Intraseasonal and Interannual Rainfall Variability over the South American Altiplano

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Most of the precipitation over the Altiplano is associated with deep, moist convection (referred as convection), explaining, among other features, the marked diurnal cycle of the rainfall over this region during the austral summer months (DJF). In the Altiplano, the limiting factor for convection appears to be low level moisture. On the basis of upper-air data taken at Visviri (southwestern Altiplano) Garreaud (1999) found that during the austral summer, the atmosphere generally becomes conditionally unstable by late afternoon, consequence of the strong surface heating, but saturation of the ascending air only occurs when the near-surface mixing ratio exceed q~5 g/kg. Furthermore, rainfall occurred in nearly all days in which this threshold was exceeded, suggesting that daytime local circulation over the complex terrain provided enough dynamical forcing to overcome the convective inhibition within the lowest hundreds meters over the plateau. During the rest of the year humidity is very low (q<3 g/kg) and rainfall episodes are rare. These results seem generally applicable to the rest of the basin, as demonstrated in subsequent analysis of pan-basin data (Garreaud 2000).

The water vapor in the free-atmosphere at the level of the Altiplano (620 hPa) is very low (<3 g/kg), and therefore the relatively "juicy" air observed over the plateau during rainy episodes has to be transported from lower-levels or produced at the local surface by evapotranspiration. Early studies and subsequent analyses have shown that the water vapor that precipitates over the Altiplano originates in the troposphere to the east of the central Andes. Modeling studies indicate that the transport of the moist air from the Bolivian lowlands toward the Altiplano is produced by regional, upslope flow over the eastern side of the Andes (Garreaud 1999). Although the upslope flow is primarily driven by the daytime heating of the sloping terrain, its magnitude, timing and extent are strongly modulated by the large-scale circulation, throughout the mixing of momentum atop of the boundary layer. Large-scale, mid and upper-troposphere easterly anomalies over the central Andes accelerate the upslope flow from the east, increasing the moisture transport into the altiplano, while the opposite occurs in presence of westerly anomalies when dry upslope flow from the west is favored. Presumably, this is the mechanism that links the large-scale anomalies with the moisture and rainfall variability over the Altiplano at several time scales.

The most clear change in the large-scale zonal circulation over the Altiplano is associated with the annual cycle, as shown in Fig. 1a by the difference in 200 hPa winds between the austral summer mean and the annual mean. At the height of the summer, weak easterly flow prevails over the Altiplano, consequence of the southward migration of the subtropical jet stream (westerly flow) and the establishment of an upper-level anticyclone to the southeast of the central Andes (the Bolivian high). This narrow time-window (DJF) of mean easterly flow defines the Altiplano wet season.

Altiplano rainfall is, however, far from be uniform during the austral summer. Basin-wide rainy days tends to cluster in "rainy episodes" lasting 5-10 days, separated by somewhat longer dry episodes when convection is nearly suppressed over the Altiplano. These rainy and dry episodes are markedly associated with changes in the intensity and position of the Bolivian high, so that enhanced easterlies over the central Andes are concurrent with enhanced precipitation over the Altiplano (e.g. Lenters and Cook 1999). This relationship is illustrated in Fig. 1b by the regression map between a convective index (CI, band pass filtered to retain intraseasonal variability) over the Altiplano and 200 hPa winds. In connection with the circulation anomalies over subtropical South America there is a signature of a wave train over the South Pacific. Thus, it has been suggested that intraseasonal circulation anomalies over the central Andes, and hence, rainfall over the Altiplano, are likely to be produced by quasi-stationary Rossby waves emanating from the extratropical South Pacific. The relationship between CI and circulation over South America weakens below 700 hPa, indicative that rainfall episodes are rather insencitive to the low level conditions as long as they are associated with easterly flow aloft.

On the interannual timescale, conditions can vary from very rainy summers to severe drought, with a weak tendency for wet conditions during the cold ENSO phase (La Niña years) and dry conditions during the warm ENSO phase (El Niño years). The weakness of the ENSO-Altiplano rainfall could be partially explained by within-basin differences in the precipitation pattern (Vuille et al. 2000). To illustrate the spatial pattern of convection and upper-level circulation associated with the year-to-year variability of the convection over the Altiplano (area-average), Fig. 1c shows the regression map of CI in the interannual range. The zonal wind anomalies upstream and downstream of the central-tropical Andes are consistent with the easterly/wet - westerly/dry relationship found in previous analysis. The circulation pattern is largely a tropical feature, in contrast with the subtropical-extratropical pattern that emerges in the intraseasonal range, with wind anomalies in geostrophic balance with changes in the meridional baroclinicity between tropical and subtropical latitudes. Significant anomalies of OLR and 200-hPa circulation related to CI variability are also found over the rest of the tropics and, overall, they bear strong resemblance to ENSO-related anomalies (e.g., Yulaeva and Wallace 1994). Thus, the relationship between ENSO and Altiplano interannual rainfall anomalies can be explained by the generalized warming (cooling) of the tropical troposphere during the warm (cold phase) of ENSO, and the associated changes in the seasonal mean zonal flow aloft at tropical-subtropical latitudes (Garreaud and Aceituno 2000).

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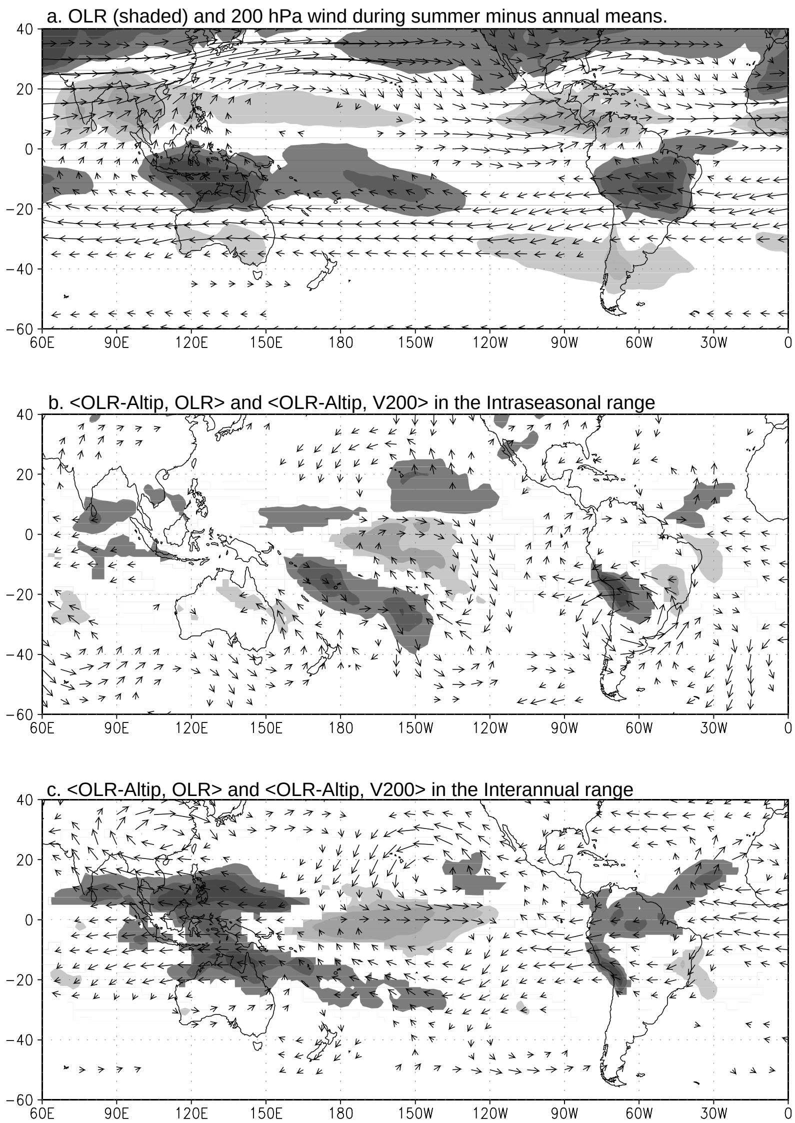

Figure 1. (a) Difference between austral summer and annual mean climatology of OLR (light shading indicates decrease convection, dark shading indicates increase convection) and 200 hPa winds. (b) One point regression map of the OLR over the Altiplano and OLR and 200 hPa winds in the intraseasonal range (5-30 days). Light shading indicates decrease convection, light shading indicates enhanced convection. (c) As (b) but for the interannual range.