

## EXTREME OROGRAPHIC PRECIPITATION EVENTS OVER THE CENTRAL ANDES OF ARGENTINA AND CHILE

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### 1. INTRODUCTION

Wintertime precipitation events in the Central Andes of Argentina and Chile (35°S-30°S) have a great impact in the regional climatic system. The total seasonal amount of snow accumulated on the mountains is the main agent controlling the hydrologic cycle in the surrounding areas. However, these events can produce a negative impact when they are of great intensity, such as land-slide and floods. Furthermore, every year, the road traffic trade between Argentina and Chile is interrupted due to heavy snowfall causing huge economic losses.

The goal of this study is to characterize the synoptic scale circulation patterns linked with heavy orographic precipitation episodes in the Central Andes. In addition, we examine local climatologic aspects associated with the strong orographic influence on precipitation in the region.

### 2. DATA AND METHODS

The Andes is one of the highest mountain range on the earth. The mean altitude of the Central Andes in Argentina and Chile varies from 3500 m to 5000 m on the southernmost and northernmost sectors respectively (Fig. 1), with many peaks exceeding the 6000 m. Its disposition, in north-south direction, is well perpendicular to prevailing westerlies, and its width is relative narrow, in the order of 250 km.

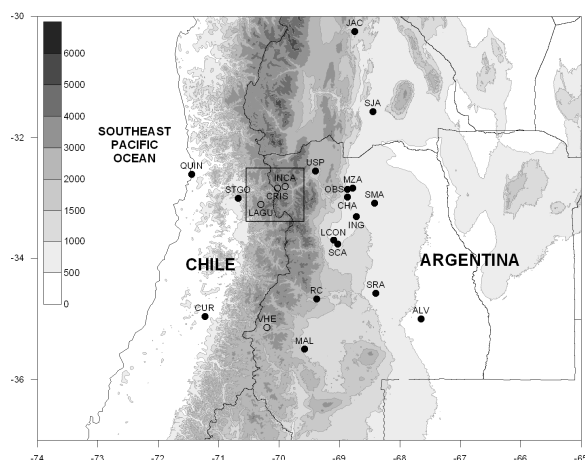


Figure 1: The Andean area of study and the station locations. The stations enclosed by a square are used to build the histogram in Fig. 2.

Daily precipitation database from the National Weather Services of Argentina and Chile were used for the 1970-1976 period. In this seven-year period there was at least four stations on highlands with observer in situ recording the snow depth and equivalent water. This situation has unfortunately changed with one of the four still recording snowfall at present, but the hidrological institute of the region has recently installed seven automatic snow pillows (SNOTEL).

Based on the wintertime daily precipitation distribution over the Andes highlands (Fig. 2), we selected 19 extreme events that met daily precipitation higher than percentile 95%. All the cases ensured independence between each other as they were separated by at least 15 days.

Then, we built the composites of standardized anomalies of geopotential heights, winds, and moisture flux at different levels using reanalysis ERA-40, in order to identify the synoptic patterns that accompanied these events. The use of standardized anomaly fields has widely been used to help forecasters identify synoptic patterns associated with significant winter weather events in the U.S.A. (e.g. Grumm and Hart 2001, Stuart and Grumm 2006, Junker et al. 2008). As applied in these studies, the departure of the meteorological variable at each grid point from its 21-day running climatologic 1961-1990 mean is divided by its 21-day running standard deviation [i.e, standardized anomaly  $N=(X-\mu)/\sigma$ ]. The grid of reanalysis ERA-40 dataset has a 2,5° x 2,5° resolution and 23 vertical levels (Uppala et al 2005).

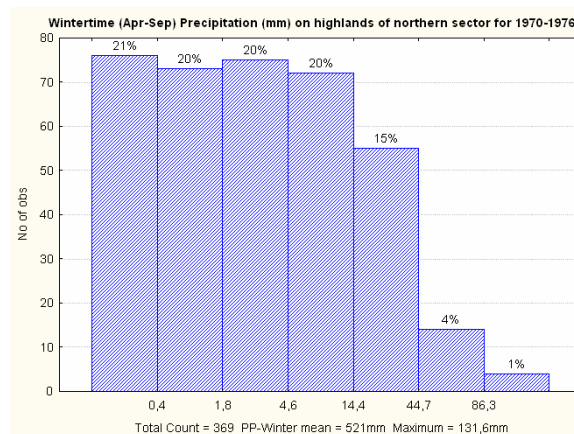


Figure 2. Wintertime (Apr-Sep) daily precipitation distribution over highlands of northern Central Andes.

### 3. RESULTS

#### 3a. Synoptic circulation patterns

Figure 3 shows that the heaviest rainfall events were associated with negative anomalies located off the central Chilean coast, and an anomalous northwesterly flow at low- and mid-levels. The larger departures from normal heights and winds exceeded the  $-1,2\sigma$  for both variables and vertical levels, and were closer to the Andes during the day of heavy rainfall. The weather systems evolution from time day -1 to day 0 is more intense when approaching to the mountain. This is an expected result that shows an anomalous circulation from an anomalous midlatitude cyclone strengthened on heavy rainfall day. Furthermore, the day of heavy rainfall was under the influence of the northeastern flank of the cyclone which transports a warm and moist cross-barrier flow. This results agree with those from Falvey and Garreaud (2007)

At high levels (Figure 4), the anomaly fields were similar to the fields at low levels but that was slightly attenuated. This suggests that the major driving force of the extreme orographic precipitation are the anomalous circulations in low levels. In all levels (Figures 3 and 4), an eastward displacement of maximum anomaly center with the height is

discernible, showing the baroclinicity of the weather systems.

It is important to emphasize that these composites represent a mean position and anomaly intensity of all the events, so the real intensity of each single cyclone event could be smoothed on the average. In many cases, we observed standardized anomalies with a magnitude higher than 2, and up to  $3\sigma$ , in all the variables. Junker et al (2008) found similar composite anomalies for heavy rainfall over northern Sierra Nevada, and also for isolated multi-days flooding events.

The cross-barrier moisture flux has an important influence on heavy precipitations over the mountains [e.g., in Sierra Nevada (Pandey et al 1999), on the central Andes (Falvey and Garreaud 2007)]. The anomalies of moisture flux exceed the  $1,2\sigma$  and  $1,5\sigma$  in northwesterly direction at 850 and 700 hPa, respectively. This anomalous moist transport was more intense at 700 hPa than 850 hPa, mainly due to the increase of wind speed with the height. This result was also consistent with that of Falvey and Garreaud (2007), who found a maximum of cross-mountain moisture flux near and below mountain-top.

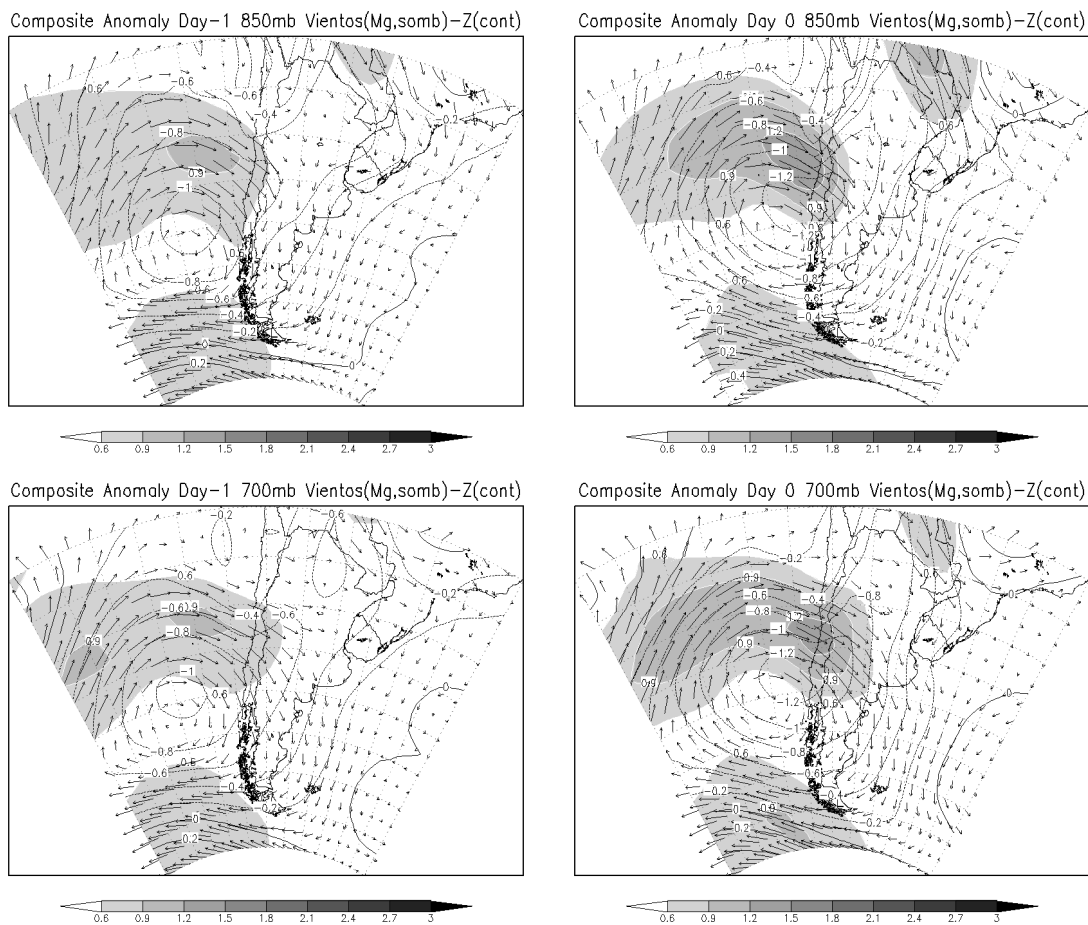


Figure 3: Composite of standardized anomalies of geopotential heights (contour) and winds (intensity is shaded) for the previous day (left) and day of maximum rainfall (right) at 850 (top) and 700 hPa (bottom).

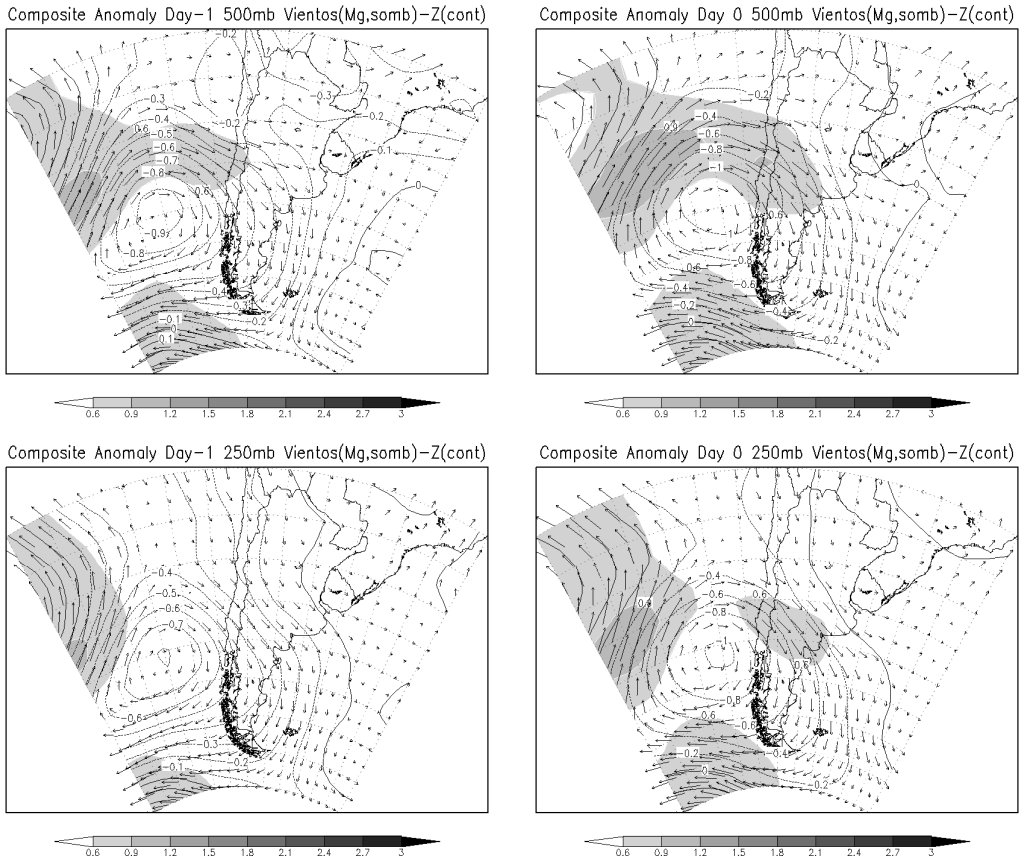


Figure 4: Same as Figure 3, but at 500 (top) and 250 hPa (bottom).

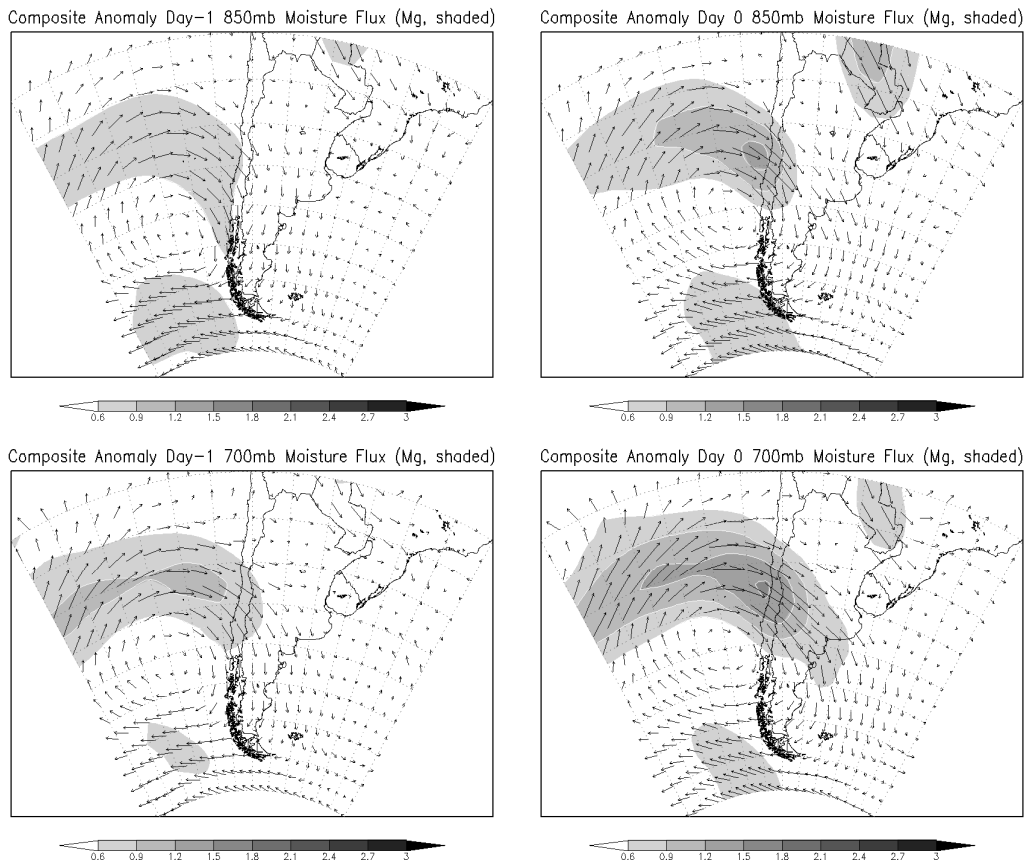


Figure 5: Same as Figure 3, but for moisture flux (intensity is shaded).

### 3b. Regional orographic influences on the precipitation

A visual inspection of daily precipitation series around the mountain revealed that the most frequent duration of each heavy event was 4 days. Precipitations were mostly not recorded in lee-side stations during the first 2 days of each event (including the one of highest intensity), but some stations reported the occurrence of "Zonda" wind (warm and dry downslope wind) during these days in most of the events. This reveals the strong influence of orography on precipitations, inhibiting them leeward due to the descending character of the airflow. Rain shadows were recorded in low-lying stations on lee side mostly in the last days of each event.

In order to examine the precipitation decrease in lee-side lowlands of the northern sector according to the precipitation intensity on the highlands (Fig.1), its daily precipitation distribution was divided by the percentiles 0-80% (weak and moderate), 80-95% (intense), and higher than 95% (extreme). Then, the days with precipitation on mountains were retained from low-lying precipitation series. It can be seen in Table 1 that the winter total snowfall, and almost the annual total snowfall, was recorded mostly during intense and extreme events (i.e., events with a 20% of frequency). When calculating the reduction precipitation rates, defined as the daily area average precipitations on the lowlands divided by it on the highlands, it can be noted that there is a sharply reduction of precipitation on lee side that increased when the intensity increased on highlands. For the extreme events on the mountains, the precipitation was almost entirely inhibited on lee side.

Precipitation conditions	Freq. (days)	Total amount in 7 winters	Reductions Rates	Maximum
Percentil 0-80% on the Andes	293	927 mm (25%)		14,0 mm
On lee side when 0-80% on the Andes	101 of 293	186 mm	80%	18,1 mm
Percentil 80-95% on the Andes	57	1478 mm (40%)		44,6 mm
On lee side when 80-95% on the Andes	32 of 57	79 mm	95%	25,0 mm
Percentil 95% on the Andes	19	1244 mm (35%)		131,6 mm
On lee side when 95% on the Andes	12 of 19	13 mm	99%	3,8 mm

Table 1: Frequency, total amount, and maximum daily rainfall for different threshold on the Andes and on lowlands lee side when precipitates on the Andes.

## 4. CONCLUSIONS

The synoptic patterns associated with extreme orographic over the Central Andes (30°-35°S) were examined by standardized anomaly fields. In addition, the regional orographic influence on precipitation was

explored. The circulation associated with these extreme events is an intense negative anomaly in geopotential heights strenghtened on the day of heavy rainfall and located off the central Chile coast. Besides, an anomalous northwesterly flow and moisture flux at low-, and mid-levels impinges on the high Central Andes. The u component (cross-barrier) and v component (along-barrier) of these flows promoted an intense orographic lifting on windward slope and humidity transport from subtropical latitudes, respectively. Thus, extreme precipitations it would generate over the Central Andes range.

The orographic influence on precipitation is very important in the Central Andes region. Most of the precipitation systems that impinges on the barrier are blocked and only a small fraction of them can cross the mountain obstacle. The reduction on lee-side precipitation with respect to highlands area was noted in frequency and intensity, and also this reduction accentuated when the precipitation intensity increased on highlands, up to 99% for extreme events.

*Acknowledgments.* The authors would like to thank the Oganizing Committee of the 13<sup>th</sup> Conference on Mountain Meteorology for helping M. Viale to attend the congress.

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