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IMPROVING PREDICTION OF THE MARINE COASTAL CLOUDS USING SATELLITE AND AIRCRAFT DATA

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1. INTRODUCTION

Accurate prediction of the structure and evolution of marine clouds remains a research challenge due to the lack of routine measurements over the ocean that are needed for model initial and boundary conditions. This is particularly evident in the northeast Pacific. The region, specifically the area of the southern California coast, is characterized by high occurrence of spatially extensive layers of marine stratus and stratocumulus clouds. These clouds form at the top of the cool and moist marine atmospheric boundary layer (MABL) and just below the strong low-level marine inversion supported by intense subsidence (Koračin et al. 2001; Koračin and Dorman 2001). To investigate the evolution of the nocturnal stratocumulus offshore of the southern California coast, the comprehensive field program DYCOMS II, including aircraft and dropsonde measurements, was conducted during July 2001 (Stevens et al. 2003).

In order to examine the roles of particular determinants such as surface fluxes, radiation, turbulence transfer, cloud processes, and synoptic forcing on the evolution of the marine clouds, we have simulated atmospheric conditions during the first two days of the field program using the Fifth Generation PSU/NCAR Mesoscale Model (MM5) (Grell et al. 1995).

Results from the operational version of the U.S. Navy's Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) (Hodur 1997) were also available during the DYCOMS-II field program. COAMPS model runs were produced twice daily at 00 and 12 UTC, and forecast parameters for the innermost grid were archived. The initialization fields were also archived so that further modeling studies can be conducted. The resolutions for the three nested grids were 54, 18 and 6 km, with the inner high-resolution grid centered on the DYCOMS-II field study area.

Both MM5 and COAMPS model results were compared to aircraft and dropsonde data. Preliminary analyses have showed that both models significantly underestimated the MABL depth as well as cloud coverage and vertical structure and, consequently, were not able to accurately represent the MABL structure and evolution. The analyses have indicated that the main cause for the discrepancy between the model and measurements lies in the initial and boundary conditions over the ocean. Global models that provide the initial and boundary conditions are not able to accurately simulate the MABL structure and evolution as well as its interaction with synoptic processes. Consequently, to improve the accuracy of the model predictions, we have developed a method that uses satellite data and modifies the MM5 initial and boundary conditions with respect to the inversion base and the temperature structure. Initial vertical profiles of the moisture were adjusted using aircraft and dropsonde data.

2. METHOD

2.1 *Satellite data*

The method of improving the prediction of marine clouds in coastal regions is based on determining more realistic MABL depth and associated vertical profiles of temperature and moisture. The first step in the analysis was to use satellite data to infer the sea-surface temperature (SST) and the cloud-top temperature (CTT). The SST was obtained from the TRMM Microwave Imager (TMI) dataset. The TRMM satellite typically passes over a given geographical area twice a day. The TMI raw data are radiances at multiple microwave frequencies which, when combined with a radiative transfer algorithm, yield estimates of emission from the ocean surface and the ocean surface temperature. These estimates are available during clear or cloudy conditions. Validation studies of satellite-derived SST against buoy measurements generally indicate an error of less than 0.5 K. The TMI product is produced as a gridded dataset with a latitude/longitude resolution of 0.25°. These values are then used to interpolate the SST at the MM5 grid points.

The CTT was derived from NOAA GOES satellite Imager data that is available every 15 min over the study region. The image pixel resolution is 4 km for the infrared (IR) channels and 1 km for the visible imagery. A multichannel GOES classification procedure uses IR, near IR, and visible image data (Wetzel et al., 2001) to determine whether the pixel is cloudy. The satellite CTT can be slightly cool-biased due to water vapor absorption/emission between the cloud top and the satellite, and aircraft measurements were used to assign a 1 K correction in this case study. The spatial resolution of the CTT analysis is 4 km and the data was spatially interpolated to the MM5 model grid. Knowing the SST and CTT, the MABL height was estimated by applying the dry adiabatic lapse rate to the difference between the diagnosed SST and CTT values at each model grid point where cloud occurred.

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2.2 *Modeling*

The MM5 simulations of the DYCOMS-II event employed a two-way nested setup with 9-km and 3-km grids. The vertical grid has 45 sigma levels from the surface to 100 mb. The highest vertical resolution is in the boundary layer, with spacing of approximately 50 m near the surface (with the lowest half-sigma level being about 20 m AGL). As for model physics, the PBL parameterization is the Gayno-Seaman scheme, and the Reisner 1 mixed-phase scheme that handles explicit moist processes. On the coarse grid the cumulus parameterization is that of Grell, while the fine (3-km) grid is run fully explicitly.

The simulations are initialized at 0600 UTC 10 July 2001. For the MM5, the first-guess field is derived from the NCEP-NCAR Reanalysis Project (NNRP) gridded datasets. The first-guess field is then enhanced with observations using an objective reanalysis (multi-quadric) technique.

Two model experiments are conducted: one with a satellite dataset and one without. The run without the satellite data (denoted by “NB”) uses archived observations, which include standard surface reports, ship data, buoy data, and synoptic radiosonde data. The run with the satellite dataset (denoted by “RH85”) uses this initial data, plus profiles of temperature and dewpoint through the MABL derived from the satellite data described in the foregoing text plus the satellite-estimated SSTs.

For experiment RH85, profiles of temperature in the MABL were generated for each point for which there was a satellite-derived cloud-top temperature and height. From this information, a dry adiabatic lapse rate was applied to obtain a temperature profile consisting of ten evenly spaced points in the vertical between cloud top and the surface. The dewpoint temperature profiles were generated by first noting the range of surface observed water vapor mixing ratios (obtained from aircraft dropsonde profile data for this case). Next, the range of saturation mixing ratios corresponding to the surface temperatures estimated from the satellite-derived profiles (over the area of the fine MM5 grid) was determined. From the observed surface mixing ratios and estimated saturation mixing ratios, the range of surface relative humidity (RH) values for the area was computed. For 0600 UTC 10 July, the average of these relative humidities was 85%. Surface dewpoint temperatures were determined such that the surface RH over the area of the profiles was approximately 85%. The dewpoint temperatures in the profiles above the surface were then extrapolated upward adiabatically. These profiles of temperature and dewpoint, as well as the satellite-derived SST values, were then assimilated into the MM5 initial conditions with an objective reanalysis package using the multi-quadric technique.

3. RESULTS

Underprediction of the height of an initial inversion base mainly leads to underprediction of marine clouds since the lifting condensation level is generally above the inversion. The absence of clouds results in the lack of boundary layer cloud-driven turbulence and cloud-top cooling that can be redistributed within the boundary layer. The depth of the MABL is then reduced and the surface fluxes become the dominant forcing of the MABL dynamics and thermodynamics. In other cases, the moisture could be trapped in the shallow MABL and, with a sufficiently low temperature, the models can overestimate the clouds and fog. In any case, the accurate prediction of the inversion base is a crucial parameter relevant to the success of simulating the structure and evolution of the MABL.

The baseline (without the use of satellite data) MM5 simulations using standard reanalysis fields for initial and boundary conditions produced a low inversion base as compared to dropsonde and aircraft measurements from the DYCOMS II flight on 10 July. Figure 1 shows that MM5 underpredicted the inversion base height by about 300 m. The figure also shows that the operational COAMPS runs underpredicted the height of the inversion base by approximately 250 m. However, the run with modified initial conditions (MABL vertical profiles of temperature and humidity using satellite data) shows an increased inversion base height that corresponds closely to the height inferred from the dropsonde data.

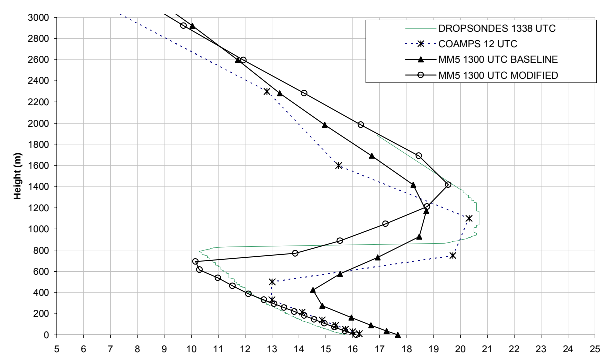

Fig. 1 Vertical profiles of ambient temperature as simulated with MM5 without using satellite data for model initial and boundary conditions (thick solid line with triangles); MM5 with using satellite data to improve initial and boundary conditions (thin solid line with circles); the operational COAMPS run (dashed line); and as measured by an aircraft-deployed dropsonde (thin solid line) during 12-13 UTC on 10 July 2001.

Due to the better representation of the inversion base height, the MM5 simulation predicted more cloud development and higher turbulence. Figure 2 shows the vertical cross section of the predicted cloud liquid water mixing ratio for both the baseline run and the run with modified initial and boundary conditions using satellite and aircraft data. The endpoints of the cross section were defined from the track of the DYCOMS II project flight during this case study. The figure confirms that the simulation using the satellite data for initialization shows deeper clouds with higher cloud tops as compared to the baseline simulations that used only standard reanalysis fields. Figure 2 indicates that the improved initial and boundary conditions resulted in a higher simulated cloud top and inversion base, deeper clouds, and almost twice the value of the maximum total cloud water mixing ratio.

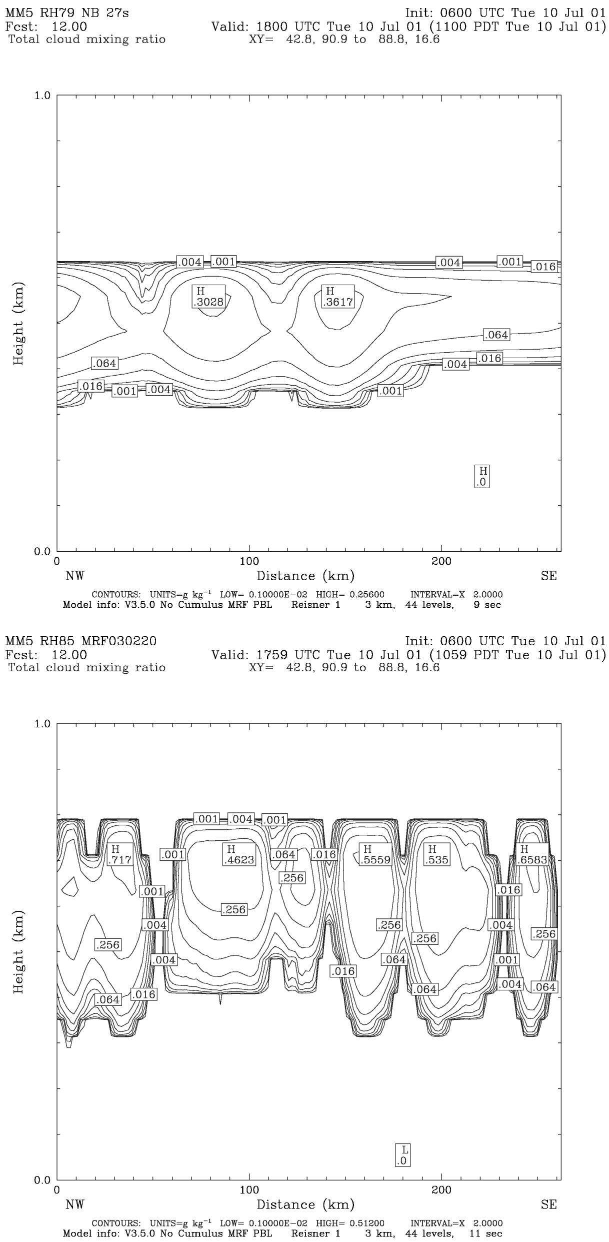

Fig. 2 X-Z cross sections of total cloud water mixing ratio (g kg^{-1}) for baseline MM5 run without using satellite data in the initialization (upper panel); and with satellite data in the initialization to improve MM5 initial and boundary conditions (lower panel). The cross section was selected by connecting the starting and ending X points of the aircraft sampling locations on 10 July 2001.

The developed method shows significant promise for improving mesoscale and regional scale simulations of the structure and evolution of coastal clouds. Further evaluation of the model results using satellite, aircraft, dropsonde, and buoy data is under way. Sensitivity tests are being conducted to investigate the effects of prescribed surface moisture conditions on the initial vertical profiles of moisture. We are continuing to develop a method for better specification of the sea surface conditions that will lead to a more accurate representation of surface fluxes.

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