Simulations of Marine Boundary Layer Clouds Using the Common Community Physics Package Single-Column Model

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Introduction

The Marine ARM GPCI Investigation of Clouds (MAGIC) campaign aimed at observing the characteristics of clouds and radiation in the transition from the stratocumulus (Sc) regime to scattered shallow cumulus (Cu) onboard a ship traversing between Los Angeles, CA to Honolulu, HI. Leg 15A (CA to HI) spanning 20-25 July 2013 sampled a well-defined Sc-to-Cu transition and boundary layer decoupling. The Common Community Physics Package (CCPP) Single-Column Model (SCM) was used to diagnose systematic errors in cloud coverage and radiative fluxes within the marine boundary layer with the Global Forecast System (GFS) v16 physics, where an underestimation of marine Sc remains during the boreal summer off the west coasts of continents.

SCM Simulation Setup

The SCM initial conditions were from the third sounding of Leg15A at 05:27 UTC on 21 July 2013 and ship-following large-scale forcings were from the European Center for Medium-Range Weather Forecasts (ECMWF) 1-hour forecasts, with relaxation towards the ECMWF analysis [initial and large-scale forcing data from Zheng et al. (2020) and McGibbon and Bretherton (2017)]. The three-day simulation used the GFS v16 physics and was driven by prescribed surface fluxes computed using the Coupled Ocean-Atmosphere Response Experiment (COARE) air-sea flux algorithm.

SCM Results

At the start of the simulation, an observed Sc layer is present at the top of the well mixed boundary layer through the end of day 2 when it breaks apart and transitions to scattered Cu on the third day (Fig. 1a). The simulated cloud fraction (Fig. 1b) also produces a Sc topped boundary layer; however, the cloud layer appears thinner and growth is slower compared to observed, which is directly related to the PBL deepening at a slower rate (Fig. 1c, d). Additionally, the simulated breakup is delayed by a day and fails to reproduce Cu on day 3. On day 1, the observed and simulated PBL heights are similar, with a cold and moist bias present at cloud top (Fig. 1c, d), which is an indication of underpredicted cloud-top entrainment. This could in part explain the slower growth rate of the simulated PBL on days 2-3 and the later Sc break-up as well if there is a deficiency in free-tropospheric air from above the inversion being mixed down. The thermal stratification of the inversion plays a key role in cloud-top entrainment, where entrainment is inhibited more the stronger the inversion is. Simulated hourly averaged liquid water potential temperature profiles show a

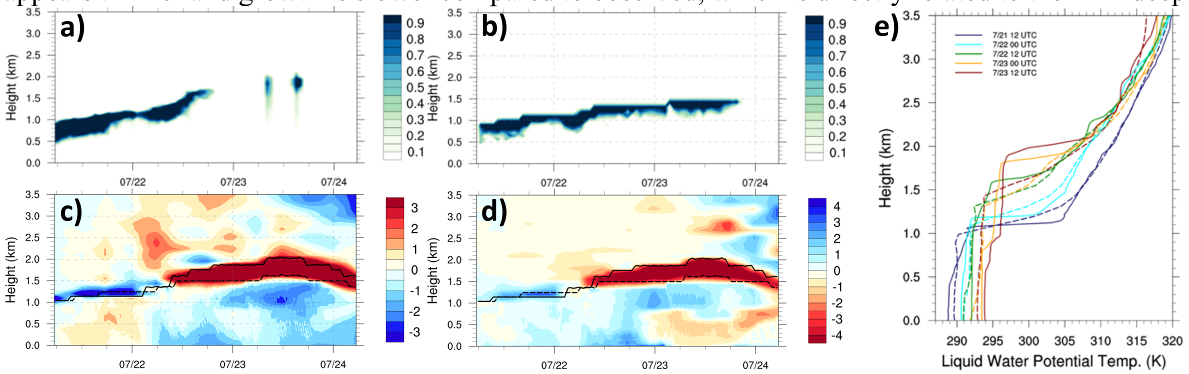

Figure 1. Contour plots of a) observed cloud fraction computed from the ARM ka-band zenith radar and cloud ceiling (Zheng et al. 2020) and b) simulated cloud fraction; difference (SCM minus observation) of c) potential temperature (K) and d) specific humidity (g kg^{-1}), where the solid lines are the observed PBL heights and the dashed lines are the SCM PBL heights, and e) the simulated (dashed) and observed (solid) profiles of liquid water potential temperature with 12-h interval.

larger temperature gradient across the inversion compared to observations as a result of a cooler inversion base throughout the run (Fig. 1e). Additional investigations will look into longwave cloud-top cooling, where weaker radiative cooling can also lower the entrainment rate.

Simulation Sensitivities

Sensitivities to the large-scale forcings were examined in order to assess the impact of each component. Runs included i) no forcing, ii) large-scale vertical velocity (omega) only, iii) large-scale advection of potential temperature only, and iv) large-scale advection of specific humidity only. The simulations with no forcings (Fig. 2a) and inclusion of moisture advection (Fig. 2c) have a persistent Sc layer for the entire duration. The inclusion of large-scale omega (Fig 2d) leads to a simulated cloud similar to the control as in Fig. 1b. The simulation advecting only potential temperature (Fig. 2b) produces the most realistic Sc as in Fig. 1a and PBL heights (not shown), which is similar to the observed break up near the end of day 2, but still fails to simulate scattered Cu. These results suggest a possible overabundance of moisture advection.

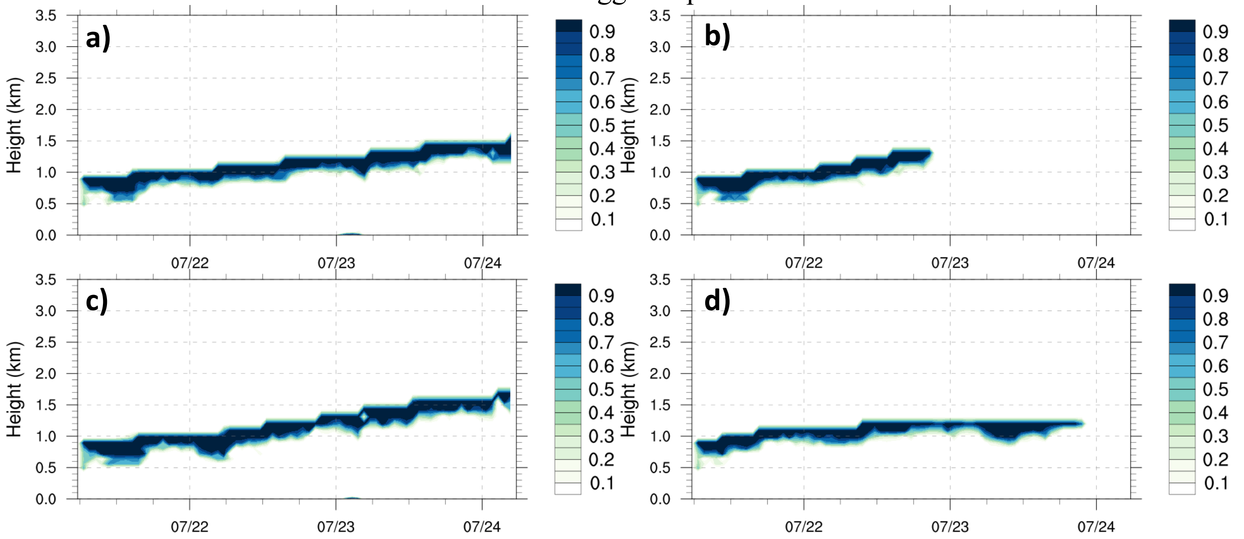

Figure 2. Simulated cloud fraction from runs with a) no large-scale forcing, b) advection of θ only, c) advection of specific humidity only, and d) advection of omega only.

Summary

This study examines biases in cloud coverage and the transition from Sc-to-Cu over the northeast Pacific, where there is a known underestimate of marine boundary layer clouds off the coast during the summer with the GFS v16. Contrary to the findings from the operational model, while the SCM simulated Sc appeared thinner, they were not largely underestimate and in fact were overestimated on day 3. During the first 6-24 hours of the simulation a cold and moist bias lead to a slower growth rate of the PBL and cloud base on days 2-3, which is a symptom of underpredicted cloud-top entrainment and could be a result of the stronger inversion present. Further sensitivities examined the impact of large-scale forcings and found that when only advecting potential temperature, Sc breakup occurred at a similar time compared to observations, indicating that other forcings may negatively contribute to the cloud bias (e.g., too much moisture advection). Further sensitivities and analysis will be conducted to examine key physical processes and error sources related to these biases, such as the relationship of entrainment and cloud-top radiative cooling and deactivating the nudging parameters.

References

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