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MECHANISMS OF NIGHT-MORNING MAXIMUM RAINFALL OFFSHORE OF HIGH MOUNTAINS

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1. INTRODUCTION

We have studied the diurnal cycle of rainfall in northwestern South America, on the western slopes of the Colombian Andes and the adjacent ~100 km coastal plain. This is the rainiest place in the Americas, with long-term mean annual totals nearing 10m. Rainfall processes in this region have been investigated using a nested-grid regional model (MM5), with grids as fine as 2km in the innermost domain. This abstract briefly describes one major result, from Mapes et al (2002). More details are in that and the companion manuscripts. Warner et al. (2002) demonstrate that the model reproduces the climatological diurnal cycle well enough for meaningful physical process diagnosis.

Daytime heating over land produces a sea breeze, with convergence at its inland edge (the "sea-breeze front"), yielding a convective rainfall maximum ~50-100 km inland in the late afternoon. The dynamics of this situation have been well understood for many years. After midnight, convection erupts near the coast and especially offshore. Prior studies have speculated that this is due to a “land breeze,” analogous to the sea breeze, caused by the land being cooler than the sea at night (e.g. Houze et al. 1981). However, a close look at the data in that paper shows it to be inconsistent with the final schematic in the matter of the land breeze.

2. MECHANISMS OF MIDNIGHT CONVECTION

The cooling of tropical land at night is much weaker than daytime heating, since the humid atmosphere is much more opaque in the infrared than in the visible. Furthermore, cooling a fluid from below is less efficient than heating in terms of driving circulations. Finally, the offshore convection after midnight does not occur along a sharp "land-breeze front", but rather erupts almost simultaneously over a mesoscale region. This envelope of rainfall propagates offshore with a speed of ~20 m/s. This suggests that gravity-wave mechanisms, not density currents along the surface, may be responsible for this night-morning convection.

Figure 1 shows the model’s diurnal cycle of rainfall, on the 2km cloud-resolving grid, averaged over 5N-7N where the western Andes are oriented north-south and the geometry is quite 2-dimensional. Soundings at the times and longitudes indicated by heavy dots are analyzed in Fig. 2, in terms of the lifted buoyancy of air from 1000 hPa.

Fig.1: Time-longitude diagram of model rainrate 5N-7N. Line: coast. Dots: sounding locations.

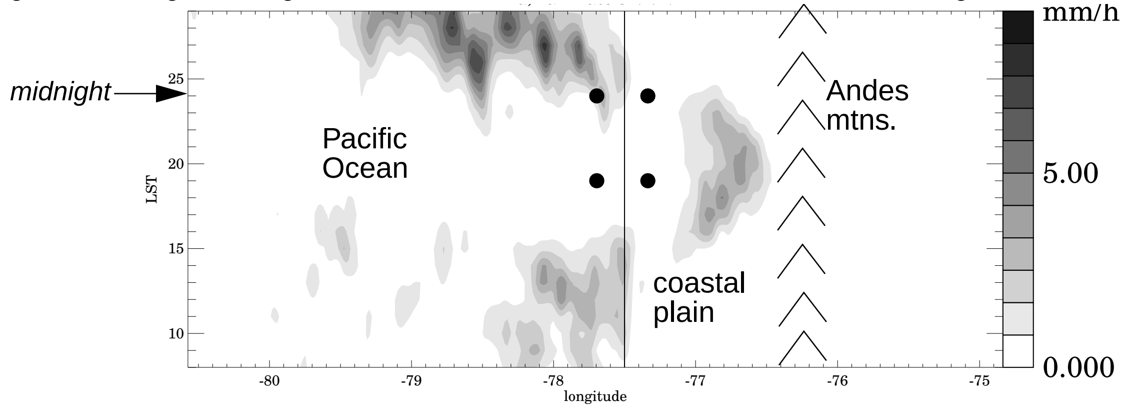

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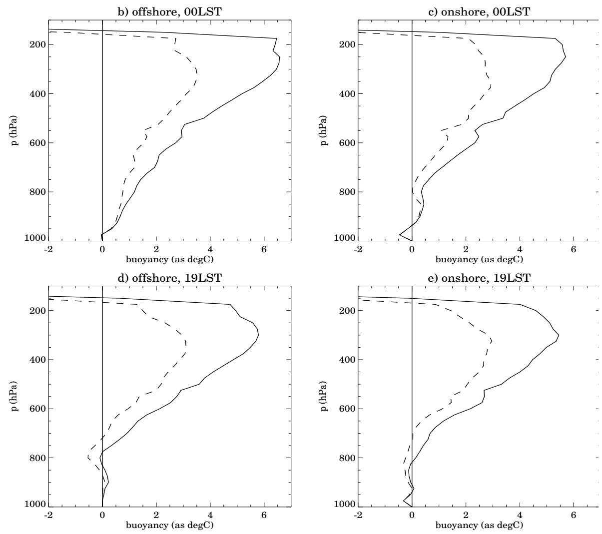
Fig.2: Lifted buoyancy of 1000 hPa air at the positions of the four heavy dots in Fig. 1 (same orientation). Solid line: undilute; dashed: entraining..



The lifted buoyancy is computed with complete thermodynamics, including water loading up to 3 g/kg and freezing, for undilute (solid) and entraining (dashed) ascent. The entrainment is as in the Kain-Fritsch convection scheme, which was used in the mesoscale model run that provided the boundary conditions for this explicitly-resolved simulation on a 2 km mesh.

The offshore midnight sounding shows positive buoyancy at all altitudes, consistent with the eruption of convection occurring at that time. The offshore sounding at 19 LST shows a similar amount of CAPE, but negative buoyancy near 800 hPa apparently prevents convection from developing. A similar evolution of buoyancy at 800 hPa, from negative to neutral or positive, is seen in the soundings over land. However, a stable boundary layer at the lowest levels apparently discourages convective development in that area after midnight. This thin stable layer is the main effect of nocturnal cooling over land, but it does not lead to the development of a significantly strong thermal land breeze.

Why does the buoyancy at 800 hPa switch from negative to positive after midnight? Figure 3 shows a time-longitude plot of the 800 hPa temperature, minus the daily mean value over water.

Fig.3: Mean diurnal time-longitude sections, repeated twice for clarity, of temperature anomalies at 800 hPa. Vertical lines indicate the coastline, wedges indicate the Andes mountains.

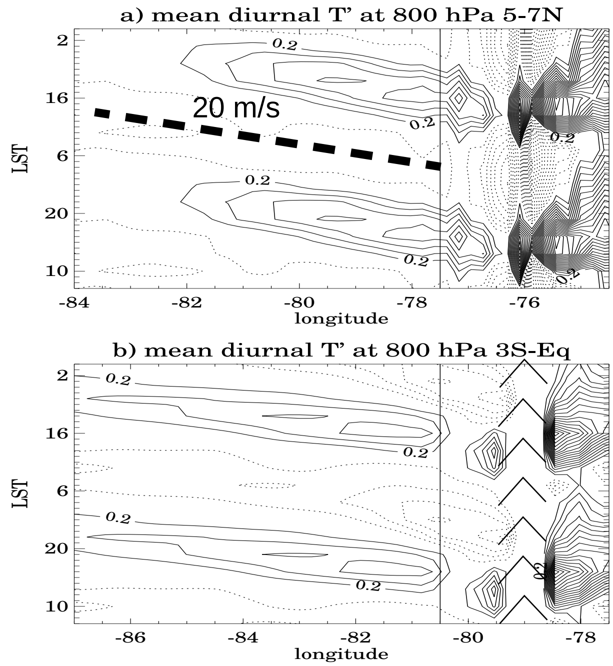


Figure 3a is for 5N-7N, and shows a very strong diurnal cycle over the mountains, associated with the afternoon mixed layer which deepens beyond the 800 hPa level. This diurnally pulsating elevated heating radiates gravity waves with phase speed c~20 m/s into the adjacent stratified atmosphere over the water. The cool phase uncaps the boundary layer after midnight and allows deep convection to develop. Figure 3b shows the same diagram for 3S-Equator, where there is no deep convection, showing that the mechanism is fairly independent of the convection it modulates (easterlies are stronger here so c>20 m/s).

Acknowledgment

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