DEFORESTATION OF THE AMAZON FOREST: UNDERSTANDING HYDROCLIMATE IMPACTS BY TRACING THE WATER THAT EVAPORATES FROM THE FOREST

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EXECUTIVE SUMMARY

The Amazon Forest has undergone significant deforestation in the past decades with natural forests being replaced by agriculture and pasturelands. In this work, the research team evaluated the impacts of continued deforestation on the hydroclimate of the South American continent. They initiated 10-year climatological simulations created with the Weather Research and Forecast (WRF) model with added water vapor tracers (WRF–WVT). The water vapor tracers track the water that originates from the Amazonian forest and follow it in space and time as the moisture is advected and contributes to precipitation. In the water-limited southern Amazon, the researchers found that the effects of deforestation are locally strong with distinct changes in the deforested areas. Although area-averaged precipitation decreases, the team also found regions with increased precipitation owing to changes in the atmospheric circulation from changes in land cover. This reveals both positive and negative feedback from deforestation and complex land–atmosphere interactions in the hydroclimate of South America.

RESEARCH CHALLENGE

Deforestation of the Amazon Forest in the past decades has seen natural forests being replaced by agriculture and pasturelands (see mapbiomas.org for the evolution of land cover since 1985). A very high rate of deforestation in the year 2005 (19,000 km^2) was followed by a sharp decline in 2012; unfortunately, the rate has since increased again to almost 8,000 km^2 in 2018 [2].

The Amazon is the largest tropical rainforest on Earth. Up to 50% of Amazonian precipitation originates as evapotranspiration from the forest [7,9]. Furthermore, downwind regions in the La Plata and Orinoco Basins are dependent on Amazonian moisture for their precipitation [4,8]. The critical question is how continued deforestation of the Amazon Forest will affect the hydroclimate of the South American continent.

METHODS & CODES

The researchers incorporated Water Vapor Tracers (WVT) into the Weather Research and Forecasting model (WRF) [3,5]. This allows users to trace moisture that originates as evapotranspiration from a tagged Amazon region. (Evapotranspiration that originates from the Amazon is numerically "tagged" as it undergoes the same physical processes as total moisture such as advection, convection, phase change, and the like.) In addition, WRF–WVT saves tracer moisture-related variables. In particular, tracer moisture advection and horizontal diffusion follow the exact same transport equations in WRF for scalar variables, including water vapor and all micrometeors. Tracer moisture changes phase and is converted to precipitation in the same proportion as full moisture in all cases. All tracer moisture species are generated or converted from one to another and to precipitation, mimicking their full-moisture counterparts.

The research team performed two 10-year continuous simulations for the period 2004–2013 over the domain shown in Fig.

Figure 1: Domain for WRF–WVT simulations, including South America and surrounding bodies of water. The green outline is the Amazon Basin and the red outline is the La Plata River Basin. The regions shown in dark red are deforested to cropland in the year 2050 based on the projections in [6].

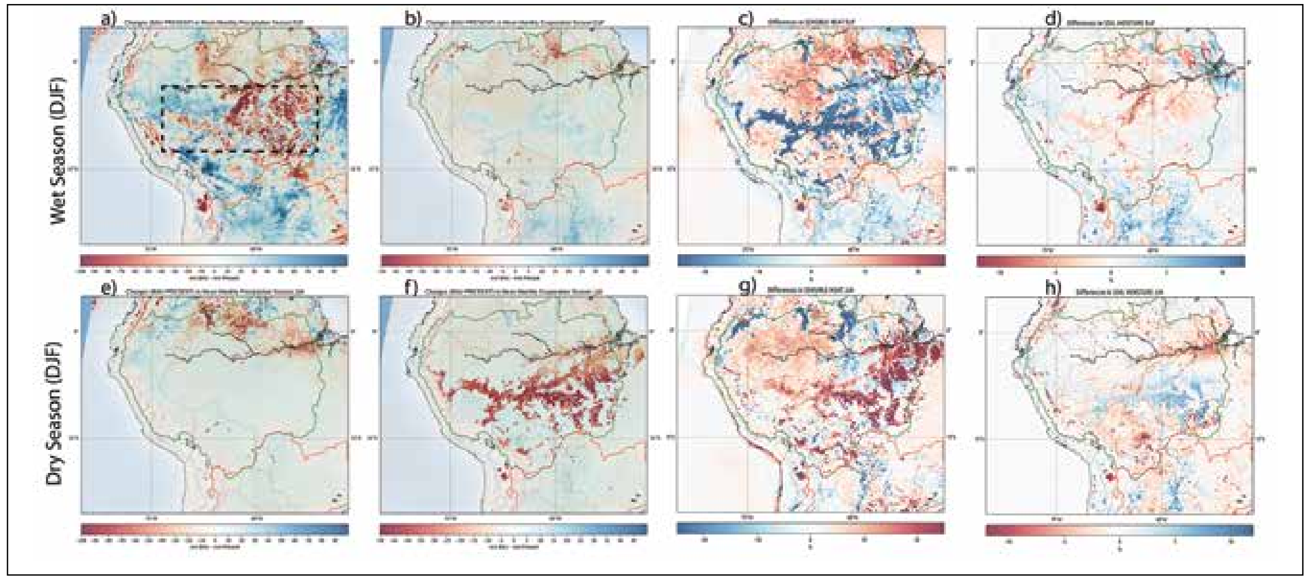

Figure 2: Ten-year average wet season–DJF (top) and dry season–JJA (bottom): (a, e) changes in precipitation; (b, f) evaporation; (c, g) sensible heat; and (d, h) soil moisture. The changes are between the business-as-usual (BAU) deforestation scenario and the control simulation.

1 using lateral boundary conditions from the ERA–Interim reanalysis data set [1]. The simulation has a horizontal resolution of 20 km and 40 levels in the vertical direction (see Yang and Dominguez, listed under "Publications & Data Sets" for details). The first simulation used observed land use for the period 2004–2013, while the second set of simulations has the projected land cover change as simulated by SimAmazonia–1 (Fig. 1, red areas), which provides land-use projections up to the year 2050 that incorporate road development in the Amazon basin [6].

RESULTS & IMPACT

The research team has focused its results on the Southern Amazon Forest (dashed black box in Fig. 2a). This region is characterized by transitional forests where precipitation is less than in the northern tropical forests, and there is a marked dry season [10]. The team has analyzed the results as changes between the deforested scenario and the control simulation for different hydroclimate variables including precipitation, evapotranspiration (ET), sensible heat, and soil moisture. In the discussion that follows, ET and latent heat are used interchangeably, and the results are for both the wet and dry seasons as they show contrasting behavior.

December–January–February (DJF). During the wet season (DJF), the deforested regions show very distinct decreases in precipitation (Fig. 2a, red areas). These changes in precipitation result in a decrease in cloudiness and increase in net radiation (shortwave radiation) that increases ET (Fig. 2b, blue areas). Soil moisture is depleted owing to increased ET/latent heat (Fig. 2d, red areas). As more energy goes into latent heat, this leads to a significant decrease in sensible heat (Fig. 2c, blue areas) and surface temperature (not shown). These results indicate that during this season of water abundance, the deforested region behaves as a radiation-limited ecosystem. Interestingly, a marked increase in moisture flux (not shown) results, rather counterintuitively, in more precipitation downwind of the deforestation area.

June–July–August (JJA). During the dry season (JJA), the deforested region shows strong decreases in ET (Fig. 2f), indicating that the vegetation is not able to access the soil moisture. This leads to increased temperature throughout the deforested region and increased sensible heat flux (Fig. 2g). Because there is less ET, the soil moisture increases (Fig. 2h). Changes in precipitation are negligible (Fig. 2e).

In conclusion, when focusing on the transitional forests of the southern Amazon, the research team has found contrasting behavior during the wet and dry seasons. During the wet season, the main control on ET is through radiation as there is still an ample supply of moisture. During the dry season, the region is water-limited and ET decreases significantly. Precipitation during the wet season is clearly decreased over the deforested areas, but precipitation downwind of the deforested areas is actually increased owing to increased moisture transport. During the dry season, there is very little change in precipitation. These results show the complex behavior of land–atmosphere interactions when changes in land cover occur.

WHY BLUE WATERS

Blue Waters was critical to performing the simulations owing to their very high computational expense. The research team would not have been able to perform them on their local cluster.

PUBLICATIONS & DATA SETS

Z. Yang and F. Dominguez, "Investigating land surface effect on the moisture transport over South America with a moisture tagging model," *J. Clim.*, vol. 32, no. 19, pp. 6627–6644, Oct. 2019.