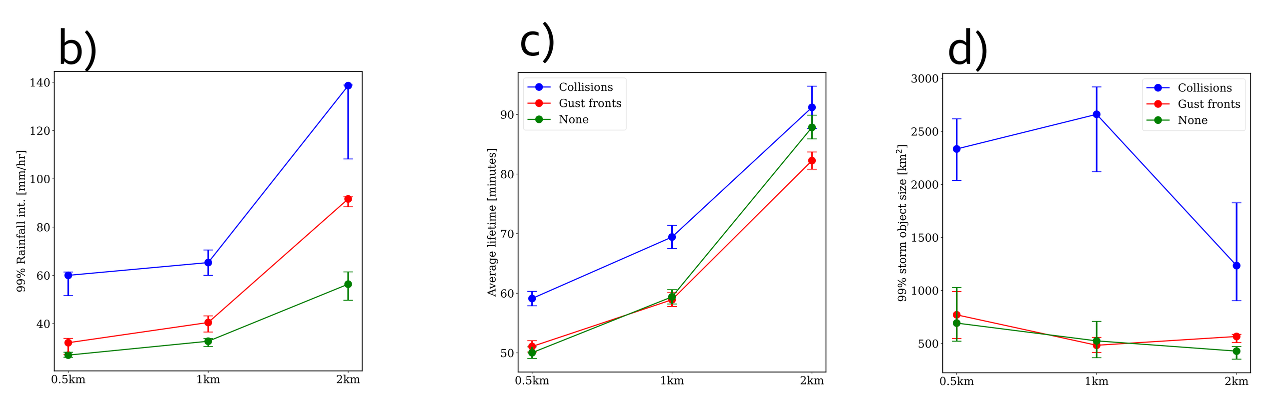
Understanding key mechanisms. We know that thermal mesoscale breezes can control convective initiation, which explains the clustering of early afternoon convection near the forest edges in the image to the left. The image on the left also suggest that CP and CP collisions play a key role in rainfall extremes over deforested landscapes. In the model we can identify gust fronts of the CPs by the change in surface virtual temperature (bottom image). Thermal breezes from the surrounding wet boxes help steer the gust fronts toward the centre of the dry patch where they eventually collide.
By tracking moist convective cells, we can determine whether they have been triggered inside a CP collision, gust front or neither.



- From 500m to 2km grids, the majority of storm are triggered by CP's (fig. a).
- 500m resolution detects the most collisions in relation to other categories.

- 99% rainfall intensity are highest within collision triggered storms (fig. b)
- The average lifetime of storms are slightly longer in CP collisions (fig. c)
- 500m and 1km resolution runs organize convection into larger storms (fig. d), while these large storms are more likely to occur after a CP collision.





Conclusion

We conclude that human-made land cover changes could potentially affect extreme rainfall events at the mesoscale. Therefore, when devising land cover changes that grow beyond 50 x 50 km, nearby metropolitan areas, or nearby areas that are susceptible to erosion and flash flood damage, should be considered beforehand, particularly within the deforested region.

REFERENCES

[1] R. Knox, G. Bisht, J. Wang, & R. Bras. Precipitation variability over the forest-to-nonforest transition in southwestern Amazonia. Journal of Climate, 24, 2368 (2011).

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