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How linear is orographic precipitation? Insights from the Nahuelbuta mountains in Southern Chile

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The Nahuelbuta massif is located in the coast of southern Chile at about 38°S, with an elliptical shape (about 150 km long , 100 km wide) reaching 1300 m at its center. A network of 15 rain gauges was deployed during the austral winter of 2011 in the context of the Andean-Front-Experiment (AFEX) complemented by permanent stations in the surrounding lowlands. Precipitation in this region generally occurs during the passage of frontal systems with moderate to strong NW flow. The observations reveal the typical orographic modification of the seasonal accumulation: coastal upstream values of about 1000 mm/year increase to 2000 mm/year at the foothills and then to about 4000 mm/year atop of the mountain. Immediately downstream of the mountains the annual precipitation decreases to 500-700 mm/year.

To determine the relative importance of linear and non-linear processes in producing the aforementioned orographic pattern, we conducted 2 simulations of the period May-September 2011: a full-physics continuous WRF run and Linear Theory (LT) model (Smith and Barstad 2004) run. The spatial pattern of the seasonal accumulation agrees very well among both models (r = 0.8). Comparisons with AFEX observations are more favorable for WRF: the LT model produces too much precipitation over the mountains and a too dry area downstream. We also analyzed each of the 27 precipitation events during 2011. The 30-min observations and WRF results reveal that the orographic modification is most notable during the prefrontal conditions when the mountain-to-lowland rainfall ratio as large as 10, and during the post-frontal conditions. Orographic effects are minor during the frontal period when the largest rainfall intensities occur. In this period the pattern is dominated by elongated bands of high rainfall leading to a high volatility of the rainfall distribution.

The LT-model produce a rainfall pattern tightly tied to the topography that remains rather invariant during the precipitation events. The LT-model fails to capture the high precipitation volatility and their maximum rainfall rates are restricted to the highest ground. Time series of LT-model precipitation are smooth and rainfall tends to begin well in advance than in observations, partially explaining the larger seasonal accumulation. Correlation between hourly rainfall maps from WRF and LT-Model are modest (0.1-0.3). These results highlight the relevance of non-linear processes at sub-daily timescales, but their effects tend to cancel at longer periods, so in a monthly or seasonal scale, linear processes tied to topography tend to dominate.