INTERANNUAL CLIMATE VARIABILITY IN THE CENTRAL ANDES AND ITS RELATION TO TROPICAL SEA SURFACE TEMPERATURE ANOMALIES

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1. INTRODUCTION

Several studies have recently provided new information on local and large-scale atmospheric conditions associated with summer precipitation variability in the tropical Andes (Vuille et al. 1998, Garreaud 1999, Lenters and Cook 1999, Vuille 1999, Vuille et al. 2000a, Garreaud and Aceituno 2000). However, most of these studies fall short in explaining the spatial precipitation variability over the Altiplano, because they are either based on data from only one part of the Altiplano or they consider the entire region as an entity, which is inappropriate, given the extreme spatial and temporal variability of precipitation. Here the spatiotemporal behavior of austral summer (DJF) precipitation and monthly temperature anomalies are analyzed based on a dense station network, covering the entire Altiplano, which allows us to resolve the aforementioned spatial variability. In addition, the influence of tropical Pacific and Atlantic sea surface temperature anomalies (SSTA) upon precipitation and temperature variability in the different parts of the Altiplano is examined. A more in depth description of this analysis can be found in Vuille et al. (2000b).

2. DATA AND METHODS

31 (11) precipitation (temperature) stations were selected for this study, equally distributed along the entire Central Andes from 11.5°S - 20.5°S and between 2500 m - 5250 m, covering the time period 1961-1990. Since the rainy season is limited to austral summer (DJF), analysis of precipitation variability was carried out for this season only on the basis of 3-monthly sums. All DJF sums were transformed into γ-probabilities because of its distinctly asymmetric distribution, skewed to the right and bounded by zero. Temperature data were smoothed using a Hamming weights low-pass filter and monthly anomalies were computed by subtracting the mean monthly values for the period 1961-1990. Temperature analysis was performed on the entire continuous record.

Monthly mean SST data were extracted from the GISST (Global sea-Ice and Sea Surface Temperature) data set and monthly anomalies were computed over the tropical Pacific (30°N-40°S, 160°E - 80°W) and Atlantic (30°N-40°S, 80°W-10°E) by subtracting the mean monthly values for the period 1961-1990.

To determine the main modes of variability, a Varimax rotated Principal Component Analysis (PCA) was performed in the S-mode (spatial) sense, based on the interstation correlation matrix of both the precipitation and temperature data sets. Next the resulting time series (factor scores) of the PCs were correlated with Pacific and Atlantic SSTA. As a result, spatial patterns emerged over the tropical Pacific and Atlantic, potentially related to a certain mode of temperature or precipitation variability over the Central Andes. All correlation significance levels account for serial correlation in the data by an adjustment in the degrees of freedom. To confirm the results, next the reverse procedure was applied by extracting the PCs from the monthly SSTA in the tropical Pacific and Atlantic. This PCA was done separately for the two basins, which allowed us to identify whether regional patterns of precipitation or temperature anomalies relate to the Pacific or the Atlantic. The score time series of the PCs, representing the main modes of tropical SST variability, were then cross-correlated with the station data from the Altiplano (DJF γ-precipitation and monthly temperature anomalies). Coherency maps of cross correlations between temperature or precipitation and tropical SSTA modes were plotted, again tested for significance, and the results of this second approach were compared to the patterns obtained previously from the first analysis to see whether they compared favorably.

3. TEMPERATURE VARIABILITY

Only two PCs were identified as describing significant, nonrandom temperature variability on the Altiplano, which is not surprising, since the analysis is based on data from only 11 stations and the spatial variability of air temperature anomalies over the Altiplano is not very large. The first mode (T-VPC1), explaining 29.6% total variance, is most dominant along the NE slopes of the Altiplano and shows a decreasing influence toward the south. This mode is clearly related to ENSO, with SSTA in the central equatorial Pacific leading the Andean temperature signal by approximately 2 months. The temperature difference between El Niño and La Niña periods amounts to 0.7°-1°C (600 hPa NCEP ~Altiplano surface level) and to 0.7°-1.3°C (based on station data). The statistical significance of this temperature difference is higher over the northern part of the Altiplano and decreases toward the south.

The second temperature mode (T-VPC2), explaining 29.4% of the total variance, shows strongest loadings south of 18°S. This mode is associated with a noticeable temperature increase since the late 1970s, consistent with similar trends observed over the entire tropical Andean range (Vuille and Bradley, 2000).

4. DJF PRECIPITATION VARIABILITY

Three eigenvectors (DJF-VPC1-3) emerged from the precipitation analysis, showing a distinct spatial separation (Figure 1a-c). They represent 31.1 % (DJF-VPC1) 17.4% (DJF-VPC2) and 16.2% (DJF-VPC3) of the total explained variance respectively. While DJF-VPC1 explains the highest fraction of the total variance in the more humid eastern Altiplano, DJF-VPC2 is the dominant mode in the dry western part and DJF-VPC3 represents summer precipitation variability to the north of the Altiplano in the southern Peruvian Andes between 11.5°S and 15°S. Both the inspection of the score time series (Fig. 1d-f) and the correlation with tropical SSTA shows that all three modes are related to variability in the tropical Pacific. The precipitation signal is however modified in different ways in the three regional domains, even though the general notion of below (above) average precipitation during El Niño (La Niña) periods is evident. Precipitation over the dry western part of the Altiplano (DJF-VPC2 domain) shows the closest relationship with tropical Pacific SSTA, because moisture flux from the

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east is inhibited (enhanced) during El Niño (La Niña) periods. A decadal-scale oscillation with above-average precipitation from the late 1960s to the mid 1970s followed by a decade of dry conditions in the late 1970s and 1980s is superimposed on the interannual variability. Apparently, the ENSO relationship over the western Altiplano is modulated by a decadal mode of Pacific SSTA variability, most likely related to the Pacific-decadal Oscillation (PDO).

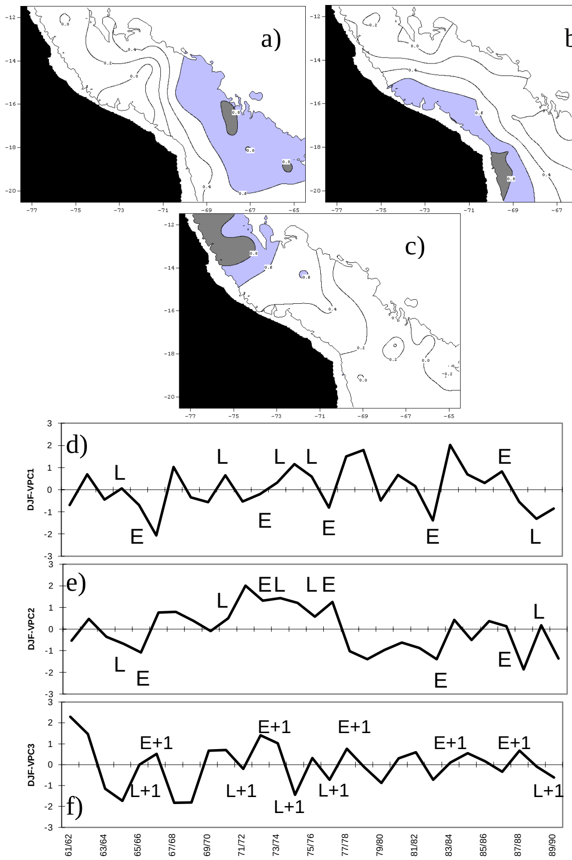

Figure 1. (a) Loading pattern of DJF-VPC1 with contour interval 0.2, values > 0.6 (0.8) shaded light (dark). (b) As in Figure 1a but for DJF-VPC2. (c) As in Figure 1a but for DJF-VPC3. Only data from areas > 1500 m are plotted (delimited by contour lines). (d) Score time series of DJF-VPC1 with E and L indicating El Niño (E) and La Niña (L) events. (e) As in Figure d but for DJF-VPC2. (f) As in Figure d but for DJF-VPC3 and E+1 (L+1) indicating year following an El Niño (La Niña) event.

The eastern part of the Altiplano shows a much weaker relationship with ENSO, because atmospheric circulation anomalies induced by El Niño (westerly wind anomalies) do not inhibit convection over the eastern Andean slopes. Nonetheless there is a significant correlation between this mode and SSTA in the eastern tropical Pacific.

Over the northern Altiplano the precipitation signal is reversed in the austral summer following the peak phase of ENSO. Above-average precipitation occurs in the year following an El Niño event (E+1), while years following a La Niña event (L+1) are consistently drier than normal. Presumably this behaviour is related to the temporal evolution of tropical Pacific SSTA, rapidly switching from one state to the other.

Interestingly enough, neither one of the three modes showed any significant relation with SSTA in the tropical Atlantic domain.

5. DISCUSSION AND CONCLUSION

Despite the demonstrated influence of ENSO the relationship with interannual precipitation variability in the Central Andes, is far from perfect. The score time series of the three main austral summer precipitation modes (Figure 1d-f) show that El Niño (La Niña) events do not always lead to decreased (increased) precipitation on the Altiplano. Presumably there are three main reasons, which might contribute to a weakening of this relationship:

1) The Altiplano is a region of high spatial precipitation variability, including regions from humid to hyperarid. While the influence of ENSO can be significant in one area in a particular year, its impact may at the same time not be felt in another region of the Altiplano. Correlating ENSO with precipitation variability on the Altiplano will thus always be imperfect, if the entire region is considered as a homogeneous entity (Vuille et al., 2000b).
2) Although ENSO is to some extent phase-locked to the annual cycle, its peak phase does not always coincide with the austral summer wet season on the Altiplano (DJF). If ENSO peaks early (or late) its influence will thus be limited despite persistence of tropical Pacific SSTs (Vuille et al., 2000b).
3) The positioning and intensity of anomalous meridional baroclinicity, induced by ENSO, is quite variable. The zone of easterly (westerly) wind anomalies, responsible for humid (dry) conditions during La Niña (El Niño) is therefore not always located directly over the Altiplano region (Garreaud and Aceituno, 2000).

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