

Cloud droplet number concentration variability over the Southeast Pacific Stratocumulus region

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1. Introduction

In spite of the important radiative role of the subtropical warm cloud (stratocumulus and stratus) deck to climate, the cloud processes remain poorly understood. This lack of understanding extends to the aerosol indirect effects. Unique features make the Southeastern Pacific stratocumulus region particularly appropriate for studying cloud-aerosol interaction processes. Variability in accumulation-mode aerosol concentrations is high, confirmed by measurements taken during 5 NOAA buoy-tending cruises (Fig. 1; see also Tomlinson et al. (2006)). While the origin of the aerosol remains uncertain, one source may be anthropogenic: oxidized sulfur emissions from the copper smelters along the coast and the Andes (Huneeus et al. 2006).

Also shown in Fig. 1 is a significant positive correlation between the ship-based aerosol concentration measurements and a satellite-derived cloud droplet number concentration (CDNC), despite the inherent difficulties to such comparisons. MODIS (MODerate Resolution Imaging Spectroradiometer) data infer large cloud droplet number concentrations (CDNCs > 200 g m⁻²) unrepresentative of pristine marine environments along the Chile-Peru coast (Fig. 2a), corresponding to the high measured aerosol concentrations shown in Fig. 1.

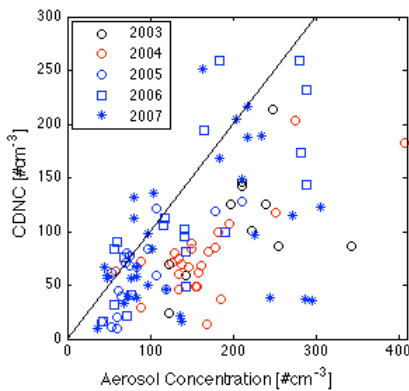


Figure 1: MODIS derived CDNC versus *in situ* ship-based accumulation-mode aerosol concentrations, sampled within 0-30S, 72-90W.

The increased CDNC, through the associated decreased droplet size, will increase the regional top-of-atmosphere albedo, all other cloud properties held constant (Twomey, 1977). Dynamical processes that affect the cloud microphysics within one of the most persistent

stratocumulus decks on the planet can therefore have significant climatic implications. Encouraged sufficiently by Fig. 1, we apply primarily satellite data to search for new insights on the impact of meteorological processes on CDNC variability.

2. Data and Methods

We used a combined set of *in situ* observations along with satellite retrievals and reanalyzed meteorological fields from NCEP/NCAR reanalysis project. Daily mean surface winds were provided by Quikscat, level 3 products. Daily-mean MODIS retrievals of cloud optical depth (τ) and effective radius (r_e) (Terra satellite, collection 5, 1 degree resolution, overcast pixels only) were recast into CDNC and cloud depth (H) after invoking an adiabatic assumption (e.g., Schuller et al., 2005). This recasting allows a separation of the cloud microphysics from the macrophysics. The equations for deriving CDNC and cloud depth are summarized in equations (1) and (2) respectively, with ρ_w corresponding to water density and Γ_{ad} to a constant adiabatic lapse rate (0.002 gm⁻⁴).

$$CDNC = \frac{\sqrt{10}}{4\pi\rho_w^{1/2}k} \Gamma_{ad}^{1/2} \frac{\tau^{1/2}}{r_e^{5/2}} \quad (1)$$

$$H = \sqrt{\frac{2}{\Gamma_{ad}} \frac{5}{9} \rho_w r_e \tau} \quad (2)$$

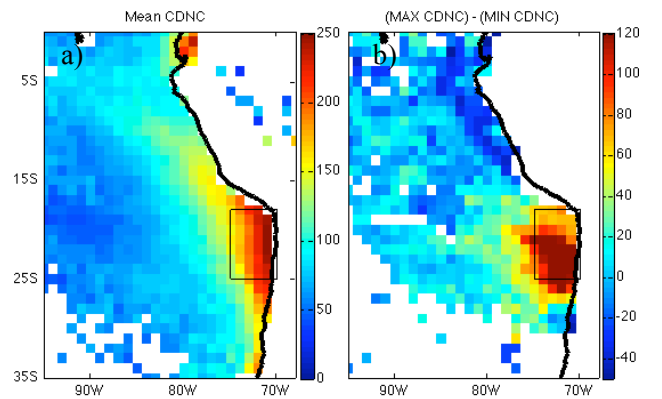


Figure 2: CDNC fields (in #cm⁻³): a) mean CDNC, b) difference between MAX and MIN CDNC composite. The box indicates the area in which the mean CDNC was averaged and then classified into MAX or MIN CDNC.

The satellite validation through comparison to shipboard measurements collected within the southeast Pacific and to other satellite datasets is ongoing (e.g. Fig. 1), but is not the focus here. For this study we selected 3 months of the validation period: October 2001, 2005 and 2006. October (austral spring) corresponds to the climatological maximum in cloud cover (Klein and Hartmann, 1993). Daily area-averaged CDNC values were calculated for a bight known, translated from Spanish, as the Arica Elbow (70°-75°W and 18°-25°S, box in figure 2). The Arica Elbow contains the highest CDNC of the marine region. The days were composited by their CDNC values, with the highest and lowest quartiles hereafter identified as the MAX (CDNC > 250 cm⁻³) and MIN (CDNC < 200 cm⁻³) composites, each containing 22 days. The associated composites of the mean sea level pressure, QuikScat-derived surface winds, 850-mb NCEP winds, 500-mb geopotential heights, and MODIS-derived cloud top heights (which can serve as a proxy for the boundary-layer heights) were then examined and interpreted.

3. Results

The MAX CDNC composite presents values higher than 250 [cm⁻³] and a westward extension of the plume of 8 degrees while MIN CDNC composite is mainly confined to the coast with values lower than 200 [cm⁻³]. Composite differences (Fig. 2.b) reveal that the maximum increase in CDNC occurs over an area between 18°S and 27°S and includes a westward extension of about 8° with values larger than 100 cm⁻³. On the other hand, the cloud droplet number concentrations along the Peruvian coast (5°S -15°S) are higher during the MIN CDNC episodes than during the MAX CDNC episodes.

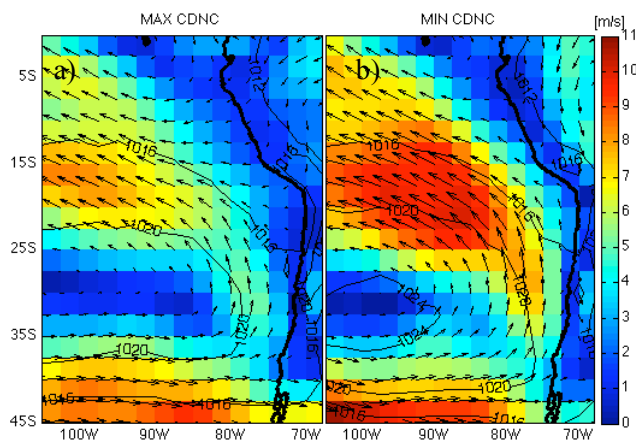


Figure 3: Wind fields at 850 mb and sea level pressure (contours) from NCEP/NCAR Reanalysis: a) composite for MAX CDNC, b) composite for MIN CDNC. Colors indicate the wind magnitude.

QuikScat (Fig. 4) and NCEP/NCAR Reanalysis data (Fig. 3) show stronger surface and 850 mb winds during the MIN-CDNC days, and weaker wind fields during the MAX-CDNC days. Changes in the subtropical high (contours in Fig. 3) are consistent: the MAX CDNC days are characterized by weaker anticyclone and a smooth

trough at 500 hPa with its axis at 95°W, while an intensified anticyclone for MIN CDNC is associated with a 500-hPa trough with its axis at 85°W.

The MAX-CDNC days were also characterized by a slightly thinner satellite-derived mean cloud depth of 270 m accompanied by both lower cloud tops and higher lifting condensation levels, compared to the MIN-CDNC composite mean satellite-derived cloud depth of 305 m. Sonde-derived zonal winds at Antofagasta, Chile (23.43°S, 70.43°W, 120 m.a.s.l.) show mean easterlies below 1500 m at all times, but slightly stronger easterlies during MAX CDNC episodes.

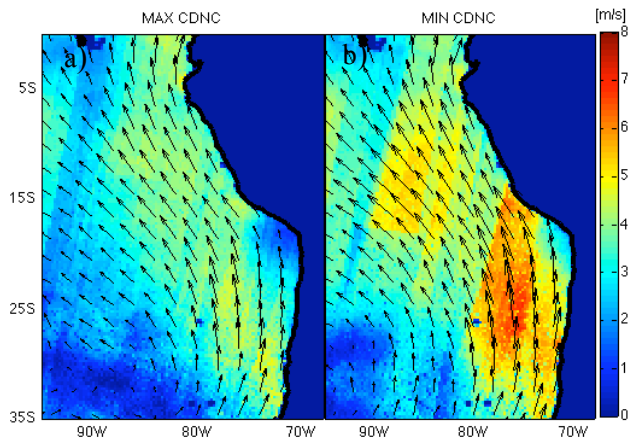


Figure 4: Winds at surface (QuikScat). : a) composite for MAX CDNC, b) composite for MIN CDNC. Colors indicate the wind magnitude.

We speculate that variability in the trade winds as well as in the boundary layer thermodynamic structure at the Arica Elbow is relevant to the aerosol longevity and/or aerosol incorporation into the southeast Pacific stratocumulus. Differences in the structure of the offshore winds during MAX/MIN CDNC episodes then help propagate different “downstream” signatures to the cloud properties characterizing each episode type. This hypothesis is guiding ongoing work. Further work is also needed to understand the cloud processes occurring over the Arica Elbow itself.

References

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