Progress in Understanding the Low Marine Cloud-Aerosol Interactions during CSET using LES

Ehsan Erfani[1]

[1]University of Washington

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Abstract

Low marine clouds are a major source of uncertainty in cloud simulations across models from LES to global scale. To address this issue, we conducted Lagrangian LES experiments that explore the aerosol-cloud interactions for case studies covering a spectrum of observed ambient conditions, and evaluated the model against observations. Our LES benefits from a prognostic aerosol model that simulates aerosol budget tendencies such as coalescence and interstitial scavenging, surface sources, and entrainment from free troposphere. To initialize, force, and evaluate the LES, we used a combination of reanalysis, satellite, and aircraft data from the Cloud System Evolution in the Trades (CSET) field campaign in summer 2015 over the Northeast Pacific. The LES follows two Lagrangian trajectories from subtropical stratocumulus (Sc) deck region offshore of California to tropical shallow cumulus (Cu) region near Hawaii. The first trajectory is characterized by a clean, well-mixed Sc-topped marine boundary layer (MBL) on the first day, and continuous MBL deepening and precipitation onset after the first day followed by a clear Sc-to-Cu transition (SCT) and a consistent reduction of aerosols that ultimately leads to an ultra-clean layer at the top of MBL. Overall, the LES simulates general MBL features seen in observations. The runs with enhanced aerosols show distinct changes in microphysics and macrophysics such as delayed precipitation onset and SCT. The second trajectory is characterized by an initially polluted and decoupled MBL, weak or no precipitation, and no clear sign of SCT throughout the simulations. It is challenging for LES to simulate observed features, and the LES underestimates (overestimates) low cloud fraction in the first (last) day. Although enhancing aerosols among cases leads to distinct changes in microphysics (e.g., enhancement of cloud optical depth and reduction of effective radius), it does not affect cloud macrophysical properties significantly. Finally, a theoretical analysis was conducted to decompose contributions to albedo of the Twomey effect and cloud adjustments. The cloud radiative forcing due to the Twomey effect shows an enhancement with an increase in aerosol, however, the cloud radiative forcing due to cloud adjustments is strongly dependent on ambient meteorological conditions.

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Ehsan Erfani, Peter Blossey, Robert Wood, Matthew Wyant, Johannes Mohrmann, Sarah Doherty

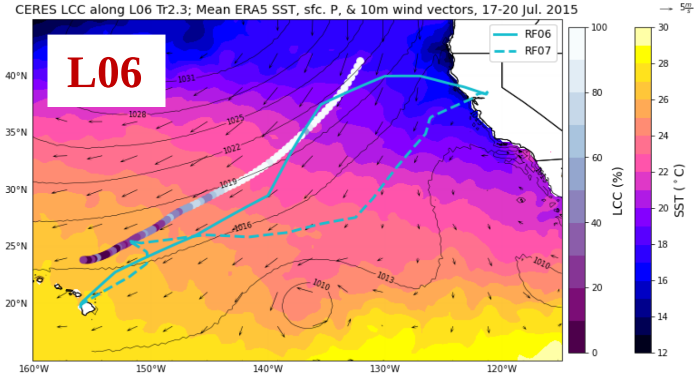
UNIVERSITY of WASHINGTON

Objective:

Assess and predict aerosol-cloud interactions during LES simulations of observed stratocumulus-to-cumulus transitions (SCTs) with both observed and perturbed aerosols

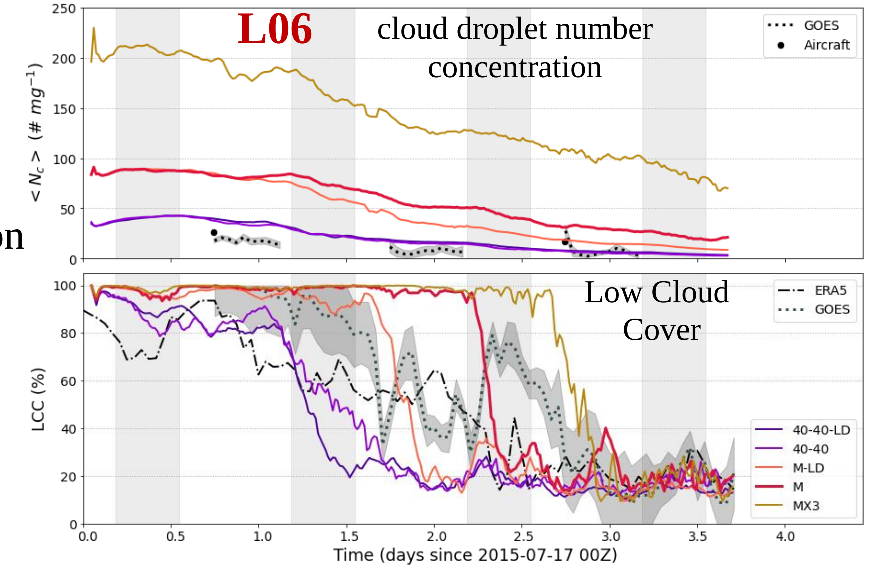
Methodology:

- Lagrangian trajectory: CSET L06 Tr2.3 (Not shown: simulations of L10 Tr6.0.)
- LES: System for Atmospheric Modeling (SAM) coupled to a single-mode bulk aerosol scheme
- Multiple experiments with different initial and free troposphere aerosols



L06 Case Study:

- Characteristics:
  - A clean, well-mixed marine boundary layer (MBL) on the 1st day
  - continuous MBL deepening, precipitation onset, and cloud breakup after the 1st day
- Overall, the LES simulates general MBL features seen in observations.
- The runs with enhanced aerosols show delayed precipitation onset and cloud breakup.



Transition by Precipitation:

The decrease in MBL cloud fraction (CF) and cloud-layer total aerosol number concentration (N_a) after the precipitation onset during SCT implies that precipitation-induced reduction in aerosol enhances the breakup of inversion cloud.