Analysis of an extreme precipitation episode over the Central Subtropical Andes using the Eta-PRM Regional Model

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1. INTRODUCTION

Like at similar places in the world, heavy precipitation and flooding are some of the most important weather problems along the mountainous zone of Central Subtropical Andes of South America (35º-30ºS). Although the High Mountain and lowlands of Central Chile (windward side) region have a winter precipitation régime (Ereño 1978, Montecinos 1999), the winter extreme precipitation episodes are not so frequent.

The winter precipitation events are usually associated with a frontal zone ("the polar front"), and an intense westerly flow in middle and high levels (sub polar jet stream); whose position in cold season is more northward than in warm season (Ereño, 1978). In addition, the intense precipitation are often linked with a strong warm and very dry downslope winds reaching the lowlands on leeside, whose name is "zonda wind" in Argentina (Norte F, 1988) (like "foehn wind" in central Europe or "Chinook wind" in United States).

In 2005 winter season, the most significant event took place on 26-29 August period, when the surroundings high areas of Santiago de Chile city experienced a intense rainfall of 109 mm in 20 hours (from 2000 UTC 26 August 2005 to 1600 UTC 27 August 2005) and a rainfall of 34 mm in 2 hours (1200-1400 UTC 27 Aug). This caused floods (with approximately 1500 residents directly forced from their homes) and many damage in the city. In High Mountain the intense precipitation and wind (locally named "white wind") caused the closing of the most important international Chile-Argentina roadway for 6 days. Events like this originate damage in commerce with Pacific Ocean countries across the principal Chilean ports.

The precipitation for this 4-day event ranged from 50-150 mm over lowlands of Central Chile (where the annual precipitation is about 350 mm) to 60-300 mm over the high Andes mountains. And also the Zonda wind was observed at some observational stations over leeside plains in Argentina.

The Andes Cordillera runs meridionally from 55ºS to 10ºN with a mean width of 200-300 km. The height varies with latitude, from the most southern latitudes till 35ºS, the mean height does not exceed 2500 m.a.s.l. allowing the westerly winds to pass over the mountains without much blocking. But northward of 35ºS, the cordillera rises rapidly, achieving a mean altitude of 4500 m.a.s.l., with many peaks over 6000 m.a.s.l. (Such as the Aconcagua peak 6959 m.a.s.l, the highest of the Americas). Here the mountain range is a great barrier for the wet winds and precipitation coming from the Pacific Ocean. This region is very singular and interesting to study many aspects of the orographic precipitation still unexplored. And in contrast with another mountainous regions, there are not reports of numerical simulations or studies. Not only to assess the forecasting capability of regional models, also to explore the spatial structure of orographic precipitation, which due to the scarcity meteorological stations, this task is very difficult. For example, Colle and Mass (2000)

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(hereafter CM2000) noted that on the Sierra Nevada and Cascades mountain range (2000-3000 m.a.s.l) in northwestern United States, relatively large and high barriers, have the maximum precipitation some kilometers upstream of the crest with significant precipitation shadowing in the lee. And also this maximum precipitation was closer to the crest of the Oregon coastal mountains (500-700 m.a.s.l), relatively narrow and low barriers. Sinclair et al.(1997) noted too that over the New Zealand Southern Alps, narrow and low barriers, this maximum is closer to the crest.

This work addresses several key questions concerning the 26-29 August 2005 episode in particular:

- ✓ What is the synoptic evolution accompanying the episode?
- ✓ How does the ability of the Eta-PRM 15-km resolution to simulate the episode?
- ✓ What is the spatial variability in model precipitation and the accuracy across the region?

Section 2 describes the data and methodology used, section 3 presents a brief synoptic overview for this event. Section 4 shows Eta-PRM verifications of the winds, temperature and dew point temperature for a selected sites as well as detailed precipitation verification. A concluding remarks are presented in the final section.

2. DATA AND METHODOLOGY

The 26-29 August precipitation event was selected based on the observations from the stations listed in Table 1. Seven stations of the Meteorological Office of Chile (DMC), nine stations of the National Weather Service of Argentina (SMN) and seven snow telemetry (SNOTEL) stations were used to verify the Eta/PRM precipitation forecasts in Central Chile and San Juan and Mendoza provinces of Argentina (Fig. 1). Some of the DMC and SMN stations were used to verify the Eta/PRM meteorological variables forecast linked with the beginning, maximum intensity and ending of the event on windward and leeward of the Andes. The SNOTEL stations belong to the Irrigation Department of Mendoza's province government. These are automated snow-pilow sensors in remote mountainous regions, and measure total water-equivalent precipitation since the start of the hydrological annual cycle (denoted in Table 1 by blue letter).

The model grid values were bilinearly interpolated at the station locations in order to compare with observation. And numeric simulation experiment with the Eta/PRM regional model was used to estimate the spatial structure of the precipitation event. This was because the scarcity of regional meteorological stations that do not allow to establish it with precision.

The synoptic evolution was analyzed using the reanalysis data from the National Center for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR; Kalnay et al. 1996). These are available every six hours at 2.5º X 2.5º latitue-longitude resolution and seventeen vertical levels.

Station name	ID	Lat.	Long.	H. (m)
La Serena	LSE	29.54ºS	71.12ºW	50
Valparaiso	VAL	33.01ºS	71.30ºW	120
Pudahuel Aero	PUD	33.23ºS	70.47ºW	475
Santo Domingo	SDM	33.39ºS	71.37ºW	0
Quinta Normal	QTN	33.3ºS	70.4ºW	520
Curico	CUR	34.58ºS	71.13ºW	228
Chillan	CHI	36.35ºS	72.02ºW	124
Jachal	JAC	30.14ºS	68.45ºW	1175
San Juan Aero	SJA	31.34ºS	68.25ºW	598
Punta de Vacas	PVA	32.51ºS	69.45ºW	2225
Mendoza Aero	MZA	32.5ºS	68.47ºW	704
San Martin	SMA	33.05ºS	68.25ºW	653
Chacras de Coria	CHA	32.59ºS	68.52ºW	921
San Carlos	SCA	33.46ºS	69.02ºW	940
San Rafael	SRA	33.35ºS	69.35ºW	748
Malargue Aero	MAL	35.3ºS	69.35ºW	1425
Horcones	HOR	32.47ºS	69.56ºW	3038
Toscas	TOS	33.09ºS	69.53ºW	3000
Palomares	PAL	33.37ºS	69.53ºW	2900
Salinillas	SAL	33.51ºS	69.47ºW	2616
Lag. Diamante	LGD	34.07ºS	69.42ºW	3300
Lag. Atuel	LGA	34.28ºS	70.01ºW	3600
Valle Hermoso	VHE	35.08ºS	70.12ºW	2250

TABLE 1: Coordinates, height of all stations used en the study (see Figure 1). Horizontal line separates groups of the Chilean meteorological stations and the Argentinean meteorological stations.

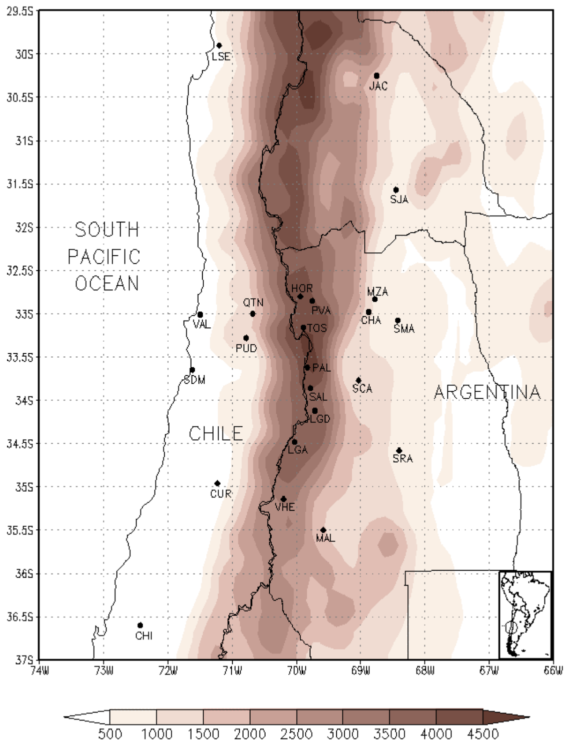

Figure 1: Map of the region under study, including orography (m, elevation higher than 500m are shaded) and locations of stations listed in Table 1.

3. BRIEF SYNOPTIC OVERVIEW

The synoptic situation was characterized by a clear baroclinic zone (polar frontal zone) between 30ºS and 40ºS denoted in 1000/500 hPa thickness (Figure 2) and linked with an intense westerly flow at 500 hPa (Figure 3). And at surface level a low pressure belt with a typically surface cyclones family (Bjkernes system) to the south of this frontal zone was noted(Figure 2).

The baroclinic zone was observed since 1200 UTC 25 August (Fig. 2a) over the Pacific Ocean, after at 1200 UTC 26 August (Fig. 2b) was closer to the Chilean coast. At midlevel the westerly flow it can see also since 1200 UTC 25 August (Fig. 3a), with a difluence flow approaching the Andes Cordillera in the next day (Fig. 3b). The event maxim intensity occurred during dawn hours of August 27 (see meteograms, in the next section). In Figure 2c the more intense cold front was arriving to the area, while the midlevel wind velocity was more intense (Fig. 3c). Finally, at 1200 UTC 28 August the last low center of the family surface cyclone was observed over the south Chilean coast (Fig. 2d); and a strong southerly flow at 85ºW-90ºW transporting polar maritime air to lower latitudes.

Figure 4 showed the “nephoanalysis“ at 0245 UTC 27 August where the frontal zone and the surface cyclones were observed. In addition, a triangled cloud pack on windward side (Central Chile region) was founded, that usually identify a surface Zonda wind episode leeward of the Andes (Norte F 1996).

4. SIMULATION OF 26-29 AUGUST 2005 EVENT

a. Model Description

The ETA-PRM model is a regional version of ETA-Centro de Previsao de Tempo e Estudos Climáticos (CPTEC-Brazil) South American continent 40-km resolution model. So, all references are the same than ETA-CPTEC model This is an hydrostatic model and uses the eta vertical coordinate defined by Mesinger (1984). The physic package and further developments are described in Janjic (1990, 1994) and Black (1994). The regional version model was adjusted with horizontal resolution of 15 km and 38 vertical levels over the central Chile and central-western Argentina region from 40ºS to 29ºS and from 75ºW to 56ºW. The model integrations began at 1200 UTC 25 Aug 2006, between 36-48 hours before maximum precipitation intensity, and ended at 1200 UTC 29 Aug 2006 (96-h forecast). The initial condition and the lateral boundaries (provided at six hours intervals) were taken from the ETA-CPTEC analysis with 40-km resolution.

b. Model time series verification

In the following subsection, the Figures 5 and 6 shows the surface evolutions and model simulations of 10-m winds, sea level pressure (SLP), 2-m temperature, 2-m dew point temperature, and precipitation for two stations at windward and three stations at leeward of the Andes Cordillera.

1) Windward surface time series

The principal cold frontal (PCF) passage at Pudahuel (PUD) was observed at 0900 UTC 27 August 2006 and was associated with a SLP minimum, a gradual wind shift to southwesterly and a principal maximum rainfall of the event (Fig. 5b). Another cold frontal (CF) passage at 1800 UTC 28 August was noted by a SLP minimum, a dramatic decrease surface temperature, a secondary

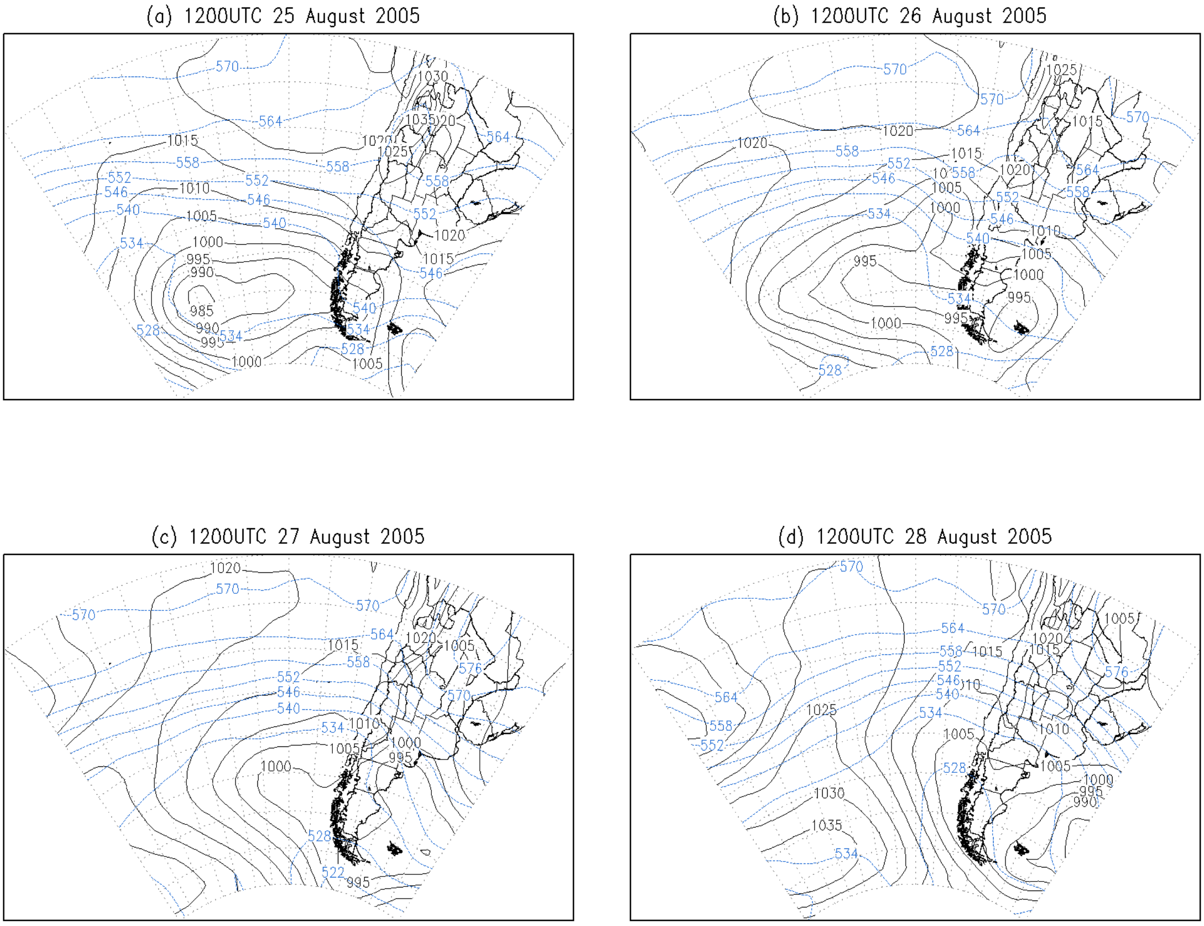

Figure 2: The surface NCEP Reanalysis at (a) 1200 UTC 25 Aug, (b) 1200 UTC 26 Aug, (c) 1200 UTC 27 Aug and (d) 1200 UTC 28 Aug 2005 showing sea level pressure (solid line every 5 hPa), 1000-500 thickness (dashed every 6 dam).

maximum rainfall of the event and veering winds from north to southwest direction (Fig. 5b). The polar air mass entrance was marked with a almost continued temperature decreasing since the PCF passage until to reach a temperature value of 1.3ºC at 1200 UTC 29 August at PUD (Fig. 5b).

The Santo Domingo (SDM) station had not observations at dawn hours, however the main characteristics registered at PUD were also observed at SDM (Fig. 5a). The principal and secondary maximums precipitation accumulated and the two SLP minimums entailed with the cold front passages, the PCF and CF respectively (Fig. 5a). The decreasing temperature was not so clear at SDM, located on the coast border where the maritime influence is greater than in PUD (see Fig. 1).

Although the model had some difficulty capturing lower magnitude of 10-m wind, 2-m dew point temperature and larger 2-m temperature daily range, many of the observed features at stations were well forecasted (Fig. 5c and 5d). There were two distinct rainy and the rising SLP periods and a general decreasing 2-m temperature associated with the two cold front passages (PCF-CF). Some of those model errors like excessive 2-m temperature day range and 2-m dew point temperature dry bias are similar with result from Betts et al. (1997) and Black et al. (1997). However, their studies utilized summertime data from the 48-km Eta-NCEP model.

The precipitation at PUD and SDM was realistically simulated by the model, but the initial time was forecasted nearly six-hour later (Fig. 5c and 5d). The 15-km Eta/PRM captured 70% and 110% of the observed storm-total precipitation at PUD and SDM, respectively. Most of the under prediction occurred at PUD and SDM during the principal maximum rainfall of the event (PCF passage, Fig. 5c and 5d). And the most of the over prediction occurred only at SDM during the secondary maximum rainfall of the event (CF, Fig. 5c).

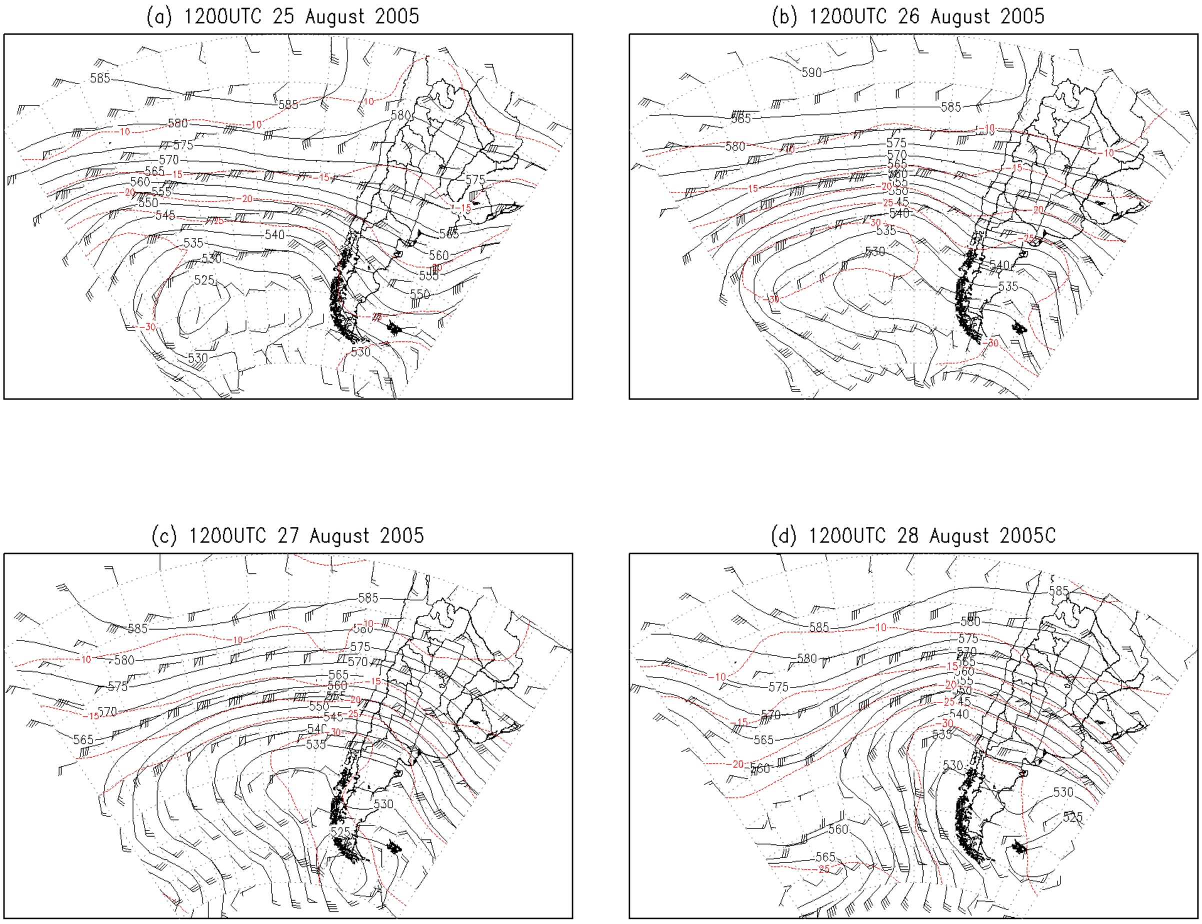

Figure 3: The 500 mb NCEP Reanalysis at (a) 1200 UTC 25 Aug, (b) 1200 UTC 26 Aug, (c) 1200 UTC 27 Aug and (d) 1200 UTC 28 Aug 2005 showing geopotential heights (solid line every 5 dam), temperature (dashed every 5ºC), and winds (one pennant, full barb, and half-barb indicate 50, 10, and 5 kts, respectively).

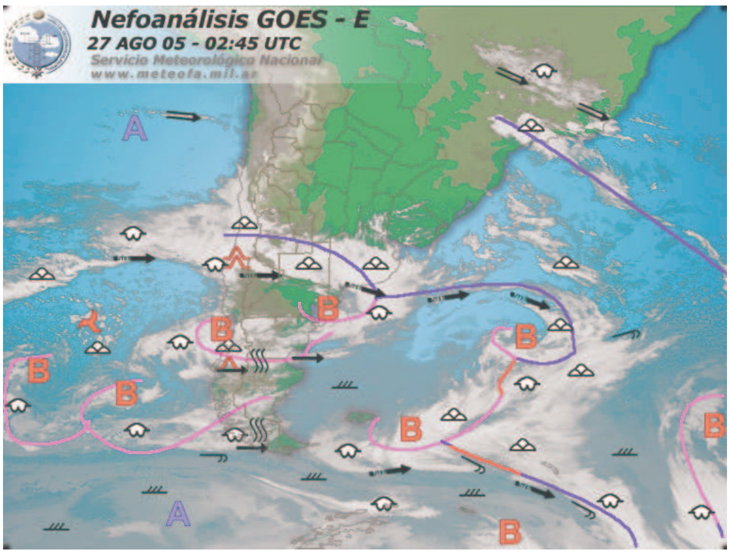

Figure 4: Nephoanalysis at 0245 UTC 27 Aug 2005 (approximately maximum event intensity) from Argentina National Weather Service. The letters B and A correspond to the low-pressure center and high-pressure center, respectively.

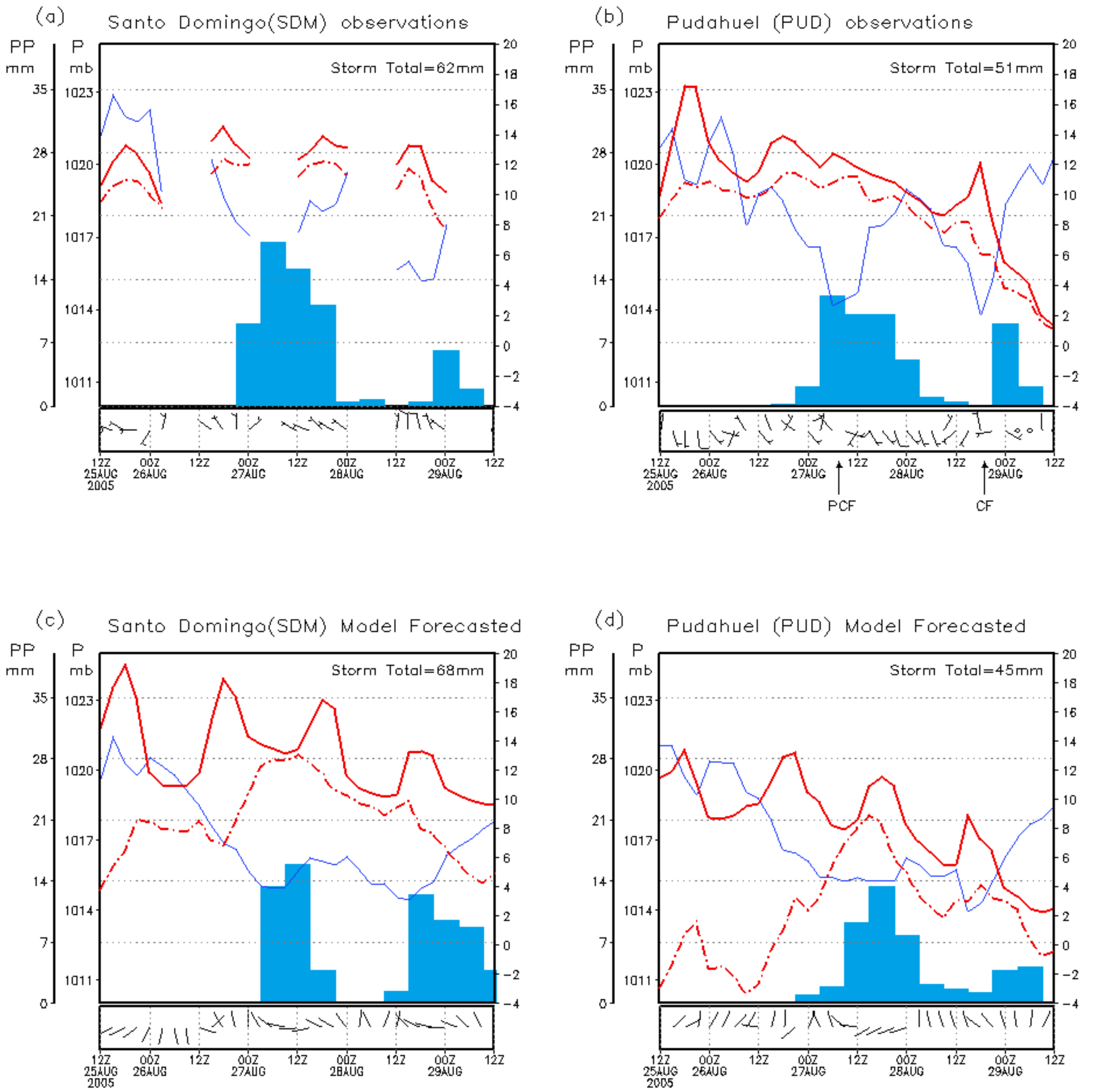

Figure 5: (a) Santo Domingo, Chile (SDM), and (b) Pudahel Aero, Chile (PUD), observations plotted every 3h from 1200 UTC 25 Aug to 1200 UTC 29 Aug 2005 showing temperature (ºC, red solid), dewpoint temperture (ºC, red dot dashed), sea level pressure (mb, blue solid), winds (full barb = 10 kts), and 6-h precipitation (shaded in mm). The locations of SMD and PUD are showed in figure 1. Gaps in temperature, dewpoint temperature, sea level pressure and winds at SMD station (a) are present in hours of the nigth. (c) and (d) same as (a) and (b), respectively, except for the Eta/PRM simulation.

2) Leeward surface time series

The more important signal at same latitude leeward of the Andes linked to PCF passage, was downslope wind situation (Zonda wind). In this opportunity wind reached surface at SJA (0000-1200 UTC 27 Aug, Fig. 6a) and JAC (Figure not shown), but their effects were noted also at MZA with high temperature, low dew point temperature and SLP minimum (Fig. 6b).

Because the mountains ranges close to Malargue (MAL) are lower than those surrounding SJA and MZA, the orography blocking effect is diminished and the event showed signals of both slopes. The principal and the secondary rainfall period at MAL coincided with the PCF and CF passage like at Central Chilean region (Fig. 6c). And the Zonda wind was present at 0000 UTC 26 Aug and between 1800 UTC 27 Aug – 0900 UTC 28 Aug at MAL like at SJA and JAC (Fig. 6c).

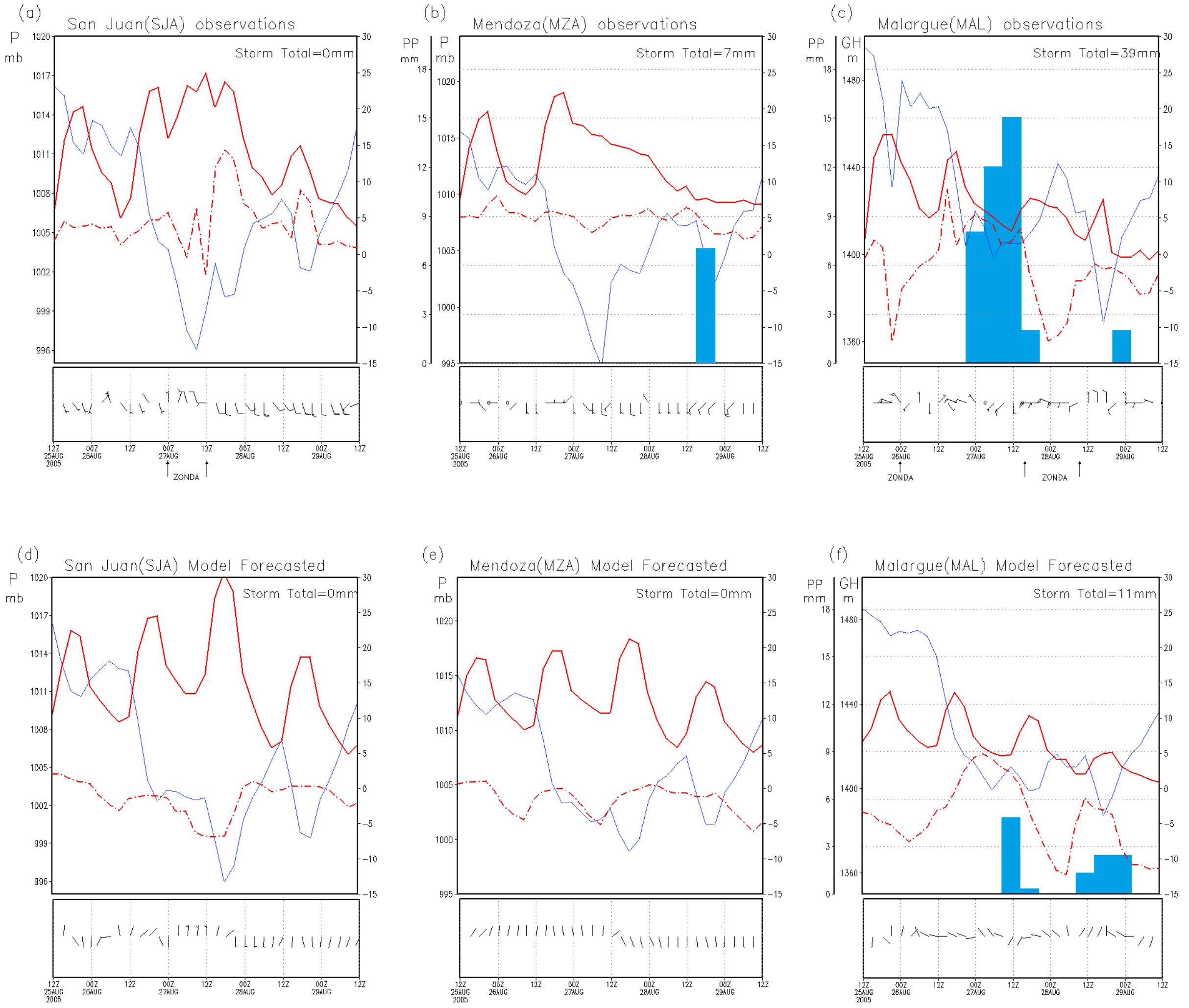

Figure 6: Same as Fig.5 but for stations at windward in Argentina, (a) San Juan (SJA), (b) Mendoza (MZA), and (c) Malargue (MAL) observations; (d), (e), and (f) are showed the Eta/PRM simulation, respectively. The locations of SAJ, MZA and MAL are showed in figure 1. The sea level pressure at MAL station are remplaced for geopotencial height (GH) of 850 mb level because its altitude is 1500 m above sea level (higher than 800 m).

The same main difficulties noted in the Eta/PRM model mentioned before, were also observed at leeside. The simulated variables such as: lower magnitude of 10-m wind, lower 2-m dew point temperature, larger 2-m temperature daily range, and the PCF passage nearly six-hour later were present in Figures 6(d), 6(e) and 6(f). In particular, the Eta/PRM model under predicted the rain at MAL and MZA. This coincided with 12-km MM5 and 10-km Eta/NCEP cold season evaluation that generates not enough precipitation on the lee of major barrier on Northwest U.S.A founded by Colle et al. (1999). Nevertheless, the model was able to forecast several aspects of the Zonda wind occurrence (that allows to identify it), such as wind strength, temperature, and dew point changes, but an extended delay in their ending time was detected (Fig. 6d and 6f). This results are consistent with those founded by Seluchi et al. (2003), where in their study realized simulation of three Zonda wind cases with the 40-km Eta/CPTEC.

c. Percents of observed precipitation (POP) and model spatial precipitation distribution

The Figure 7 shows the storm-total precipitation forecasted and the POP at the stations locations (bold numbers with •).

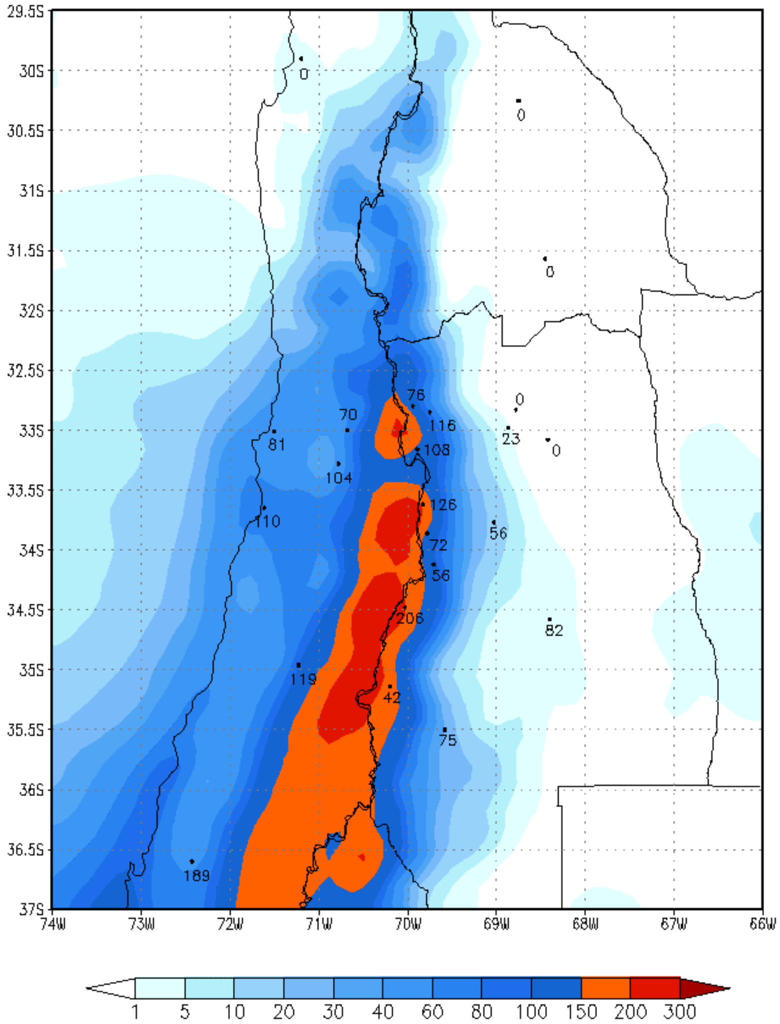

Figure 7. Storm-Total precipitation 96-h forecasted (shaded in mm) for the Eta/PRM model from 1200 UTC 25 Aug through 1200 UTC 29 Aug 2005. The numbers at the • locations indicate the percent of observed precipitations.

This POP or bias is defined as forecast divided by observed (*F/O*) precipitation, and then multiplied by 100. In general, the better bias scores (70%-130%) are situated over the lowlands of Central Chile and to the northward 34ºS on downstream of Andes crest (near the Chile-Argentina border). While the higher bias (>130%) are located over the southernmost station (CHI) and the orographyc transitions zone station (LGA, between the highest mountains northward 35ºS and lower mountains southward 35ºS). In contrast, the model predicted less than 70% of observed storm-total precipitation at most stations downslope of the Andes range. Similar results founded CM2000 when simulated a flooding event over Cascades ranges in north-western U.S.A.. The bias equal 0, in some isolated locations of the northern part of area, correspond to stations that reported no precipitation or very little precipitation when model forecasted no precipitation.

Despite the fact that the scarcity of meteorological stations in the region do not allow to establish a accuracy observed spatial precipitation distribution of the event, the model simulation was used to estimate it. The maximum precipitation (200-300 mm) was observed upstream of the high Andes crest (like “pools” near of Chile-Argentina border). This is consistent with that founded by CM2000 over higher Cascade ranges. And also, a very large zonal precipitation gradient was simulated downstream showing the great barrier blocking effect.

5. CONCLUDING REMARKS

The principal synoptic conditions during the 26-29 August 2005 extreme precipitation event were: a frontal zone and an intense zonal flow in middle and high levels; a wide persistence low pressure belt (35ºS-50ºS) with a typically surface cyclones family (Bjkernes systems).

The ability of the 15-km Eta-PRM model showed that the precipitation of the event windward of the Andes Cordillera was realistically simulated and was able to forecast Zonda wind (Fhoen/Chinook) occurrence leeward. But this model had some difficulties over both sides of the Andes range capturing lower magnitude of 10-m wind and 2-m dew point temperature, larger 2-m temperature daily range, and the cold fronts passages nearly six hours later.

The spatial model precipitation distribution of the event showed the maximum precipitation (200-300 mm) upstream of the high Andes crest and a very large zonal precipitation gradient downstream showing the great barrier blocking effect.

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