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Can aerosols close open cells in the Marine Boundary Layer?

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The concentration of Cloud Condensation Nuclei (CCN) is known to control the Marine Stratocumulus Cloud (MSC) cover extent as manifested by two cloud regimes. The two regimes are closed and open cells, which are related to high and low concentrations of CCN, respectively. The open cells convection is generated by surface heating, while the closed cells are maintained by inverted convection that is driven by radiative cooling from the cloud tops. The MSC naturally changes its cloud regime from closed to open cells in a process that involves drizzle that cleans the Marine Boundary Layer (MBL) from aerosols. While models successfully simulated this natural transition, the opposite transition, from open to closed cells, is not successfully simulated. In this study we examine by observational means whether such a transition can occur. If so, the aerosol effect on cloud coverage can potentially explain vast areas of closed MSC that substantially affect Earth's radiation budget.

Polluting ship exhausts in the pristine oceans allow us to observe the effects of aerosols on MSC through the formation of ship tracks. By examining time series of satellite images, we documented the creation of ship tracks, their evolution, expansion and life time. Each time step was analyzed microphysically for the differences between the ship tracks and the surrounding MSC. The Meteosat Second Generation (MSG) and the Geostationary Operational Environmental Satellite (GOES) offered the needed high time resolution, while the MODerate-resolution Imaging Spectroradiometer satellite (MODIS) offered the higher spatial resolution.

Our observations show that the additional CCN emitted from the ship's exhaust can restore the full cloud cover by closing open cells. The closed cells morphology of ship tracks is easily detected in the visible satellite imagery. The ship tracks also feature the same microphysical characteristics as found in closed cells, with smaller effective radius in comparison to the surrounding pristine clouds. In addition, they found to spread and form vast closed cell areas with a life time of over 36 hours.

According to these observations, we propose a conceptual model which can explain the closing of open cells by aerosols. Following this model, addition of CCN to open cells generates nucleation that increases the concentration of cloud droplets, decreases their size and suppresses the drizzle. Consequently, the smaller cloud droplets remain longer in the thin anvils of the open cells and increase their liquid water content, thus making the anvils thicker and more radiatively active. The convection inverts to form the closed cell structure at the point when the radiative cooling from the anvils becomes stronger than the surface heating. Once the closed cells are created, a positive feedback involving aerosols entrainment from the free atmosphere keeps them from breaking apart. These closed cells may reopen hours later when drizzle is renewed gradually and cleans the MBL from aerosols.

The sensitivity of the MSC cloud cover to aerosols raises questions regarding their role in the Earth's radiation budget. This is so because closed cells have larger cloud cover in comparison to open cell, therefore, contribute higher negative radiative forcing. The findings of this study suggest that ship emissions and other sources of anthropogenic aerosols may be responsible to the formation of large areas of closed cells, which presently are not associated with such aerosol perturbations. Furthermore, according to our proposed mechanism of cloud cover change, these effects might even moderate global warming.