16.1 FORCED DOWNSLOPE FLOW OVER THE WESTERN SIDE OF THE SUBTROPICAL ANDES

René D. Garreaud and José Rutllant
Department of Geophysics. Universidad de Chile.

1. THE BACKGROUND FLOW

The western side of subtropical South America (27°-37°S; central Chile) is year round under the influence of the southeast Pacific anticyclone that results in a semi-arid climate and very stable conditions in the lower troposphere. The region is also characterized by its prominent topography: a coastal range that in many places rises above 1000 m and the Andes cordillera that rises sharply to its top above 4000 m within 300 km of the coastline. The main features of the regional circulation over this complex terrain can be identified in the wintertime mean diurnal cycle of the temperature and wind profiles at station La Platina (33.5°S, 70.7°W, 700 m ASL), just to the west of the Andean front range (Fig. 1). Between 2000 and 4000 m ASL the NNW flow results from the mechanical blocking of the Andes upon the upstream, large-scale westerlies. Below 2000 m ASL, the wind is controlled by the baroclinicity between the sloping terrain and the free atmosphere. Weak easterly flow (mountain-to-valley) prevails during nightime, with a maximum at ~ 700 m AGL. The presence of a very stable layer prevents the easterly flow to penetrate the lowest ~300 m AGL. After sunrise, the low-level wind changes to southwesterly (upslope flow), reaching a maximum speed during afternoon at ~200 m AGL.

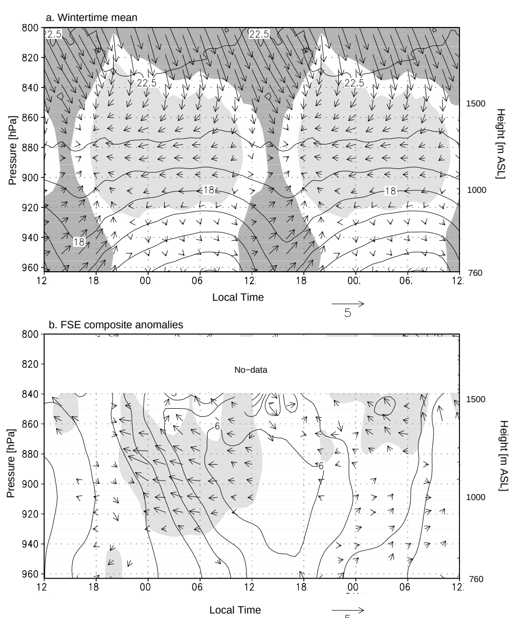

Figure 1. Profiles of θ (contoured every 1.5°C), **v** (arrows) and *u* (light/dark shaded easterly/westerly) at La Platina.

* Corresponding author address: Dr. René D. Garreaud. DGF-U.Chile. Blanco Encalada 2085. Santiago, Chile. E-mail: rgarreau@dgf.uchile.cl

2. FORCED DOWNSLOPE FLOW EPISODES

The aforementioned seasonal-mean, regional-scale circulation is frequently disrupted by synoptic-scale perturbations, especially during winter months. With a quasi-weekly periodicity, the nocturnal mountain-to-valley flow is significantly amplified and tends to extend well into the morning hours. We refer to these episodes as forced downslope flow episodes (FDE), and we identified them using the surface wind data from 1997-2001 at El Manzano (33.5°S, 70.4°W, 890 m ASL). The station is located in a narrow, east-west oriented section of the Andean valley of the Maipo River. Consistently, the wind is largely zonal and its direction exhibits a marked diurnal cycle (Fig. 2). FDEs are defined as those days in which the early-morning (06:00-07:00 LT) downslope wind speed (projected along the valley) exceeds 6 m/s. The threshold was chosen as to select 15% of the austral winter days (April-to-September). FDEs tend to last one or two days (45% and 40%, respectively), with a maximum duration of 5 days.

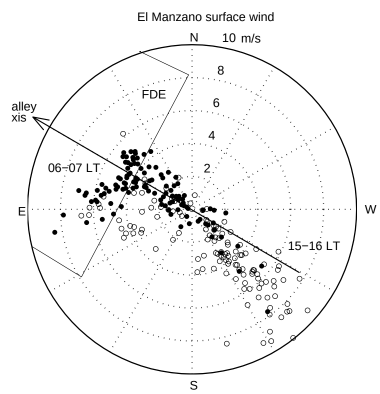

Figure 2. Polar plot of sfc. wind at El Manzano.

a. Regional aspects

Similar FDE's selection procedure was applied to surface wind data at other Andean valleys between 30° and 35°S (not shown), revealing that over 80% of the forced downslope flow episodes occurs simultaneously in this region. Further regional aspects of single-day FDEs are shown in Fig. 3 by means of the episode-mean evolution of several surface variables in the Santiago basin (similar results hold for longer FDEs). Day 0 correspond to the day in which the selection criterion was met.

The downslope flow anomalies at El Manzano (Fig. 3b) begins during the evening just before Day 0, increases during the night and reach a maximum intensity around dawn, coincident with the time of maximum seasonal-mean downslope flow. Later on, the anomalous flow weakens but it still persists during the rest of the day as to substantially reduce the afternoon upslope flow. A similar evolution is seen in the zonal wind at Lo Prado, a station located in a saddle point of the coastal range at about 1100 m ASL (Fig. 3c). Significant anomalies of easterly wind begin 12-18 h before the along-valley wind anomalies at El Manzano, a behavior seen in most of the individual episodes, suggesting a downward propagation of the wind anomalies. The composite anomalies of the wind profiles at La Platina (Fig. 1b) gives further evidence of such downward propagation. In any case, both La Platina data and pibal observations reveal that the anomalous easterly wind flow (mountain-to-valley) comprises the lowest 2-3 km of the atmosphere and generally it doesn't reach the surface except within the narrow Andean valleys where it exhibit a low-level jet structure (Garreaud and Rutllant 2002).

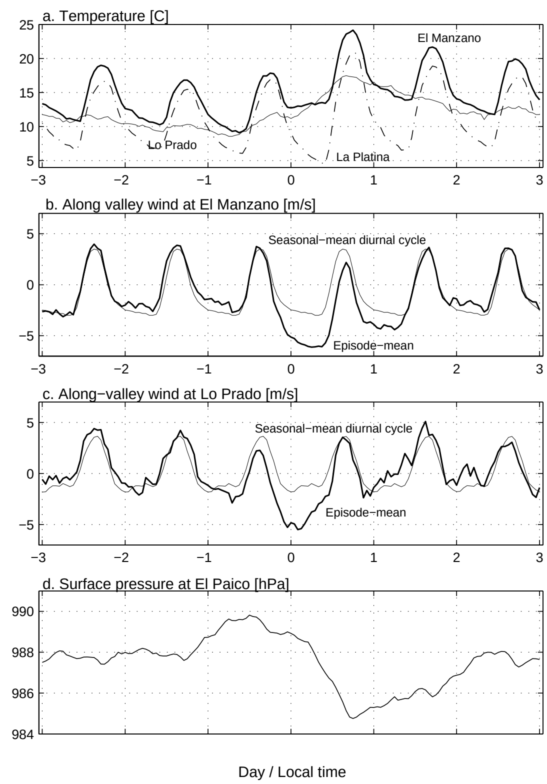

Figure 3. Composite time series during FDEs

La Platina data also reveal a pronounced low-level warming during Day 0 (Fig. 2b). Numerical simulations suggest that the warming is largely produced by enhanced subsidence in connection with the forced downslope flow (Garreaud and Rutllant 2000b). The maximum warming takes place between 900-850 hPa (near the climatological top of the subsidence inversion in this region), being well recorded in station Lo Prado (Fig. 4a). Consistently with the increase in static stability and a reduced growth of the daytime mixed layer, there is a generalized increase in maximum surface air temperature (as large as 15°C in individual episodes) at lower elevations. The minimum temperatures also increase sharply within the Andean valleys where the strong, turbulent downslope flow prevents the formation of the nocturnal stable layer. Such effect doesn't occur in the central valley between the Andes and the coastal range, where clear skies and low humidity during FDEs leads to very cold minimum temperatures (Fig. 4a). The low-level warming also leads to a local drop of the surface pressure (Fig. 4d) that culminate late on Day 0. Notice that the onset of the easterly flow in the lower troposphere (e.g., at Lo Prado) precede the initial surface pressure drop by 12-18 h.

b. Synoptic-scale patterns

NCEP-NCAR reanalysis were used to identify the most recurrent synoptic-scale patterns during FDEs. Visual screening of surface and upper variables reveals almost 90% of the FDEs occurs in connection with the developing of a coastal low in central Chile. The SLP field features an enhanced subtropical anticyclone over the SE Pacific connected with a cold, migratory high that has crossed southern Chile (where the Andes are less than 1000 m high) into central Argentina. The coastal low lies in between the subtropical anticyclone and the Andes. The mid-level circulation is characterized by a mid-latitude ridge with its axis near the Andes. In most FDEs the 500 hPa wind over the subtropical Andes is westerly (albeit weaker than normal), consistent with the shallow character of the easterly flow seen in the profile observations at La Platina.

Further climatological aspects of the coastal lows are documented in Garreaud et al. (2002), and the relationship between the forced downslope flow and the evolution of the coastal low is investigated using a numerical simulation of a typical case in Garreaud and Rutllant (2002b). It is found that the low-level easterly anomalies in central Chile are initially driven by the passage of the surface anticyclone farther to the south. Large-scale subsidence is enhanced near the western slope of the Andes due to the upwind-barrier effect of the topography (i.e., mass continuity). Adiabatic warming (due to the enhanced subsidence) leads to the drop of surface pressure in central Chile marking the onset of the coastal low, which in turns further increase the easterly flow. In this context, the strong downslope flow observed in the Andean valleys results from local channeling effects upon the synoptically driven easterly flow to the west of the Andes.

Acknowledgements. This research was supported by FONDECYT (Chile) under Grant 1000913. We want to thank the collaboration of many individuals during the field work of this project, especially to Mrs. Patricia Angoy, Director of Colegio Almenar del Maipo, and her colleagues; the Director of Escuela Pública de Cuncumen and Prof. Sergio Salinas; and Mr. Ramon Esposito from Junta de Vigilancia Río Maipo.

References

Garreaud, R.,J. Rutllant and H. Fuenzalida, 2002: Coastal lows along the subtropical west coast of South America: Mean structure and evolution. *Mon. Wea. Rev.*, **130**, 75-88.

Garreaud, R., and J. Rutllant, 2002: Coastal lows along the subtropical west coast of South America: Numerical simulation of a typical case. Submitted to *Mon. Wea. Rev.* [available from RG].