5D.7 RELATIONSHIP BETWEEN AMAZON AND HIGH ANDES RAINFALL

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1. INTRODUCTION

Present and past precipitation records from over South America suggest that there is a relationship between rainfall over the Amazon and high Andes region of Peru, Bolivia, Argentina, and Chile, one that is presently not well understood. A period in time that exemplifies this is the Last Glacial Maximum (LGM, ~ 21,000 years ago), as paleo-proxy evidence generally indicates that the high Andes were wetter during this period, while conditions over the Amazon were drier, although there is more uncertainty about the latter.

The purpose of this study is to better understand the relationship between Amazonian and high Andes rainfall by utilizing a regional climate model. Simulations from the present day and the Last Glacial Maximum (LGM; ~21,000 years ago) provide two cases.

2. EXPERIMENTAL SET-UP

The model used is a version of the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) MM5 (v3.6) model adapted for tropical climate use. A complete model description and an in-depth validation of the modeled present day South American climate is presented in Vizy and Cook (2005) and Cook and Vizy (2006). The model provides a 60-km resolution state-of-the-art representation of the present day South American climate, as good as or better than those available from previous modeling studies.

Lateral and surface boundary conditions are derived from climatological monthly mean values updated twice daily during the 382-day integrations (a full year plus a 17 day spin up) from the NCAR/NCEP reanalysis [see Vizy and Cook (2005) for further details]. The model has a 1- minute time step and 24 vertical σ-levels. The top of the atmosphere is set at 50 hPa.

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Two model simulations are analyzed. The first is a present day control, with modern orbital parameters, CO_2 concentrations (330 ppmv), vegetation, and SSTs. The second simulation is a full LGM forcing simulation with LGM orbital parameters, CO_2 concentrations of 200 ppmv, and SSTs from the reconstruction of Paul and Schäfer-Neth (2003). Present day vegetation distributions are retained, as recommended by the Paleoclimate Modeling Intercomparison Project Phase II protocol.

3. RESULTS

Fig. 1a shows annual rainfall from the present day simulation, and Fig. 1b displays annual precipitation differences between the LGM and present day simulations. The model simulates drier (wetter) annual conditions over the Amazon (High Andes), which agrees with the paleo-proxy evidence.

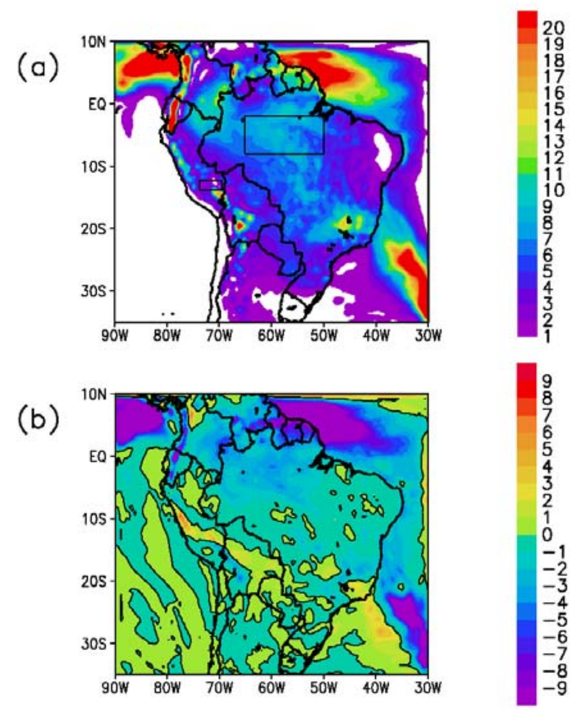

Figure 1 (a) Annual rainfall rates in the present day simulation, and rainfall differences from the present day for the full LGM simulation. Units of shading are mm/day. Boxes denote averaging regions used in Figure 2.

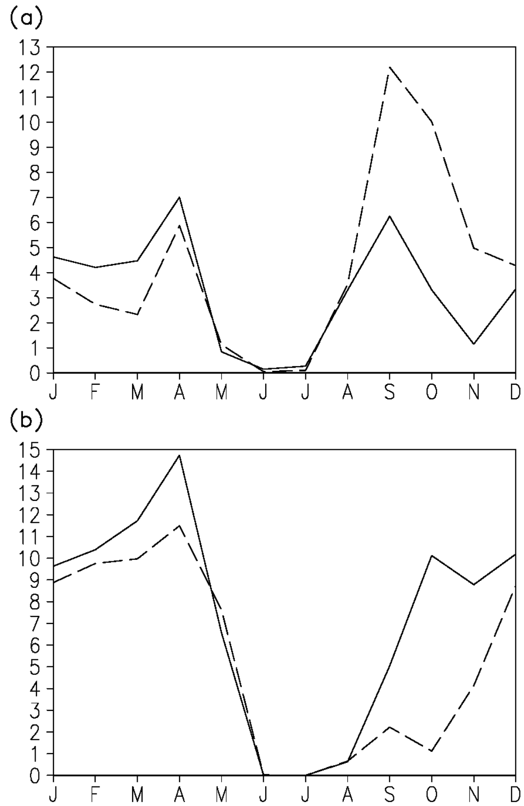

Figure 2. Area-averaged monthly precipitation (mm/day) for the (solid line) present day, (long dashed line) LGM for (a) 13.82°S – 12.25°S; 73.77°W – 69.44°W, and (b) 8°S - 2°S; 65°W - 50°W.

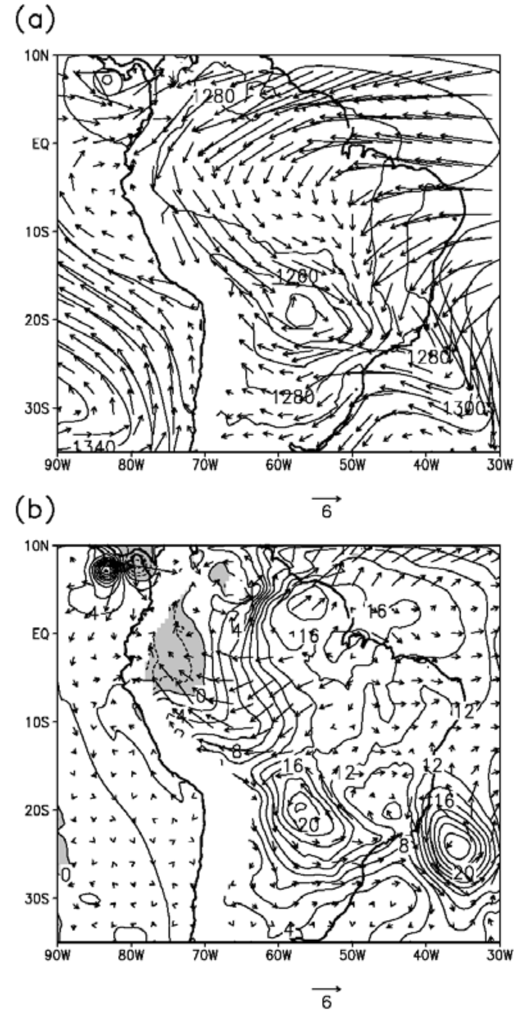

Figure 3. 870 hPa October (a) geopotential heights (m) and winds (m/s) from the present day simulation, and (b) Full LGM minus present day height and wind differences. Shading denotes negative height anomalies.

Fig. 2 shows the monthly, area-averaged rainfall rates for the present day and LGM simulations for a region over the High Andes (Fig. 2a) and the Amazon (Fig. 2b) as denoted by the boxes in Fig. 1a. Model results for the LGM indicate that a delay in the onset of convection in the Amazon during austral spring (Cook and Vizy 2006) is associated with an enhancement of rainfall over the high Andes.

During the months of the delayed onset in the LGM, in austral spring, zonal height gradients between the Andes and the Atlantic Ocean are more intense than those in the present day simulation, resulting in anomalous easterly flow between the Amazon and the high Andes. Fig. 3a shows the October 870 hPa geopotential heights and winds for the present day run, while Fig. 3b shows the October LGM geopotential height and wind anomalies. In the present day climate, the low-level flow runs parallel to the Andes (e.g., northwesterly) during the austral spring months, but in the LGM simulation it is instead directed up the eastern slopes of the Andes (e.g., northeasterly) and transports lower-tropospheric moisture from the Amazon up into the mountains.

Figure 4 illustrates this circulation difference near the Andes. Figs. 4a and b show October meridional cross-sections of the vertical moisture flux, qw, in addition to meridional (v-wind component) and scaled vertical velocity (w-wind component) vectors for the present day and the LGM, respectively, along 70°W. North of about 12°S, the flow below 700 hPa has a northerly component associated with the South American low-level jet (SALLJ), while the flow between 600 and 300 hPa generally has a southerly component during the present day (Fig. 10a). Vertical motion is weak below 600 hPa. Along the northeastern slopes of the Andes (14°S – 12°S) there is some upward motion, but it is generally confined below 700 hPa. Above 700 hPa, subsidence inhibits further vertical uplift.

During the LGM (Fig. 4b), the northerly component of the flow (i.e., the SALLJ) below 800 hPa is weaker, while the mid-tropospheric flow between 600 hPa and 400 hPa reverses directions and becomes northerly. Between 800 hPa and 300 hPa, subsidence along the northeastern slopes of the Andes diminishes, and is replaced by an increase in upward motion and enhanced moisture flux transport into the middle and upper troposphere.

Once the LGM summer rains become established over the Amazon, simulated rainfall rates over the Andes quickly become similar to, or even slightly lower, than present day values for the rest of the season (Fig 2). This suggests that the dynamical circulation changes

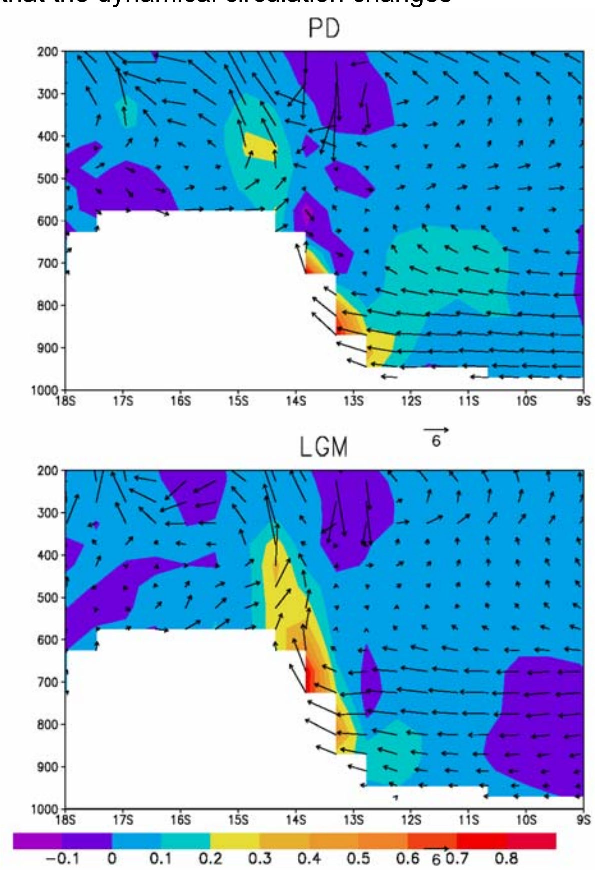

Figure 4. October meridional cross-sectional profiles along 70°W of the vertical component of the moisture flux, qw (g m kg^{-1} s^{-1}), in addition to meridional v-wind (m s^{-1}); and scaled vertical velocity ($\times$ 100 m s^{-1}) vectors for the (a) present day and (b) LGM. Shaded values represent qw.

associated with the Amazonian convection during the austral spring onset are important for rainfall variability over the high Andes. However, the opposite does not appear to hold true, as there is no clear evidence from these simulations suggesting that the variations in high Andes rainfall influences the Amazon response.

4. CONCLUSIONS

A regional climate model is used to study the connections between Amazon and high Andes rainfall. The modeling effort focuses on understanding the rainfall response during the LGM.

The delayed onset of Amazon convection in the LGM during austral spring, which was found to be related to lower annual precipitation totals in the Amazon and related to cooler tropical Atlantic SSTs (Cook and Vizy 2006), is associated with an enhancement of rainfall over the high Andes. In the absence of convection over the Amazon in September and October, zonal geopotential height gradients between the Andes and the Atlantic Ocean remain strong and even intensify, resulting in anomalous easterly flow between the Amazon and the high Andes. Instead of the low-level flow remaining parallel to the Andes (e.g., northwesterly), the flow impinges more directly onto the eastern slopes of the Andes during the LGM, where it rises and transports moisture from the Amazon up into the mountains, enhancing convection over the Andes.

This circulation mechanism explains how atmospheric moisture, and rainfall, over the high Andes of Peru and Bolivia can increase despite large-scale LGM drying over South America. Our study as well as previous work (e.g., Fuenzalida and Rutlland 1987, Vuille et al. 1998, Chaffaut et al. 1998, Garreaud 1999) indicates that the moisture source for the Andes region is the Amazon basin, but that rainfall variability over the central Andes is not directly controlled by moisture changes in the Amazon basin (Garreaud et al. 2003).

This most likely is related to the elevation differences between the Amazon and central Andes. Regardless of the lower tropospheric variability of moisture over the Amazon, any transport of moist air from low-levels (i.e., below 800 hPa) onto the Altiplano (i.e., 600 hPa or less) will generally result in an increase in moisture. Our study of the LGM climate provides an example of this disconnection between moisture variability in the Andes and the Amazon. In this case, the atmospheric moisture content over the Amazon basin is lower during the LGM, yet the moisture content increases during the austral spring months over the central Andes.

Present day observations are explored to identify whether mechanisms identified in the paleoclimate modeling are observable in the present day climate. This mechanism identified for the LGM is also influential for present day variability. For example, a comparison of the austral springs of 2002 with 2003 reveals a rainfall and circulation response comparable to the LGM model response. Not all of the variability between these two contrasting years can be explained via this mechanism since other processes are at work, but the comparison of these two springs indicates that this mechanism is operating in the present day, at least in some form.

In conclusion, our modeling results, the LGM paleoclimate proxy evidence, and present day observational analysis agree that wet conditions over the high Andes should be associated with a delay/reduction Amazon rainfall, especially during the austral spring months. However, it is not clear from our results whether this would mean that the annual conditions over the Amazon would be drier. This is not surprising since the Amazon rainy season is generally longer in duration and much more complex (e.g., more moisture sources, thus more sources of variability) than that over the high Andes.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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