P1.11 VERIFICATION STUDY: MODELING THE EVOLUTION AND STRUCTURE OF NOCTURNAL STRATOCUMULUS DURING DYCOMS-II

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1. INTRODUCTION

Stratocumulus clouds occur over the subtropical oceans off the west coasts of the major continents extending beneath the descending branch of Hadley circulation throughout most of the northern summertime. Their persistence is favored by strong subsidence over a cold ocean surface. This large-scale condition creates a very moist, shallow planetary boundary layer (PBL). The large static stability associated with the cold sea-surface temperatures and atmospheric subsidence results in extensive marine stratocumulus cloud decks with areal coverage of 40-90%. This cloud regime typically covers tens of thousands of square kilometers, and the cloud layer is often 100-500 m thick vertically.

Persistent stratocumulus topped marine atmospheric boundary layers with no drizzle are frequently well mixed (i.e., total water mixing ratio, vapor mixing ratio, potential temperature do not vary significantly with height in the PBL). The PBL is generally mixed because of the combination of the surface fluxes, moderate to strong winds, wind shear, and the existence of cloud-top radiative cooling (Rogers and Koračin, 1992). Therefore, within the stratocumulus topped PBL, turbulent transport, cloud microphysical processes, and radiation are strongly coupled. The interactions among these occur in small spatial and temporal scales, and are not adequately understood. Hence, these interactions should be appropriately parameterized in numerical models in a fully coupled mode. Other physical processes such as entrainment, drizzle, and solar heating (Stevens, et al. 2003a), may also play important roles in regulating the turbulence fluxes and the cloud field. Especially over ocean, accurate prediction of the morphology of clouds remains a research challenge due to the paucity of observations that are essential for initial and boundary conditions for numerical models.

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The goal of this study is to improve the accuracy of mesoscale numerical predictions of the structure and evolution of the summertime nocturnal marine stratocumulus over the Eastern Pacific Ocean. Advanced observational technology used in Dynamics and Chemistry of Marine Stratocumlus (DYCOMS II field program) helps the research community to focus on the regulating and coupling mechanisms, and to validate the theoretical findings (Stevens, et al., 2003a).

2. CASE STUDY AND MODEL SETUP

The southern coast of California is pertinent to high occurrence of extensive layers of marine stratus and stratocumulus clouds during summertime. To investigate the evolution of the nocturnal stratocumulus offshore of the southern California coast, a comprehensive field experiment DYCOMS-II took place in July 2001. The objective of this field program was to collect data to better understand the formation and evolution of nocturnal stratocumulus. This program included intensive aircraft and dropsonde measurements in this region.

The synoptic conditions on 10 July 2001 were conducive to conduct model simulations. A homogenous widespread marine stratocumulus was observed within the target area on this day. The synoptic setup consisted of a slow eastward moving surface high over the eastern Pacific, causing the boundary layer off-shore winds to be nearly uniform from the northwest at around 5 m s^{-1}, and the propagating high resulted in the formation of widespread stratus and stratocumulus clouds in the target area.

In order to examine the roles of turbulent transfer, cloud processes, surface fluxes, and synoptic forcing, model simulations were carried out for the period 10-11 July 2001. The mesoscale model chosen for this study is the PSU-NCAR Fifth Generation Mesoscale Model (MM5) (Grell, et al. 1995), a limited area non-hydrostatic model.

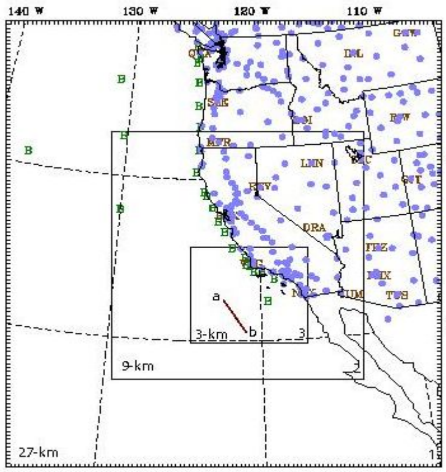

Figure 1. MM5 modeling domains. Observational data coverage is indicated by (i) blue dots for surface observations, (ii) label B for buoy stations (archived by the National Buoy Data Center), and (iii) upper-air stations using the station ID's. Line ab indicates the mean aircraft track on 10 July 2001 00 UTC.

High-resolution numerical simulations were carried on two domains with horizontal grid resolutions of 9, and 3 km, respectively, nested within a coarse parent domain of 27 km resolution. The numbers of grid points in the horizontal direction are, 101 x 113 (27 km), 175 x 187 (9 km), and 244 x 217 (3 km). The model setup is shown in Fig. 1. Sixty-seven unequally spaced vertical levels were chosen between the surface and 100 hPa, with the finest resolution in the boundary layer. The lowest model level was set at 5 m. High-resolution synoptic fields obtained from the ETA model output archives were used for the first guess fields. Assimilation of the upper-air observations from radiosondes and surface observations over land and ocean (buoys) was performed by Cressman's objective analysis (shown in Fig. 1). Two-way interaction was used among the grids. The physical parameterizations used in the model are: (1) parameterization of turbulence in the PBL based on the 1.5 order (Level 2.5 of Mellor and Yamada, 1982) turbulence closure approach following Janjic (1996), (2) radiative forcing following Rapid Radiative Transfer Model (Mlawer et al., 1997), (3) convective processes (Kain 2004) were represented in the 27-km grid in addition to explicit moisture processes (Reisner, et al., 1998), while for the inner grids 9 and 3 km, the moist processes are explicit.

The setup was finalized after a series of sensitivity experiments with different model grid structure, various initial and boundary conditions, selection of physical parameterization parameters and four-dimensional data assimilation. We refer the above model setup a "**baseline**" simulation.

The simulation was initialized for the 27 km grid at 00 UTC on 9 July 2001, and ran for a period of 18 hours. Four-dimensional data assimilation of wind, temperature, and moisture fields was applied in this domain to nudge the model fields toward the surface and upper-air gridded analyses during this period. The simulation on the inner 9 and 3 km grids starts on 9 July 2001 at 18 UTC, by interpolating the MM5 analysis from the 27-km grid.

3. **RESULTS**

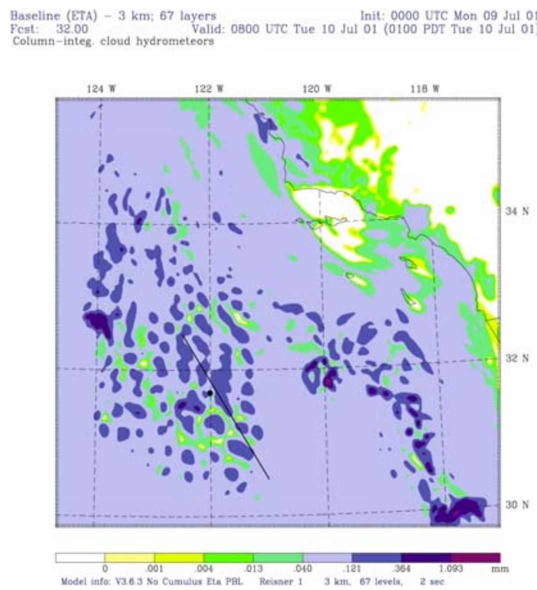

Figure 2. Column-integrated model cloud hydrometeors (mm) on 10 July 2001 at 0800 UTC.

The verification of the baseline simulation of the marine PBL consisted of comparing the model forecast against aircraft soundings and satellite imagery. The forecast sounding is extracted from the model grid point within the 3 km domain nearest to the aircraft sounding location. The aircraft observations on 10 July 2001 at 0805 UTC are used for the model verification. A summary of the DYCOMS-II aircraft observations can be found in Stevens et al., (2003b).

Figure 2 shows the model generated integrated cloud hydrometeors on the 3 km resolution grid at this time. A large quantity of water was observed in the vicinity of the aircraft track. Figure 3 shows the two-dimensional vertical cross-section of the predicted cloud water-mixing ratio. The figure indicates cloud tops penetrating at greater heights (~800 m). The cloud-free zone near the southern coast of California is well represented compared to satellite imagery.

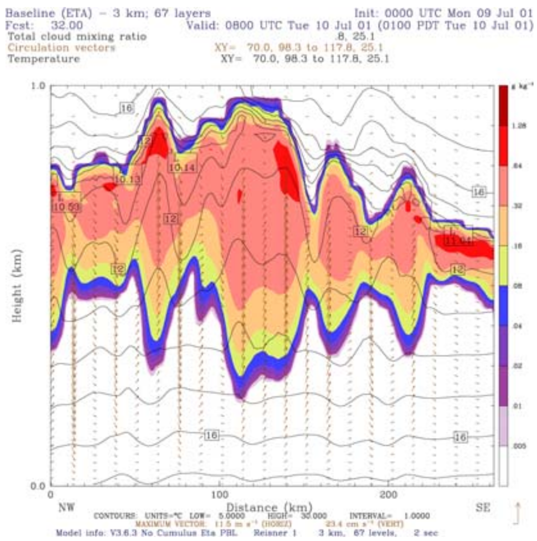

Figure 3. X-Z cross section of the predicted cloud water mixing ratio (g/kg), temperature (º C), and winds (m/s) along the mean aircraft flight track (line ab of Fig.1)

Comparing the model soundings against the aircraft measurements, the baseline temperature prediction was in agreement with the observations (Fig. 4). However, the model could not accurately simulate the extreme strength of the inversion as observed by the aircraft. The inversion height is better predicted over the ocean than over land (Vandenberg, 34.7^o N, 120.6^o W, VBG in Fig. 1 used for comparison over land; not shown here). Also, MM5 predicted a more moist PBL than observed (Fig. 5).

Some of our preliminary sensitivity experiments using initial conditions from a different source such as NCEP/NCAR archived 1^o x 1^o or 2.5^o x 2.5^o first guess analysis fields showed significant moisture bias in the PBL, and the inversion base heights were simulated at 400-500 m compared to aircraft observations. Koračin et al., (2003) showed that a better representation of model conditions improves the predictions of marine coastal clouds and turbulence. Our baseline simulation showed significant promise for improving the mesoscale predictions of the structure and evolution of the nocturnal stratocumulus over the ocean.

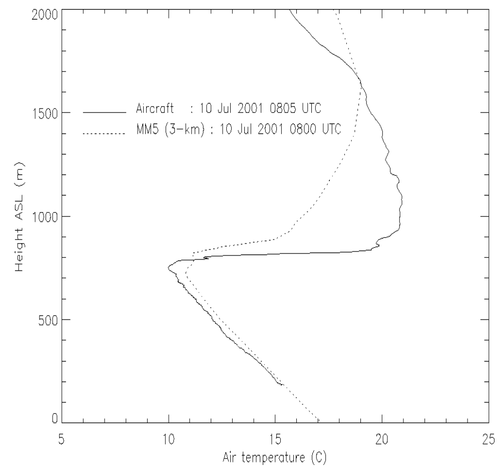

Figure 4. Ambient temperature (^{o}C) profiles as simulated with MM5 and observed from aircraft.

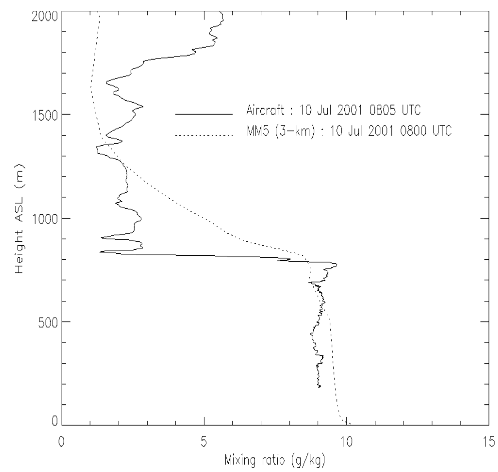

Figure 5. As in Fig. 4, but for mixing ratio (g/kg).

We are continuing to develop methods for better specification of more accurate sea surface conditions and assimilating aircraft and satellite data to improve the skill of MM5 predictions. An ongoing study focuses on the performance and comparison of various turbulence parameterizations and their evaluation using aircraft data. The model verification on the inversion structure, turbulence transfer, diurnal marine PBL morphology, entrainment processes, and the production of drizzle will be presented at the conference.

Acknowledgements

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