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THE COASTAL BOUNDARY LAYER DIURNAL CYCLE ALONG NORTH-CENTRAL CHILE: OBSERVATIONS AND MODEL SENSITIVITIES.

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1. Introduction

The coastal strip along north-central Chile (19-35°S, 70-71°W) is located in a region of considerable climate interest. To its west the subtropical anticyclone of the SE Pacific maintains an extensive and persistent deck of low-level stratocumulus clouds that have a large impact in the planetary radiative budget. To the east, topography rises up to the peaks of the Andes Cordillera (heights >3000 m) in less than 200 km, leaving in between a region encompassing the extremely arid Atacama Desert. In this work we analyze available data and perform numerical modelling aimed at describing and understanding the dynamics of the diurnal cycle of the marine boundary layer (MBL) along this coastal region.

2. Observations

The climatology of the offshore wind field is characterized with sea surface winds derived from Version 3a QuikScat data for years 2000-2006. The data are on a 0.25°x0.25° lat/lon grid derived from the original swath data available from Remote Sensing Sys. (www.ssmi.com). There are 2 daily passes of the satellite, occurring over this region at about 12 and 23 UTC, which we call AM and PM wind fields, respectively. During April-October 2003 a second scatterometer operated on Midori-II satellite providing surface wind fields at times ~ 05 and 15 UTC over this region. We use here the Sep-Oct 2003 period to partially validate the modeled wind diurnal cycles in this region.

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Figure 1 shows the mean fields of the QuikScat meridional winds (V) computed over 3-month periods. Upper panels show the PM-AM differences, which have a region of maximum amplitudes near the coast at ~25°S, especially in the warm season. PM-AM mean differences of the zonal winds show remarkably little values (not shown). The lower panels in Fig. 1 show the mean PM V fields, which have a low level jet structure around ~30°S that has been studied in previous work (Muñoz and Garreaud, 2005).

The variability around these mean fields is illustrated in Fig. 2, where boxplot diagrams have been constructed for December meridional winds occurring in 2° latitudinal bands and up to ~100 km from the coast. It is evident that north of ~29°S the PM and AM distributions of V are significantly different.

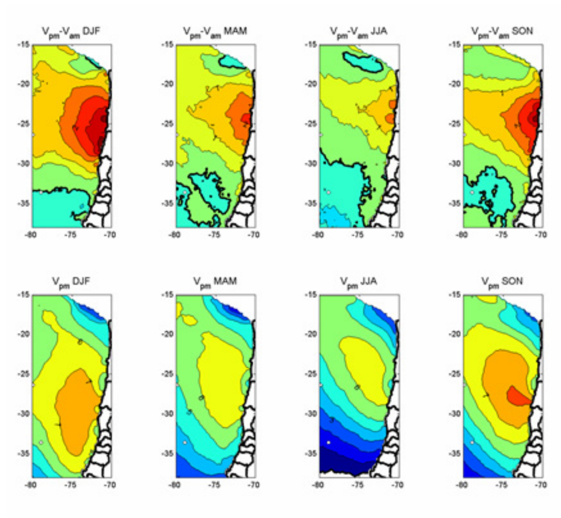

Figure 1. 2000-2006 Meridional Wind Climatology from QuikScat data. Upper: PM-AM V differences, Lower: PM V mean fields.

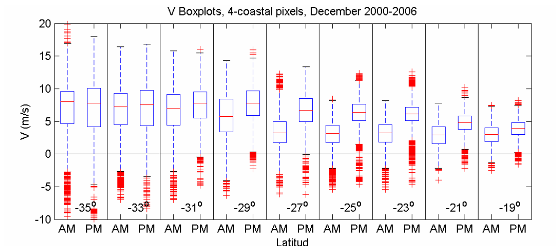

Figure 2. Boxplots of December coastal meridional winds along 2° latitudinal regions and up to 100 km off the coast.

3. Model Results

3.1 Model setup

We have used the PSU/NCAR MM5 mesoscale model to compute surface wind fields over the region of interest. One model domain is used with horizontal resolution of 25 km and 32 levels in the vertical (first model layer at ~23 magl). Turbulence in the PBL is computed with the TKE Gayno-Seaman parameterization. Boundary conditions are taken from NCEP/NCAR Reanalysis and sea surface temperature is kept fixed in time at the monthly mean fields derived from AMSR-E fields obtained from www.ssmi.com.

3.2 Model validation

The model is partially validated in Sep.-Oct. 2003, because in this period there exist 4-daily scatterometer wind fields available. Fig. 3 shows observed (left panels) and modeled fields (right panels) obtained by subtracting meridional winds between 23 and 12 UTC (upper panels) and between 15 and 05 UTC (lower panels). Model results have been interpolated in time and space to match the exact points and times when satellite data are available. There is general agreement between model results and observations. Some discrepancy is found in the north-eastern portion of the oceanic domain, where the model results suggest that the abrupt change in orientation of the coastline and topography produces a complex response of the low level flow.

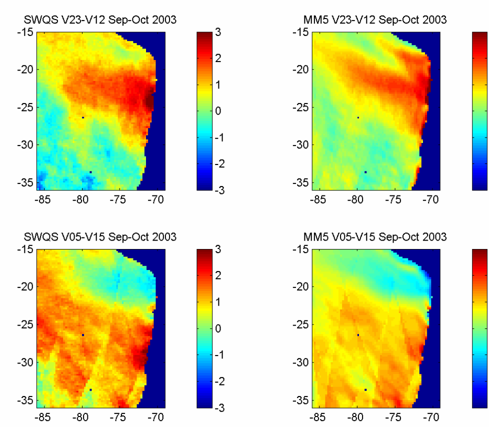

Figure 3. V semi-daily differences from model (left) and observations (right) for 09-10 2003.

3.3 Model diagnostics

The study of the diurnal cycle in the region is based upon a similar model setup, but for December 2003, a period in which the QuikScat climatology has shown that the diurnal cycle signal in the surface winds is stronger. One of the intriguing questions posed by the QuikScat climatology is the weakness in the PM-AM difference of the zonal winds. Fig. 4 attempts an explanation by showing 3-hourly mean differences of the surface zonal winds according to model results. The coastal strip along north-central Chile shows indeed a marked intensification of the zonal winds between 18 and 12 UTC, but this is compensated by a subsequent decrease in magnitudes between 24-18 UTC.

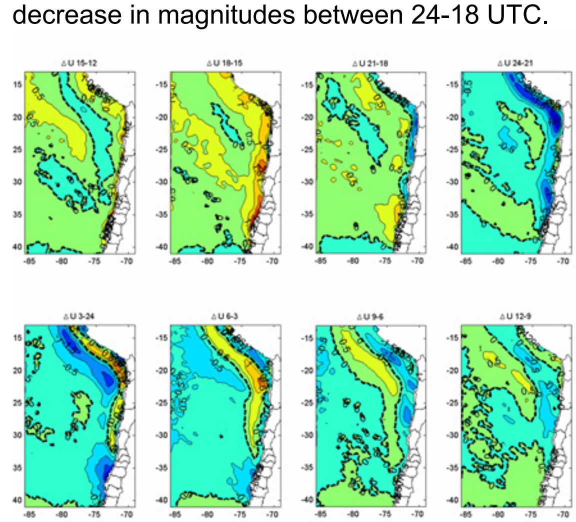

Figure 5. 3-Hourly changes in zonal winds.

Figure 6 illustrates the change of the wind diurnal cycle with height. At selected oceanic grid points we have plotted the hodograph of the mean diurnal cycle at ~23 masl (left panel) and ~700 masl (right panel). Near the coast and at latitudes ~25°S the amplitude of the diurnal cycle increases with height in the first km above the surface, while the surface wind field shows a more complex hodograph in which a double cycle of the zonal wind is also evident.

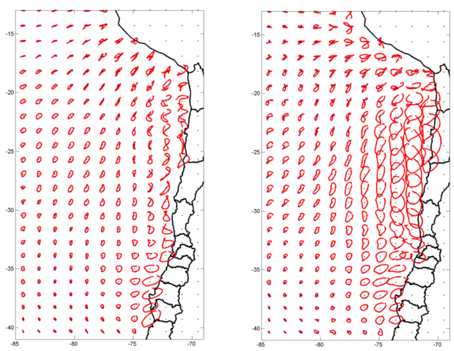

Figure 6. Model computed hodographs of the mean diurnal cycle at 23 masl and 700 masl.

More detailed diagnostics of the model results (not shown) suggest that the diurnal cycle of the wind in this region is mainly forced by the pressure gradient force, and that the latter is controlled in turn by the vertical velocity field in the lower troposphere. Therefore, we illustrate in Figs. 7 and 8 aspects of the mean diurnal cycle of the vertical velocity field (W) according to the model results. Figure 7 shows smoothed vertical-meridional cross sections of W averaging at each latitude grid points close to the coast. Cross sections are drawn every 2 hours to show the diurnal cycle of the coastal W. Between 22 and 12 UTC a region of positive W in the lower troposphere moves from north to south, a feature reminiscent of the upsidence wave described by Garreaud and Muñoz (2004). The daytime phase of the diurnal cycle, in contrast, shows a rather simultaneous enhancement of the coastal subsidence in a region sloping from ~1000 masl at 35°S to ~3000 masl at 22 °S (see 18 UTC panel). The timing and slope of this enhanced afternoon subsidence suggest that it may be related to the heating of the Andes topography to the east, as proposed by Rutllant et al. (2003).

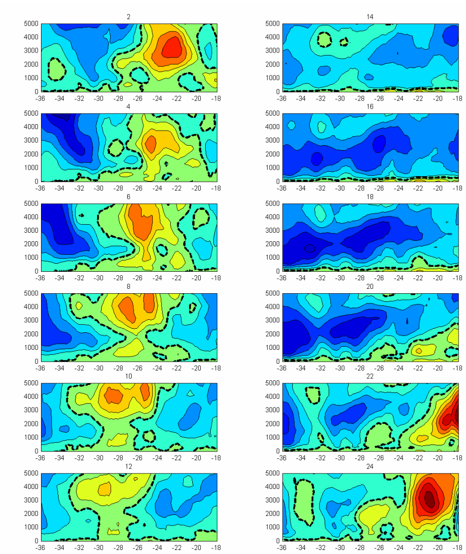

Figure 7. Meridional cross sections of the diurnal cycle of coastal vertical velocities.

Finally, Fig. 8 is a Hovmuller diagram in which the W diurnal cycle is shown at 26°S and for averages between 0-1000 masl (left panel) and between 2000-4000 masl (right panel). Zonally, the diagram spans from the coast up to 80°W, and the diurnal cycle has been repeated for clarity. The figure shows that while W in the mid-lower troposphere has a 1-cycle diurnal cycle, the lowest km has a distinct double cycle in the W field, a similar feature shown previously for the zonal wind in this same region.

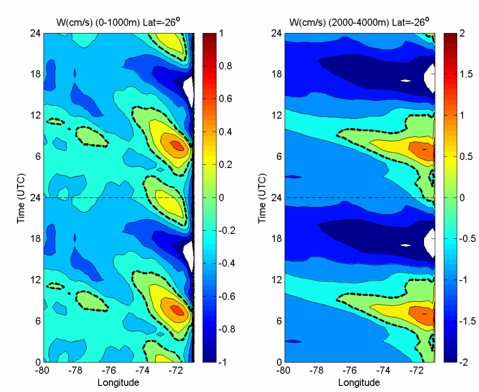

Figure 8. Hovmuller diagrams for W diurnal cycles at 26°S. Left panel for 0-1000 masl averages and right panel for 2000-4000 masl averages.

4. Conclusions

We have used results of a mesoscale model in order to understand better some features of the diurnal cycle of the surface winds over the SE Pacific, as suggested by the PM and AM QuikScat wind fields. Among these features we can mention:

- a larger meridional PM-AM difference as compared to the relatively modest PM-AM zonal wind difference.
- a seasonal cycle with larger PM-AM magnitudes in the warm months.
- a coastal region with maximum PM-AM differences spanning between 20-30 ^{o}S and extending about 5^{o} offshore.

Model results suggest that the diurnal cycle of low level winds in this region is forced by processes occurring above the marine boundary layer, among which enhanced afternoon subsidence associated with heating of the Andes mountains appears to play an important role. The response of the boundary layer winds to this upper level forcing appears to be rather complex, taking in some regions near the coast the form of a double cycle in the zonal wind and in the vertical velocity fields.

Acknowledgements

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