A NUMERICAL CASE STUDY OF AN OROGRAPHICALLY ENHANCED FRONTAL SYSTEM IN CENTRAL CHILE

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Abstract: The interaction of a frontal system with the extreme orography of the Andes mountain range is examined for a case of intense precipitation in central Chile during June 2002. The heavy rainfall was associated with a synoptic scale rainband that moved slowly over central Chile during a 48 hour period. Numerical simulations with the WRF mesoscale model show that both the intensification of precipitation within the rainband, and its semi-stationary character, were fundamentally determined by interaction with the topography. It is suggested that the intensification of otherwise weak frontal zones by orographic flow deformation may be an important precipitation mechanism in central Chile.

1. INTRODUCTION

Central Chile, a narrow strip of land between the South American Pacific coast and Andes mountain range between 32-35°S, is a region of extreme orography (Figure 1). From the coast to the main ridge of the Andes, over a distance of only 150 km, the terrain rises from sea-level to a mean height of over 4000 m, and embraces a central basin that holds Chile's capital city of Santiago (pop. 6 million). Annual rainfall is on average 300 mm, distributed a few winter-time events associated with mid-latitude disturbances passing over the south of the country. During these events, wind speeds upwind of Andes are typically between 5 and 15 m/s and the air mass stable (N ~ 0.012), indicative of a completely blocked flow regime (Overland and Bond, 1995). Orographic interactions are thus expected to play a major role in determining rainfall distributions in the region, not only by uplift over the steeply sloping terrain (e.g, Smith and Bastard, 2004), but also by dynamical modification of the storm systems themselves (e.g., Doyle 1997).

In this study we present a preliminary examination of a major rainfall event that occurred in Central Chile in early June 2002. This event was the heaviest that the region had experienced for over 77 years, caused several fatalities (due too collapsed bridges and housing) and forced over 50,000 people from their homes[1]. While the event was extreme, its structure and evolution was similar that of other, less dramatic, precipitation episodes in the region. In the next section, we present an overview of the observational characteristics of the event. In section 3 a numerical model is used to simulate the event and isolate the influence of the orography. Our conclusions are presented in section 4.

2. EVENT OVERVIEW

The rainfall episode occurred within synoptic scale northwesterly flow associated the successive passage two cyclonic systems across southern Chile. Rainfall in Santiago began on June 3 at 0200 UTC (Figure 1b). Satellite observations (Figure 2a-b) show that a synoptic scale frontal band of precipitation, oriented 45° to

1 Source: NOAA

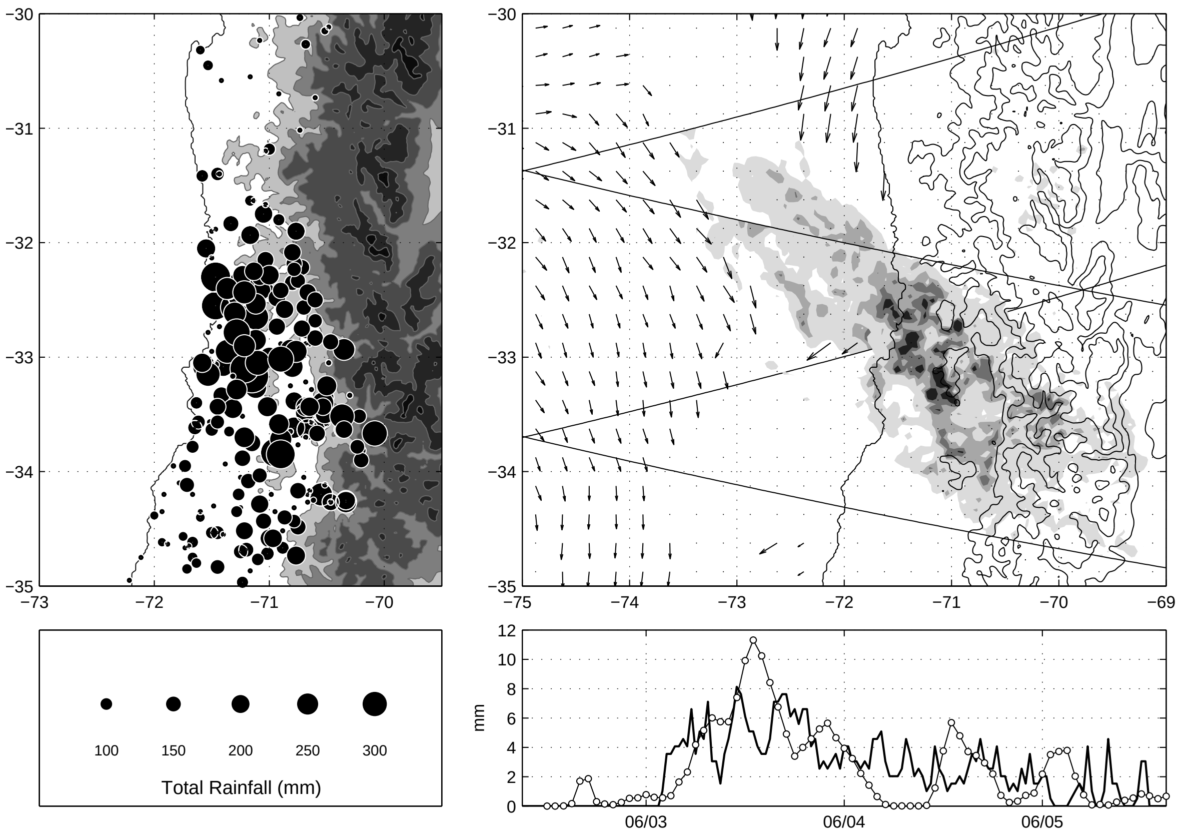

Figure 1: The upper left panel shows the topography of Chile's central zone (contour interval 1000 m) along with the storm accumulated rainfall. The upper right panel shows surface precipitation rates on June 3 derived from TRMM space-borne radar scans at 0845 and 1130 UTC. The gray contour intervals are 1,5,10 and 20 mm/hr. Also plotted are QuikScat ocean wind vectors from a 1100 UTC satellite pass. The lower right panel shows the hourly precipitation rates recorded at Santiago, along with the simulated precipitation from the CONTROL model.

the coast, developed over central Chile at this time. The rainband moved slowly northward during the next 48 hours, during which nearly 200 mm fell in Santiago, and over twice that at some coastal stations (Figure 1a). Coastal radiosonde observations (not shown) show weakening and northward turning of flow below heights of about 3000m, indicative of low level blocking of flow approaching the Andes.

A 'snapshot' of the detailed structure of precipitation derived from TRMM space borne radar on June 3 is shown in Figure 1. Notable is the strong intensification of precipitation between the coast and the foothills of the Andes Cordillera. TRMM 3D reflectivity observations (not shown) indicate that the rainfall was generally stratiform with embedded convective elements (note the structure of the region of intense precipitation near the coast). QuickScat wind velocity estimates over the oceans clearly show the low level convergence associated with the rainband. At points near to the cast these winds a phenomena likely to be strongly influenced by the coastal orography (Overlad and Bond, 1995).

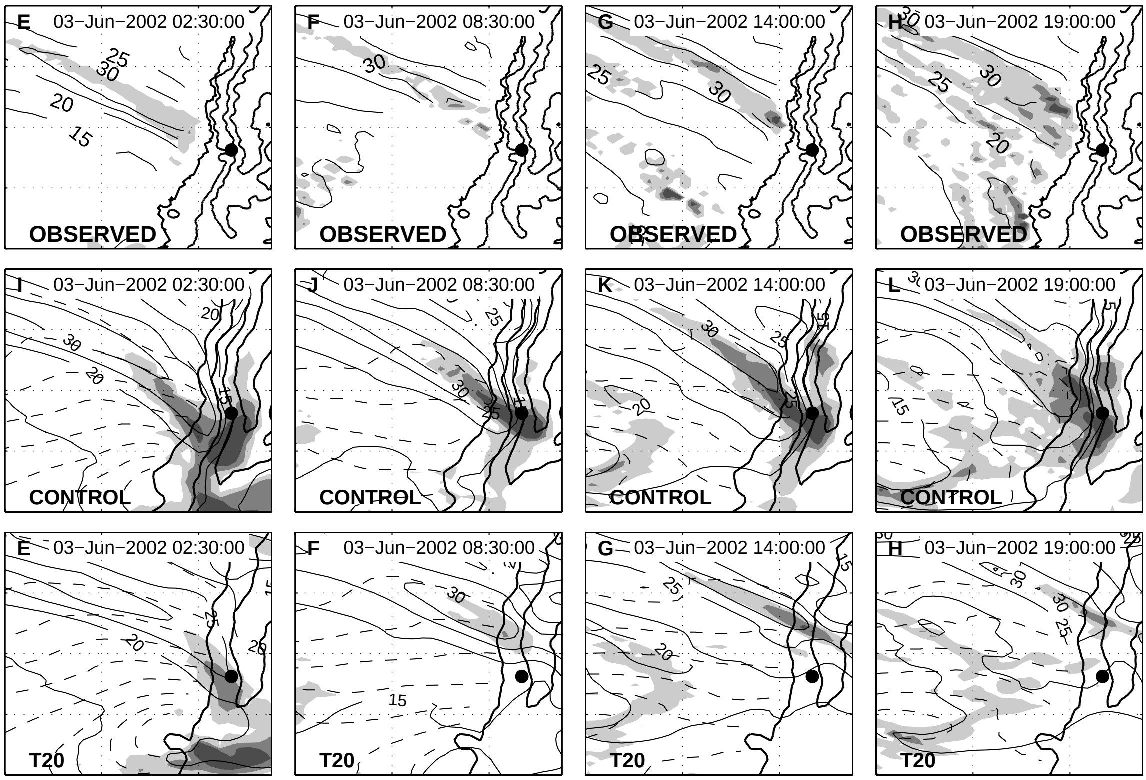

Figure 2: Upper panels (a-d) show the early evolution of the rainfall episode using radiometer observed PW (solid contours) and precipitation rate (gray contours). The radiometer observations are at 0.25 resolution and are only available over the ocean. The middle (e-h) and lower (i-l) panels show the same variables calculated from the CONTROL and T20 simulations respectively. The gray scale range for precipitation is between 0.5 (light) and 5 mm/hr (dark). Also shown with the model data are the simulated surface pressure contours at 2 hPa intervals. The black circle indicates Santiago. The thick black lines show the actual and model orography, at contour intervals of 500, 1500 and 3000 m.

3. NUMERICAL RESULTS

Numerical simulations were performed with the Weather Research and Forecasting (WRF) mesoscale model with a horizontal spacing of 36 km and 31 vertical levels, initialized and forced at the boundaries by 6 hourly NCEP-NCAR Reanalyses. The model was run in a more or less default configuration, with the most relevant settings being the use of the advanced mass dynamical core, Lin microphysics and Kain-Fritsch convective parameterization. The model was initialized at 1200 UTC June 02, 2002, 14 hours before the onset of rainfall at Santiago. A CONTROL experiment was initialized with standard orography from the WRF Standard Initialization (WRFSI) scheme. A second experiment (T20), was performed with model orography reduced by a factor of 0.2.

The CONTROL simulation was carefully validated against several observational datasets. For example in figure 2e-h it is seen that the development of the rainband and its slow northward progress was well reproduced by the model, as was the time series of hourly precipitation at Santiago (Figure 1). The evolution of the PW field (Figure 2) was also well simulated, indicative of a correct representation of the moisture distribution and advecting winds. Comparison of the model with radiosonde observations at a coastal site (not shown) indicates that the model correctly simulated the conditions upstream of the Andes.

The effect of orography may be examined by comparing the evolution of the CONTROL and T20 simulation. In the latter, the effective barrier height of the Andes is reduced to about 800 m, and the flow regime changes from blocked (Fr ~ X) to unblocked (Fr ~ Y). The T20 simulation (Figures 2i-l) also shows the development of the extended frontal region as evidenced by the band of moisture and embedded rainfall. However, the frontal precipitation is weak and there is little intensification over the coastal region and in the mountains. The frontal system also propagates northwards too rapidly. It thus appears that while the ambient synoptic situation is sufficient to explain the development the rainband, it's stagnation and intensification over central Chile depended crucially upon interaction with the elevated topography of the region.

A detailed diagnosis of the CONTROL in order to determine the nature of the mechanism by which the rainband is intensified model has not yet been completed. However, initial results (not shown) strongly indicate that the dominant mechanism is enhanced low-level (i.e., below the Andes ridge height) convergence associated with a southward deformation of flow ahead of the frontal zone. Initial results also suggest that 'classic' orographic precipitation due to mechanical uplift of cross mountain flow makes a relatively minor contribution to the overall rainfall budget except at high altitude points in the mountains.

4. CONCLUSION

In this study we have investigated the influence of the extreme orography of Central Chile on the evolution of a destructive precipitation event using observational data and the WRF mesoscale model. The heavy rainfall was associated with a slowly moving synoptic scale rainband. Numerical results show that both the strong intensification of precipitation within the rainband, and its semi-stationary character were fundamentally determined by interaction with the topography. Our results provide preliminary evidence that intensification of otherwise weak frontal zones by orographically enhanced convergence in blocked flow regimes may be an important precipitation mechanism in central Chile under appropriate synoptic conditions. Further model validation, diagnosis and sensitivity testing will be required to determine detailed functioning of this mechanism. Studies spanning multiple cases will also be required to determine the generality of the processes that occurred during the June 2002 case.

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REFERENCES

Doyle J. D., 1997: The Influence of Mesoscale Orography on a Coastal Jet and Rainband. Mon. Wea. Rev., Vol. 125, No. 7, 1465–1488.

Overland J. E. and N. A. Bond. 1995: Observations and Scale Analysis of Coastal Wind Jets. Mon. Wea. Rev., Vol. 123, No. 10, pp. 2934–2941.

Smith R. B. and I. Barstad. 2004: A Linear Theory of Orographic Precipitation. J Atmos. Sci.: Vol. 61, No. 12, pp. 1377–1391.