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VOCALS/Southeast Pacific science: Impacts of particles on properties of stratocumulus clouds

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The southeast Pacific Ocean is covered by the world's largest stratocumulus cloud layer, which has a strong impact on ocean temperatures and climate in the region. The effect of anthropogenic sources of aerosol particles such as power plants, urban pollution and smelters on the stratocumulus deck was investigated during the VOCALS field experiment. Aerosol measurements below and above cloud were made with a ultra-high sensitivity aerosol spectrometer and analytical electron microscopy. In addition to more standard in-cloud measurements, droplets were collected and evaporated using a counterflow virtual impactor (CVI), and the non-volatile residual particles were analyzed. Many flights focused on the gradient in cloud properties along an E-W track from near the Chilean coast to remote areas offshore. Mean statistics from seven flights and about forty individual legs were compiled. Consistent with a continental source of cloud condensation nuclei, below-cloud accumulation-mode aerosol and droplet number concentration generally decreased from near shore to offshore. Liquid water content and drizzle concentration tended to increase with distance from shore, but exhibited much greater variability. Aerosol number concentration in the >0.05 and >0.1 μm size ranges was correlated with droplet number concentration, and anti-correlated with droplet effective radius, and the effect is statistically significant. The impact of aerosol pollutants was to increase droplet number and decrease droplet size within a region extending about 1000 km offshore. Cloud droplets were more numerous and smaller near shore, and there was less drizzle. However, in-situ and MODIS measurements were used to show that despite the smaller droplets near shore, cloud albedo is not higher near shore than offshore. This is due to the generally thinner clouds and lower liquid water path near shore. Analysis of the droplet residual measurements showed that not only were there more residual nuclei near shore, but that they tended to be larger than those offshore. Single particle analysis over a broad particle size range was used to reveal types and sources of CCN, which were primarily sulfates near shore. Differences in the size distribution of droplet residual particles and ambient aerosol particles were observed due to the preferential activation of large aerosol particles. By progressively excluding small droplets from the CVI sample, we were able to show that the larger drops, which initiate drizzle, contain the largest aerosol particles. However, the scavenging efficiency is not sharp as expected from a simple parcel activation model. A wide range of particle sizes, down to at least 55 nm in size, act as droplet nuclei in these stratocumulus clouds. A detailed LES microphysical model was used to show this can occur without invoking differences in chemical composition. To summarize, particle number concentration increases near shore due to pollution from continental sources. The effect extends ~800 to 1000 km. The additional particles are mainly sulfates from anthropogenic sources. Sulfate internally mixed with sea-salt also occurs in and out of cloud. A variety of particle sizes act as cloud nuclei stratocumulus clouds, not just the largest ones. Increased pollutants result in higher droplet number concentrations and contribute to the smaller droplet effective radii near shore. However, cloud thickness and liquid water path are also smaller near shore. This also results in smaller droplet sizes overall. The net effect is that cloud albedo is not significantly higher near shore relative to offshore in this region, despite the aerosol effects on clouds.