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THE DIURNAL CYCLE IN THE COASTAL ATMOSPHERIC BOUNDARY LAYER ALONG NORTH-CENTRAL CHILE: OBSERVATIONS AND MODELS.

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1. Introduction

The prototype of diurnal cycle in the coastal atmospheric boundary layer (ABL) is controlled by the sea-breeze regime forced by the differential heating/cooling of the land and the adjacent water. Important factors affecting the sea-breeze circulation are the synoptic pressure gradient, the coastal land use and topography, the cloud cover, the sea surface temperature, and certainly the latitudinal variation of the Coriolis parameter. Rotunno (1983), for example, used a linear model of the sea breeze to demonstrate significant differences of the circulation for latitudes greater or smaller than 30°. Along the extensive Chilean coast, all factors of the sea breeze show considerable variations, and thus diurnal cycles of temperature and wind at coastal stations may show similarities and differences that can be related to the various physical mechanisms at play. The purpose of this work is to use available data and model results to produce a preliminary description of the diurnal cycles in the coastal ABL along north-central Chile, aimed at improving the understanding of the main physical factors that control the coastal ABL in this region. Besides its importance for the local weather, the coastal circulation may also affect the persistent and extensive Sc layer of the Southeast Pacific (Rutllant et al., 2003).

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2. Data description

The offshore wind field is characterized with sea surface winds derived from Version 3 QuikScat data for years 2000-2004. The data are on a 0.25°x0.25° lat/lon grid derived from the original swath data available from Remote Sensing Systems (www.ssmi.com). There are 2 daily passes of the satellite, occurring at about 12 and 00 UTC. The daytime variation in cloud cover is characterized by analysis of raw GOES-12 visible data available from NOAA's CLASS electronic library (www.class.noaa.gov). Results presented here make use of the 1145 and 1745 UTC images for October-December of years 2003 and 2004. We also analyze wind and temperature data for several automated meteorological stations along the coast of Chile, between latitudes 20.8 °S and 34.4°S (Table 1 and Fig. 1a).

Table 1. Coastal Stations

#	Location (see Fig. 1)	Period
1	Pt. Patache	2001
2	Cal. Constitución	5/98-4/99
3	Pt. Caldereta	10/97-9/98
4	Huasco	11/93-10/94
5	Pt. Lengua de Vaca	5/02-4/03
6	Pichidangui	2000
7	Ventanas	2001
8	Pichilemu	2004

3. Satellite winds and cloud cover

Prevailing winds along north central Chile are from the South in all seasons, with maximum afternoon speeds in late spring and summer. Fig. 1 shows mean properties of the surface wind field derived from the QuikScat data. Fig. 1a shows the averaged wind speed, with a maximum that has been related to a low level jet by Garreaud and Muñoz (2005). Panel b) describes the difference between the PM and AM Quikscat wind fields (Δ) for October to March. Δ is taken as a first approximation of the diurnal cycle of the surface winds. Fig. 1b shows that the magnitude of Δ maximizes over a ~200 km wide strip along the coast. There is, however, substantial variation with latitude in the character of Δ. North of 30°S the magnitudes of Δ reach up to 3 m/s, more than 50% of the local mean wind speed. The direction of Δ here is very parallel to the coast and the off-shore extension of significant Δ is large. South of 33°S the Δ field is more constrained to the coast, reaches magnitudes ~ 2 m/s and is more perpendicular to the coast.

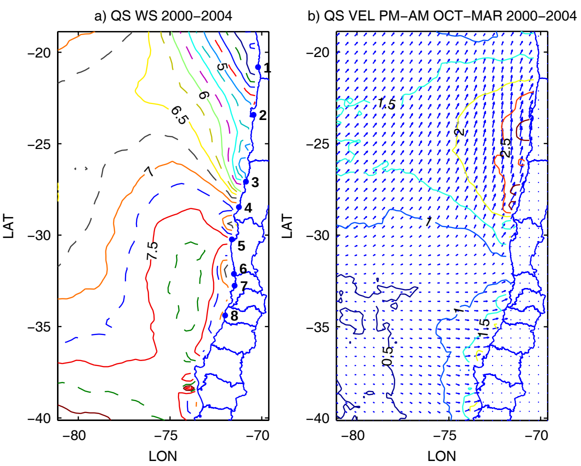

Fig. 1. a) 2000-2004 averaged Quikscat surface wind speed (m/s) and locations of coastal stations. b) Mean PM-AM wind vector differences (Δ) for October-March (contours are vector magnitudes in m/s).

Between 30-33°S the coastal strip shows very small Δ. The intensity of the features in the Δ field is larger in the warm season than in the cold season (not shown), indicative of the importance of the solar radiation cycle in its development.

Fig. 2 shows results of a basic analysis of the GOES visible images aimed at the characterization of the daytime variation of the cloud cover along the coast of north-central Chile. Fig. 2a shows the number of days (for Oct.-Dec. 2003-2004) in which the 1745 UTC (1345 LT) visible raw data has a count greater than a fixed threshold (5000). The field provides a first approximation to the cloud climatology in this region, showing that in these months the coastal Sc are more frequent in a region between 25-30°S. Fig. 2a shows also a distinctive coastal strip ~100 km wide with reduced cloud cover frequency, especially north of 25°N. The diurnal variation of the cloud cover near the coast is described in Fig. 2b. We have computed the number of "cloudy" days averaged for the 100 pixels nearest to the coast. Fig. 2b shows the

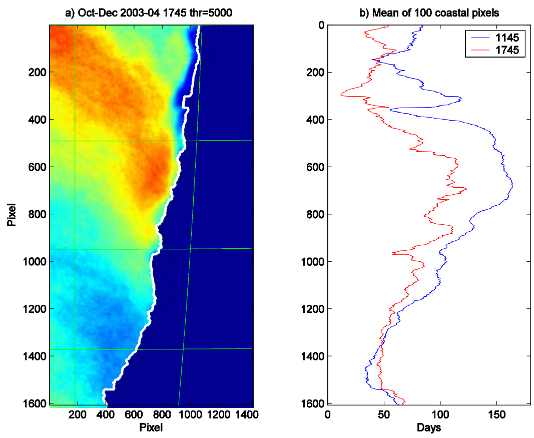

Fig.2 a) Cloud cover frequency over ocean pixels for 1745 UTC GOES visible images (Oct.-Dec.,2003-2004; axis are pixel counts, green lines mark 25°S,30°S,35°S, and 75°W, 70°W). b) Meridional distribution of the mean number of cloudy days for 100 pixels closest to the coast (blue line for 1145 UTC, red line for 1745 UTC GOES images).

meridional distribution of this coastal cloudy frequency for 1145 UTC and 1745 UTC. Although there are some small scale variations that can be related to coastline changes, the maximum in the daytime decrease of the coastal cloud cover is found in the region between 23-29°S. South of ~ 33°S there is little change between the 1145 and 1745 UTC mean coastal cloud cover.

4. Coastal stations

The hourly data for the 8 coastal stations shown in Fig. 1 are used to perform a preliminary assessment of the latitudinal variation of the diurnal cycles of wind and temperature along the coast. Due to the different periods and sources of the data, the comparison must be necessarily limited. Fig. 3 shows the fractions of the total annual variance explained by the diurnal, inter-daily, and annual cycles, for temperature, zonal and meridional wind. The relative importance of the diurnal cycle in temperature increases polewards, while in the northern stations the annual cycle being dominant. The variability of the zonal wind at the coast is largely controlled by the diurnal cycle at all stations. The variability of the meridional wind, on the other hand, is mostly diurnal in the northern stations, with inter-daily variability (including the synoptic period) increasing in importance to the south.

For the stations in Table 1 we have computed the mean diurnal and annual cycles of temperature and wind speed (see Fig. 4 for results at stations 1 and 5). In contrast to the offshore winds represented by QuikScat, all coastal stations show a very marked diurnal cycle in the winds, with substantial decrease of magnitudes from midnight to midmorning. Mean wind and temperature diurnal and annual cycles at the coast are generally in phase.

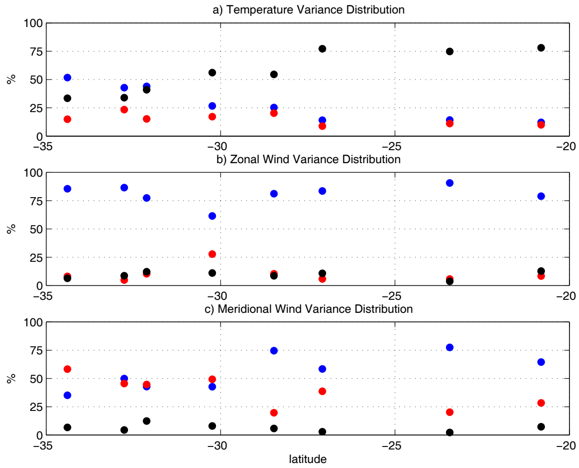

Fig. 3. Latitudinal variation of the partition of the total annual variance in temperature (a), zonal wind (b) and meridional wind (c). Circles mark the fraction (%) of variance due to the annual cycle (black), diurnal cycle (blue), and inter-daily variability (red). Data are for coastal stations and periods of Table 1.

An apparent deviation of the latter is suggested at stations around 30°S. For station at Pt. Lengua de Vaca, for example, Fig. 4 shows that the annual cycle in afternoon wind speeds peaks in November, and maximum wind speeds tend to occur later in the day than the maximum temperatures. Limited data at coastal stations in the same region appear to confirm these features.

5. Mesoscale model

The Dept. of Geophysics at the U. of Chile runs the MM5 mesoscale model in real-time to produce forecasts for the central part of the country. With model runs starting at 00 UTC we have constructed time series of surface wind speed for the grid points shown in Fig. 5, by concatenating the model forecasts for hours 24-47 (Model Domain 2, 45 km resolution). For 2004 there are 257 days with model results available. Fig. 5a displays for each point the correlation coefficients between MM5 and Quikscat

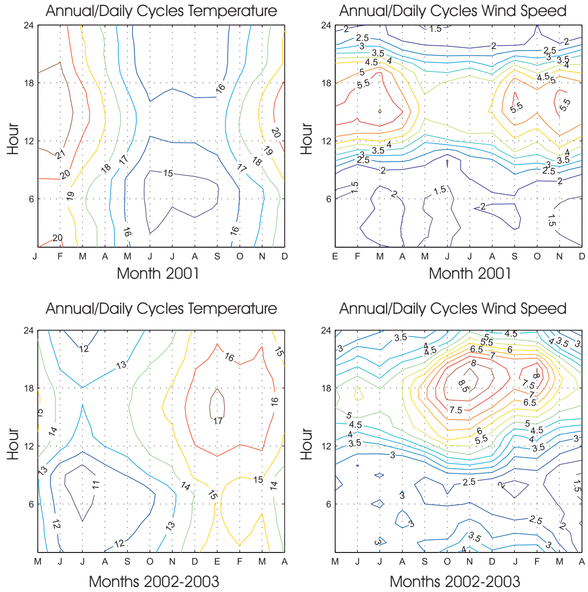

Fig. 4. Diurnal and annual cycles of temperature (contours in C, left panels) and wind speed (contours in m/s, right panels) for stations Pt. Patache (upper panels) and Pt. Lengua de Vaca (bottom panels).

wind speeds, for the AM (upper numbers) and PM (lower numbers) satellite passes. The correlation values show that the MM5 is quite skillful in predicting surface winds over the open ocean, especially in the northern part of the domain. There appears to be a slight decrease in skill in the points nearer to the coast. Fig. 5b shows the averaged PM-AM wind vectors computed with the model results. It shows a similar pattern and magnitudes as the QuikScat differences (see Fig. 1b).

6. Conclusions

We have used several sources of data to construct a preliminary picture of the diurnal cycle of winds, temperature and cloud cover in the coastal ABL along north-central Chile. Interesting features suggested by the results are the latitudinal variation in the PM-AM wind difference of the Quikscat data near the coast, the phase relationship between wind and temperature cycles at coastal stations, and the interactions between coastal cloud cover and circulation. Model results appear to reproduce some of the features of the data, which encourages future modeling of this coastal ABL to increase our understanding of its main physical forcings.

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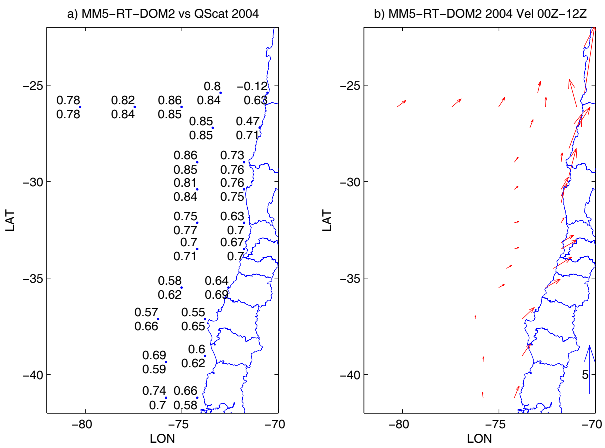

Fig. 5. Analysis of MM5 model results for 257 days in 2004. a) Correlation coefficients between MM5 and Quikscat data for selected grid points over the ocean. Upper (lower) numbers are for AM (PM) fields. b) Mean PM-AM model wind vectors (scale in m/s shown at lower right corner).