PLAUSIBLE EFFECTS OF PALEOLAKE TAUCA ON THE ALTIPLANO CIRCULATIONS AND RAINFALL FROM WRF MODEL SIMULATIONS

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ABSTRACT

Previous studies based on ice cores and sediment samples collected along Andean Ice Caps and the South American Highplane (Altiplano) revealed the development of Paleolake Tauca during the late Pleistocene (15000 - 13000 BP). During its maximum expansion, the lake occupied an area of ~50% of the Altiplano basin. Motivated by understanding the role of lake-induced circulations on Altiplano climate transitions towards wetter conditions, numerical simulations were made using the Weather Research and Forecasting (WRF) model. In order to do so, combinations of paleolake/no-paleolake and moist/dry atmospheric conditions were analyzed. The results suggest that Paleolake Tauca produced a moister environment in the Altiplano with respect to the present through, enhancing nocturnal mesoscale circulations and rainfall. However, the intensity and distribution of rainfall appears to be modulated by the large-scale moisture field.

1. INTRODUCTION

The South American Altiplano is an elevated plateau (the second largest) located in the Central Andes between 14°S and 22°S. It is also a closed basin with a surface area of about 205,000 km^2. The orography (Fig. 1) is characterized by a flat corridor that slopes gently from 3850 meters above sea level (m ASL) at 15°S to 3650 m ASL at 21°S. The plateau is surrounded by mountain ranges that exceed 6000 m ASL, and shelters numerous lakes (e.g. Lake Titicaca) and dry salt flats (hereafter, salars), such as the Salar de Uyuni (world's largest salt flat).

Paleoclimatic findings have revealed that transitions between salars and shallow lakes have occurred several times in the past with different intensities. The reason is that the Altiplano has been exposed to many extended dry and wet periods, some of them with durations of several millenia. Of the lakes that formed during the wet periods, the largest developed over the southern half of the basin between 15,000 and 13,000 BP.
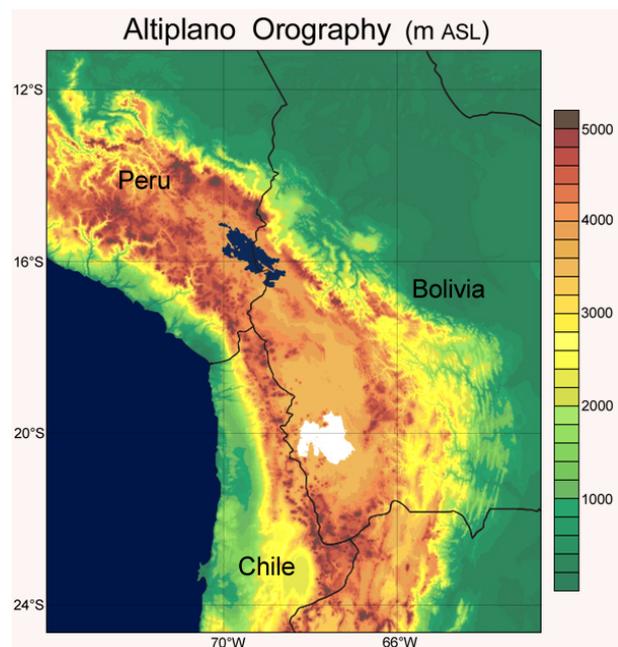
Fig. 1. Altiplano 30-second USGS terrain elevation. Lake Titicaca (16°S/69.5°W) and Salar de Uyuni (20°S/67.5°W) are indicated with dark blue and white respectively. The Pacific Ocean to the west is indicated in dark blue. Country names and boundaries are indicated in black.

largest developed on the southern half of the basin between 15000 and 13000 BP is referred as This

paleolake, known as Tauca, reached depths of about 100m above the current Salar de Uyuni – at 3653m ASL, the current low spot of the southern altiplano (Condom et al., 2004).

The main goal of our study is to determine the role of the lake-induced mesoscale circulations on the dry-to-wet climatic transitions that have occurred over the Altiplano. Athough many researchers have looked at these transitions in terms of changes in the large-scale circulation and solar radiation budget, few if any have considered the mesoscale forcings we are suggesting here. The approach taken here is to compare the current mesoscale circulations and rainfall simulated over the altiplano with an altiplano that includes Paleolake Tauca. We use the Weather Research and Forecasting (WRF) model to simulate both situations, and also some variants. Specific questions we would like to address include: 'Did Paleolake Tauca produce wetter conditions over the altiplano through stronger lake-induced mesoscale circulations and heavier precipitation? If so, how much wetter? How do large-scale conditions of atmospheric moisture modulate the effects of the Paleolake?'

2. METHODOLOGY

The WRF model simulations with/without Paleolake Tauca and with atmospheric conditions of high/low moisture content are compared. This blend of environments produces a set of 4 experiments: no-paleolake/dry (ND) also taken as the control simulation, no-paleolake/moist (NM), paleolake/dry (PD) and paleolake/moist (PM). The horizontal resolution is set to 15 km and 31 sigma levels are employed in the vertical (Table 1). The domain is centered over the southern Altiplano (Figure 2) and the boundaries are placed over relatively flat terrain far away from the region of interest. A second simulation domain, with a 4 km grid, was designed for the area of interest that covers Paleolake Tauca (Figure 2). For this domain two experiments were performed: no-paleolake/moist (NM) and paleolake/moist (PM).

Several modifications were performed in the model in order to approach more realistic conditions for the present time and simulate the presence of the Paleolake Tauca. For experiments ND and NM, the USGS 30s landuse files were modified by introducing Salar de Uyuni (20°S) and smaller Salar de Coipasa (19°S). The salt surface properties such as emissivity, thermal inertial and specific heat were assumed as wetland properties.

The salar albedo was set to 50%, value suggested by L. Blacutt derived from a field experiment in the salar (personal communication). The Lake Titicaca was set to a constant of 13°C, which represent its climatological value (Carmouze, 1991). For experiments PD and PM Paleolake Tauca was introduced by flooding the altiplano terrain located below 3760 m ASL (Fig. 2), and its temperature established as 13°C like Lake Titicaca.

Table 1. Weather Research and Forecasting (WRF) model parameterizations

Parameters	Domain 1	Domain 2
Horizontal resolution	15 km	4 km
Vertical resolution	31 σ level	31 σ level
Horizontal dimension X	170	210
Horizontal dimension Y	170	220
Center point latitude	18° South	
Center point longitude	67° West	
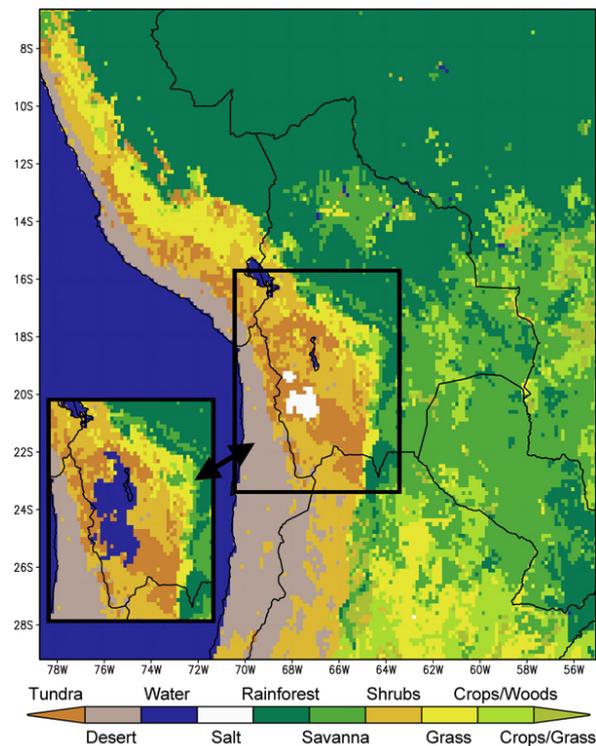
Fig. 2. Second Domain size and land use configurations used for the no-paleolake experiments (box placed over the altiplano) and the paleolake experiment (box placed over the Pacific Ocean). Country borders, Lake Titicaca (16°S) and Lake Poopó (18.5°S) are indicated with thin black lines.

The humidity conditions used to initialize the simulations were averages based on analyses

over the domain of the South American Low Level Jet Experiment (SALLJEX) data for the period November-February 2002-3. They represent realistic moist profiles and dry profiles for this region (Figure 3).

All the simulations were initialized using an atmosphere at rest and the boundary conditions were left open. These settings were used to allow the initial thermodynamic state and the diurnal cycle of solar radiation to drive the circulations.
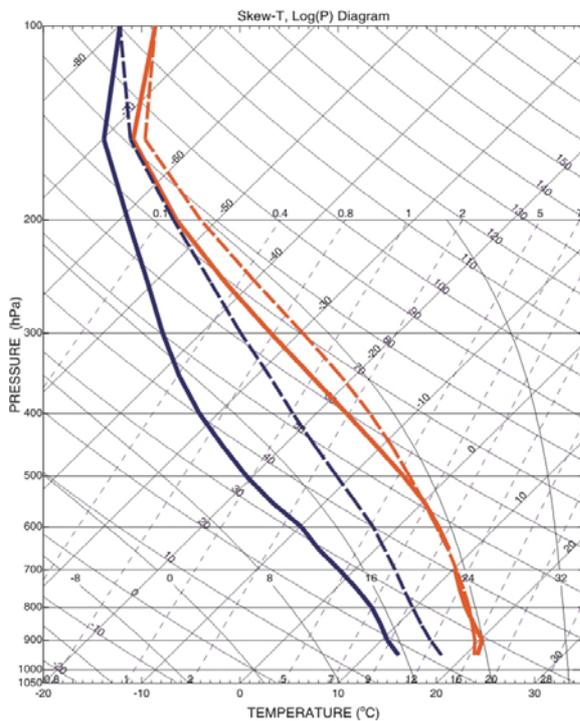
Fig. 3. Dry (solid) and moist (dashed) atmospheric soundings used to initialize the simulations. The right curves represent temperature in °C and the left curves dew point temperature in °C.

3. RESULTS

It is important to mention that with the coarse (15 km) resolution used, the orographic effects on the circulations seem to overwhelm those produced by the lakes and salars. Consequently, the results do not show sharp variations between the different simulations given that the topography is fixed, however, they provide some insight about the changes in the circulations that may occur if Paleolake Tauca were present. The coarse 15km

simulations provide a general background for the ongoing study of the effects of Paleolake Tauca on the circulations using 4km simulations.

3.1. Domain 1 simulations analysis

Some preliminary results obtained by comparing the 15-km resolution simulations are discussed here. Figure 4 shows the simulated nocturnal (20 - 08 LST) total rainfall and departures with respect to the control simulation (ND) in mm 12-hs^{-1}. Rainfall has been averaged over the last two nights of simulation (forecast hours 24-36 and 48–60). Figure 5 displays specific humidity integrated over the 640-560 mb layer and averaged over the same period considered for Figure 4. When compared to the control simulation (ND), the paleolake/dry (PD) environment results suggest that the presence of the Paleolake Tauca enhances moisture in the basin (Figure 5), and as a consequence the production of larger rainfall totals. This is the case for any simulation that is compared with the control run with the largest increases observed in the PM (paleolake/moist) simulation. Positive rainfall anomalies in the southern sector of the basin imply enhanced nocturnal mesoscale circulations in this region compared to those induced by the current land-surface environment. Although the rainfall increase when including the paleolake is subtle, larger changes are observed in distribution of rainfall. Certain areas present enhanced precipitation whilst others receive less.

Overall, the largest rainfall seems to occur in the central altiplano in response to the nocturnal convergence of drainage flows that originate in the eastern and western mountain ranges. A wide region of about 15 mm day^{-1} and locally 40 mm day^{-1} is present over and just to the southwest of current Lake Poopó. These rainfall amounts are unrealistic when considering the climatological amounts that fall in that portion of the altiplano, but again, it should be considered that the synoptic forcing mechanisms have been removed by setting the initial and boundary condition winds to zero. In the current altiplano, a band of enhanced convection can actually be observed over this region of the altiplano. The Salar de Uyuni and Salar de Coipasa, both salars located in the southwestern end of the altiplano (20.5°S and
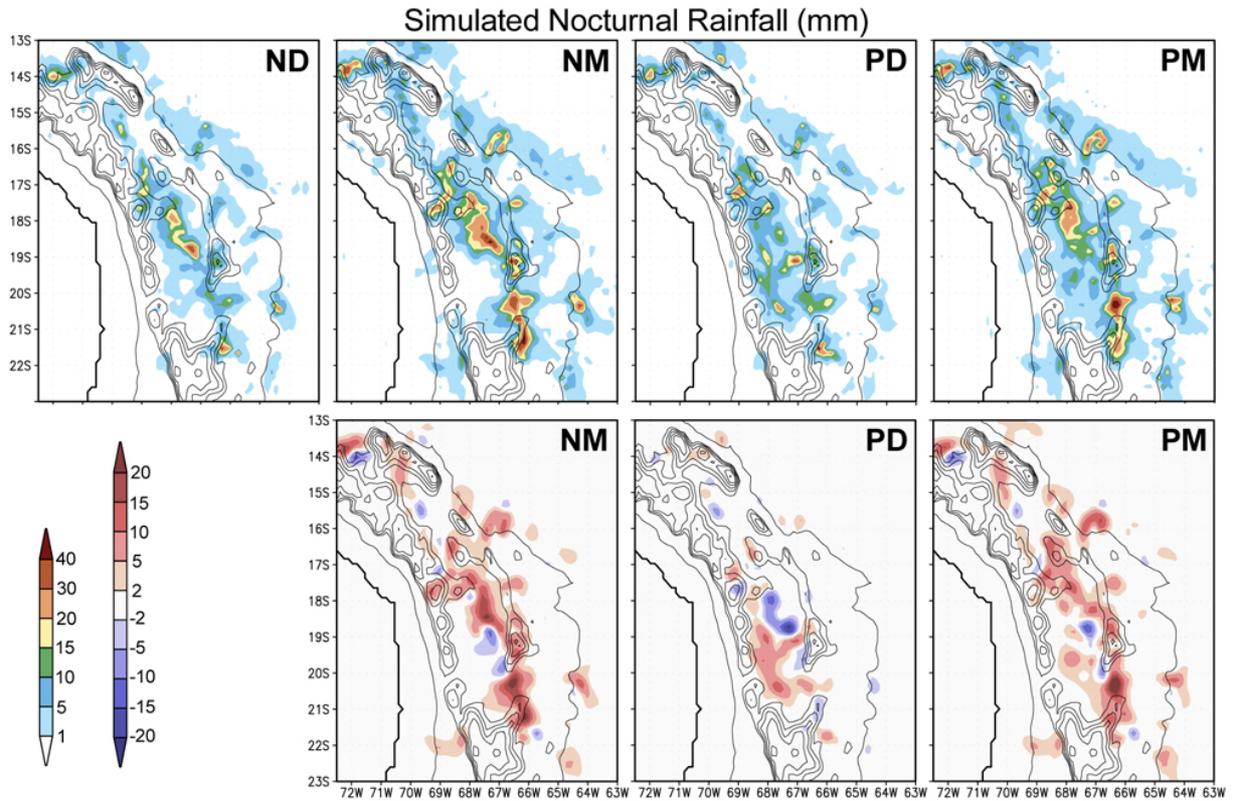
Fig. 4. WRF model simulated nocturnal (20 – 08 LST) rainfall (top) and anomalies with respect to the control simulation (bottom) in mm/12-hours. Rainfall has been averaged over the two last nights of simulation (forecast hours 24-36 and 48–60). The top left panel (ND) illustrates the control run (no-paleolake/dry) results. Simulations for the no-paleolake/moist (NM), paleolake/dry (PD) and paleolake/moist (PM) simulations are presented for comparison. The terrain at 2000, 4000, 4200, 4400, 4600, 4800 and 5000 mASL is indicated with thin black lines. The coastline is indicated with a thick black line.
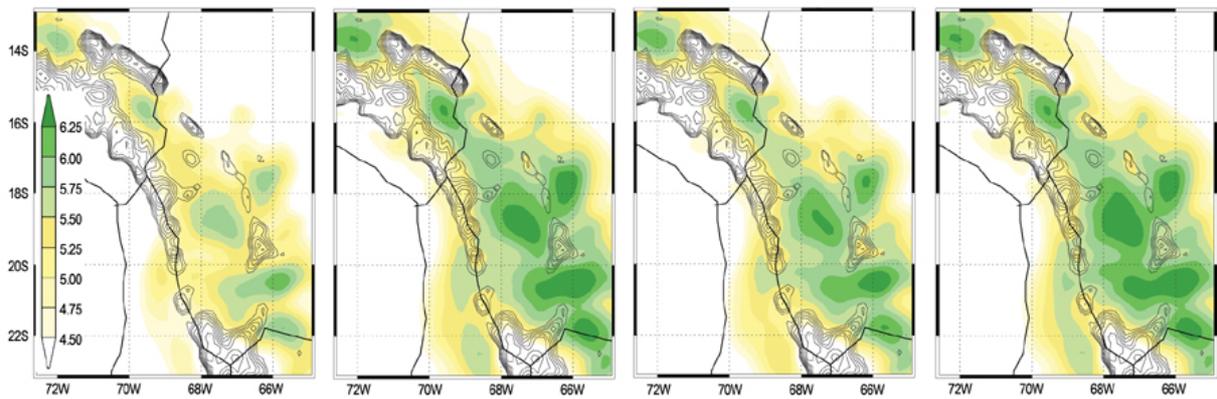
Fig. 5. WRF model simulated nocturnal (20 – 08 LST) specific humidity (g/Kg) integrated between 640 mb and 560 mb. The specific humidity have been averaged over the two last nights of simulation (forecast hours 24-36 and 48–60). For more details see figure 4.
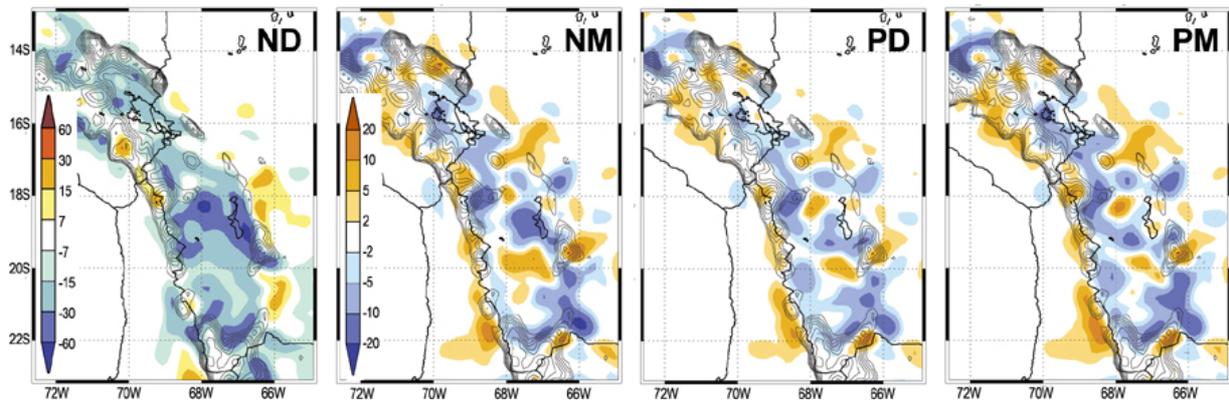
Fig. 6. WRF model simulated nocturnal (20 – 08 LST) divergence (first to the left) in 10^{-6}xs^{-1} and anomalies with respect to the control simulation (the rest of figures). Divergence has been averaged over the two last nights of simulation (forecast hours 24-36 and 48–60). For more details see figure 4.

19°S respectively), seem to play a role in the location of this region of convection according to the simulation results, but further analysis is necessary to support this statement. The low-level divergent flow that the salar's produce seems to reinforce the evening low level convergence that occurs in the central altiplano. When Paleolake Tauca is included in the land-surface, the evening divergent flow in the south-central altiplano is no longer present and as a result the region of convergence in the central altiplano weakens. The precipitation distribution among the basin becomes more homogeneous with less rainfall over the central altiplano and enhanced rainfall over the southwestern sector of paleolake Tauca.

The divergent flow (Figure 6) generated by differential heating between the salar and the surrounding environment creates an area of subsidence over the salar bringing dry air from the upper levels. This is noticeable in Figure 5 where the salar area has less moisture. Then, the addition of the Paleolake Tauca (PD) not only represents a source of moisture that contributes with the formation of clouds and production of precipitation, but also enhances the convergence over the paleolake due to an increase in the temperature gradient between the lake and the land. Furthermore, topography drives the flow and induces wind forcing toward the paleolake due to katabatic winds.

Figure 7 shows the time series of precipitation along the entire simulation period and the peaks of nocturnal rainfall. Even when Paleolake Tauca represents a source of moisture and induces lake-breeze circulations, the most important factor for the production of precipitation is the moisture

content in the atmosphere. The moist soundings present more precipitation in the basin than the ones in a dry environment even with the addition of the paleolake. Another important characteristic of the time series is that with the addition of the paleolake the peaks of rainfall occur earlier than the ones without Tauca, which is pronounced in a dry environment.
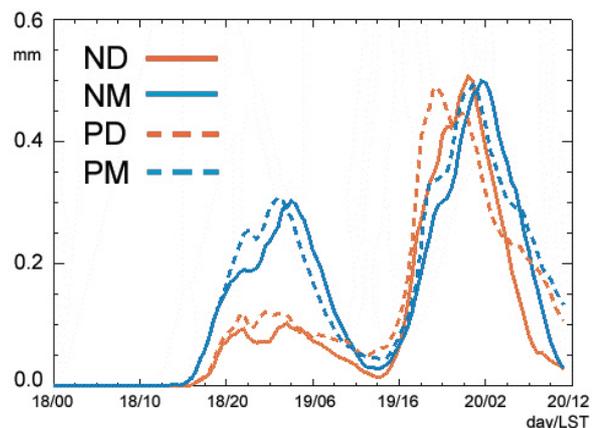
Fig. 7. Precipitation (mm) each 30 minutes, during the entire simulation period. The solid lines represent the no-paleolake environment precipitation and the dashed lines represent paleolake conditions. The color blue depict the moist sounding cases and the orange the dry sounding cases.

3.2. Domain 2 simulations analysis

Given the current need to complete the first set of finer resolution (4km) simulations, the preliminary results currently available can only be used as examples. These preliminary results verify some of the ideas provided by the 15-km results. A more complete set of fine resolution results will be included in the poster.

4. CONCLUSIONS

This ongoing study constitutes the first attempt to understand the role of Paleolake Tauca in the mesoscale circulations and rainfall of the South American Altiplano using numerical simulations from a mesoscale model. Since the study is still in progress, a more detailed set of results, including finer resolution simulations, will be presented in the poster session.

Preliminary results suggest that changes in the land surface from salar (considered as a wet land) to water produce changes in the circulation patterns and in the distribution of rainfall. However, the large-scale flow and moisture field seems to play a crucial role in the intensity and distribution of precipitation. The differences between rainfall totals among wet/dry simulations is larger than that between no-paleolake/paleolake simulations.

REFERENCES

Carmouze, J.P., 1991: El Balance Energético, El Lago Titicaca, *ORSTROM pub*, pp. 149-160.

Condom, T., A. Coudrain, A. Dezetter, D. Brunstein, F. Delclaux, and Sicart, J. E., 2004: Transient modeling of lacustrine regressions: two case studies from the Andean Altiplano. *Hydrological Processes*, **18**, 2395-2408.

Kampf, S. K., and S. W. Tyler, 2005: Spatial characterization of land surface energy fluxes and uncertainty estimation at the Salar de Atacama, Northern Chile. *Advances in Water Resources*, **29**, 336-354.