

Boundary Layer and Entrainment Parameterizations in Mesoscale Models

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LONG-TERM GOAL

The long-term goal is to improve the surface flux and boundary layer parameterizations in the Navy's operational mesoscale model, COAMPS.

OBJECTIVES

The objective of this research is to systematically evaluate boundary layer parameterizations currently used in COAMPS with a focus on boundary layer mixing and entrainment process in the stratocumulus-topped boundary layer. In particular, we emphasize intercomparisons between model results and observations in order to understand the model discrepancies. Our work in FY03 has focused on understanding the capability of current COAMPS in simulating boundary layer roll structure and stratocumulus-topped boundary layers and the coding to incorporate entrainment parameterization into COAMPS. Observations from past experiment, The Development and Evolution of Coastal Stratocumulus (DECS) and Dynamics and Chemistry of the Marine Stratocumulus (DYCOMS-II) are used for this purpose.

APPROACH

Our approach is to perform COAMPS simulations on selected cases with the sufficient observations to quantify the marine boundary layer and surface characteristics. This enables us to compare multiple aspects of the boundary layer and near-surface properties between the model outputs and the observations in order to clearly identify the model inadequacy. The model sensitivity to a variety of boundary layer parameters is also tested in order to better understand the model physics.

Qing Wang is responsible for the overall project. LCDR. Daniel P. Eleuterio, Ph. D student at NPS worked on the 3-D COAMPS simulation for stratocumulus-topped boundary layers, LCDR Michelle K. Whisenant, Ph. D student at NPS worked COAMPS simulation of roll convective boundary layers. Dr. Anping Sun, visiting scientist at NPS worked on initial coding the explicit entrainment parameterization in COAMPS. Ms. Lisa Chang, a visiting Ph. D student, also worked observational analysis of the aircraft measurements of coastal stratocumulus-topped boundary layers. Observations made by the Twin Otter research aircraft operated by the Center for Interdisciplinary Remote Piloted Aircraft Studies (CIRPAS) at the Naval Postgraduate School (NPS) during the Development and Evolution of Coastal Stratocumulus (DECS, PI: Qing Wang) and the Japan/East Sea Experiment (JES, PI: Carl Friehe, UC Irvine), and by the NCAR C-130 during DYCOMS-II experiment (PI: B. Stevens, UCLA) played important roles in this study.

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WORK COMPLETED

1. We performed a case study with COAMPS for Feb. 16, 2000 over the Japan/East Sea during the JES experiment to examine the roll convective boundary layer in the post-frontal marine boundary layer in cold air outbreak conditions simulated by COAMPS. Roll structure and cloud were observed on this day as indicated by satellite images. Analysis of the JES aircraft observation (original data provided by Djamel Khleif and Carl Friehe from U.C. Irvine) also revealed the presence of roll structure. COAMPS simulations of this case was examined against the observations and improvement to boundary layer parameterizations in COAMPS were made and tested using this case.
2. Additional efforts were made to utilize the MPI version of COAMPS at NPS, an effort that was not successful in FY02. We are now able to run the most updated version of COAMPS available to NPS. The latest COAMPS with modified drizzle parameterization were tested against aircraft observations.
3. Working together with S. Wang at NRL, modifications to original operational COAMPS were made to diagnose cloud layer based on saturation instead of condensation rate. This modification was tested with the DYCOMS-II observations for stratocumulus over the open water. It is also tested for the near-coast stratocumulus clouds using a case observed in DECS.
4. A TKE budget analysis was made for COAMPS simulations of the coastal boundary layer. To achieve this, modification of current COAMPS were made to output components of the TKE budget. This additional information allows us to examine the relative importance of the various forcing terms that generate/consume TKE so that we can better understand the model physics, particularly those associated with the diurnal cloud evolution in the coastal region.
5. Boundary layer height is a diagnosed quantity in COAMPS. It is a very important quantity if we are to implement explicit entrainment parameterizations into COAMPS. We have examined the COAMPS diagnosed boundary layer height using both the JES aircraft data and the DECK data and tested the sensitivity of the diagnosed boundary layer height with different algorithm. This is a necessary step toward implementing explicit entrainment parameterization into COAMPS.
6. Performed COAMPS analysis on the sensitivity of the cloud field to enhanced entrainment flux at the top of the cloudy boundary layer. This is achieved through modification to the minimum mixing length at the boundary layer top as a surrogate to enhanced entrainment.
7. Modification/new programs were added to COAMPS in the effort to implementing explicit entrainment parameterizations. Testing of the modified code were made to single-column COAMPS. This work is still ongoing.

RESULTS

COAMPS simulations of the convective roll structure observed in JES: On Feb. 16, 2000, extensive boundary layer roll structure was observed over the Japan/East Sea during the JES experiment. We performed a detail study for this case using both high-resolution COAMPS and the JES aircraft observations. The COAMPS inner-most domain was set to have 500 m grid resolution centered on the JES aircraft observational region. Our data analysis of the aircraft measurements revealed signatures of the roll structure. With adjustment to the NOGAPS SST field using aircraft observed SST, the high-resolution COAMPS simulation was able to generate the observed surface sensible and latent heat

fluxes and the surface stress comparable to the observation. The mean fields for wind and water vapor were also comparable to observations, except with a consistent cold bias of about 1.5°C. Figure 1 shows the downwind development of the boundary layer in vertical cross-sections of potential temperature and water vapor field. The evolution of the boundary layer is similar to the aircraft observed fields. However, COAMPS failed to generate the roll structure in the resolvable field. Efforts were made to improve the COAMPS boundary layer parameterization (this effort was reported in the FY03 annual report for Awards N0001403WX20542 and N0001403WR20195). With the modified mixing length, the COAMPS simulation successfully modeled the roll circulations in the boundary layer and improved the model generated surface fluxes as well.

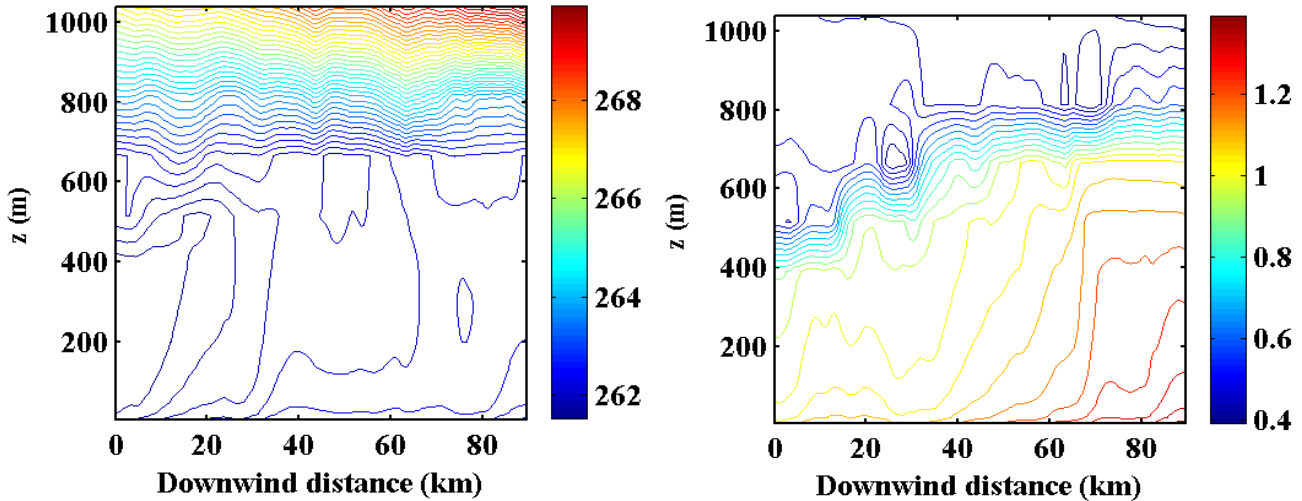


Figure 1. COAMPS simulated downwind boundary layer development over JES in cold air outbreak conditions. (a) Vertical cross-section of potential temperature; (b) Vertical cross-section of water vapor.

COAMPS simulations of the coastal stratocumulus cloud evolution: In Collaboration with S. Wang at NRL, we modified the COAMPS in-cloud buoyancy flux calculation to use saturation instead of condensation rate to diagnose the cloud layer. The modified COAMPS was tested last year and again was tested this year with the updated COAMPS for the near-coast regions using the observations from DECS. This modification resulted in significant amount of the simulated cloud similar to that observed by satellite, while the operational COAMPS produced nearly cloud-free coastal field. Figure 2 shows a comparison of integrated cloud water field before and after the modification.

Using COAMPS, we also studied the diurnal variation of the low-level clouds near the coast and tried to understand the role cloud-top entrainment play in the cloud evolution. Figure 3 shows the comparison of the TKE budget at an overland location (SNS for Salinas) and an over water location (M3 for a buoy location off shore of the Monterey bay). The buoy location was covered by stratocumulus cloud throughout the day while daytime clearing was found in both the model and the observations in Salinas. Here, the TKE budget show dominant shear forcing near the surface at both locations, with the shear effects extending to a higher level over land. The nighttime cloud-covered boundary layer generated by COAMPS appear to show reasonable balance among different terms of the TKE budget equation consistent with past observations and numerical studies. Over the coastal land, the shear gen-

eration of TKE can be seen in the upper boundary layer as well. COAMPS results also revealed the increasing surface forcing overland after sunrise and the dissipation of stratocumulus clouds during the day. Due to the complicated interaction between the boundary layer and the mesoscale flow field in the coastal region, the daytime growth of the boundary layer height was not seen in the model results in spite of the increased forcing and TKE.

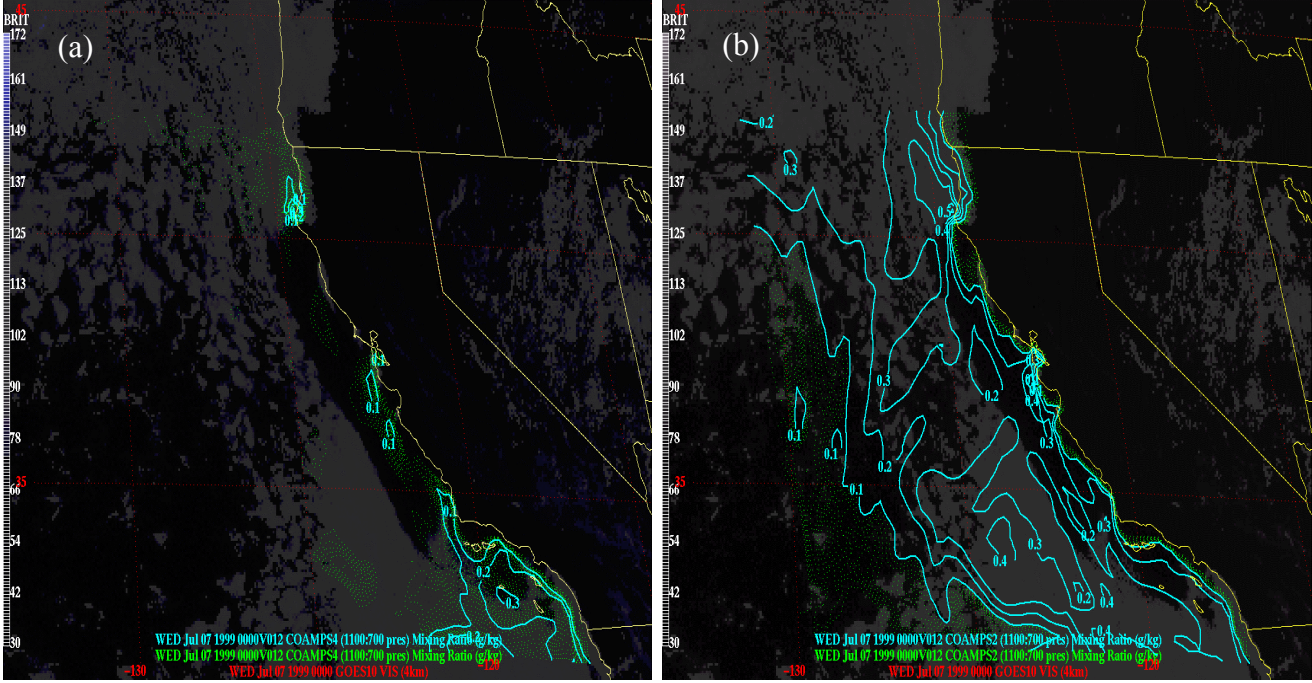


Figure 2. Comparison of the modeled liquid water path from (a) the operational COAMPS and (b) from the COAMPS modified for in-cloud buoyancy calculation.

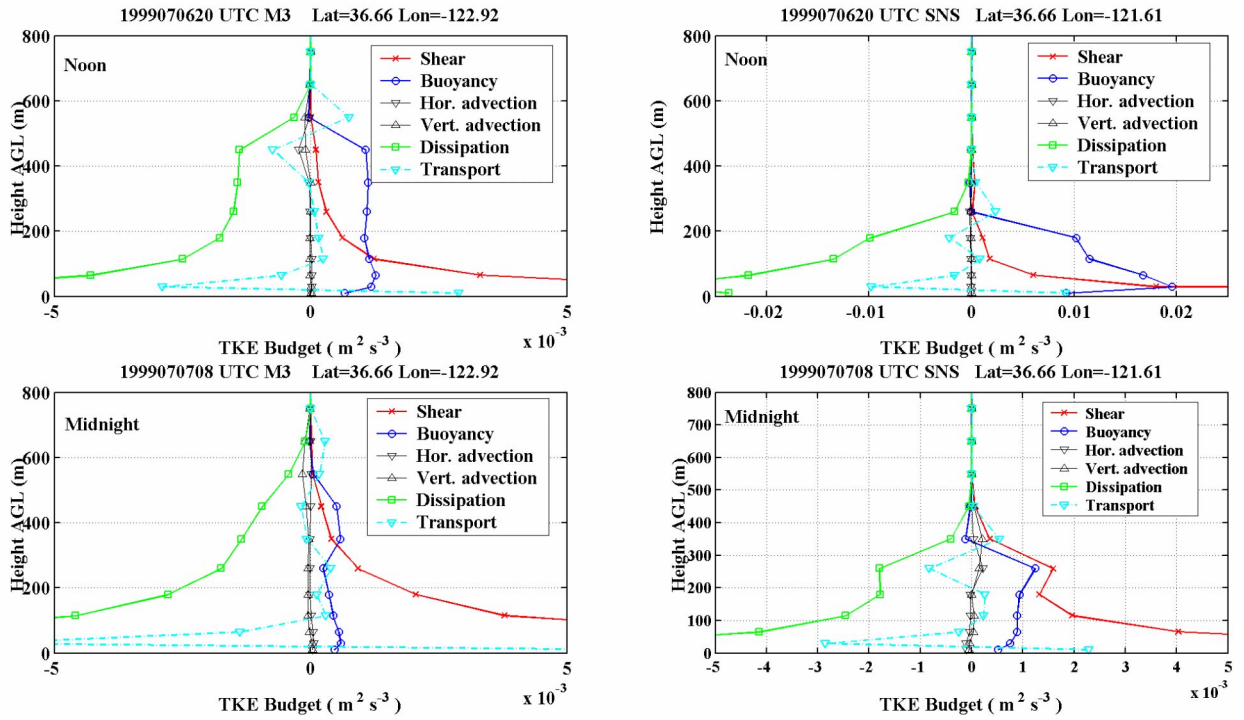


Figure 3. Terms of the TKE budget equation for noon (upper panels) and midnight (lower panels) from over the water (right panels) and over land (left panels).

Entrainment in stratocumulus-topped boundary layer: Overestimated cloud water and underestimated boundary layer height have been identified as existing problems of current COAMPS by our COAMPS simulations as well as other studies. We hypothesize that enhanced cloud-top entrainment through explicit entrainment parameterization is a possible solution to improve the model. Sensitivity tests are made to evaluate this hypothesis by increasing the mixing length at the boundary layer top. The results are shown in Figure 4 in comparison with available aircraft observations. Figure 4 shows a reasonable boundary layer development away from the coast. The magnitude of liquid water content is also closer to observations compared to the unmodified simulations. These results confirmed our initial hypothesis on the role of entrainment and provided the basis of further model development to include explicit entrainment parameterization.

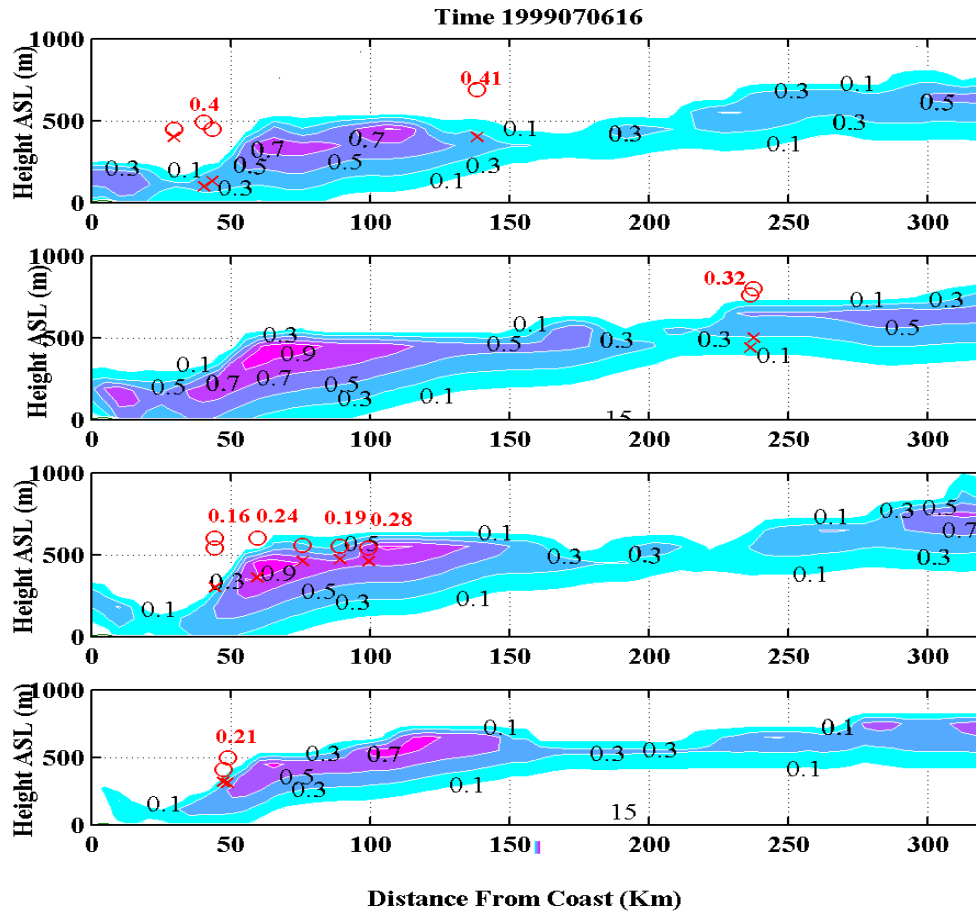


Figure 4. Vertical cross-section of liquid water content along the coast from (36.71N, 121.71W) to (36.68N, 125.39W). Red “o” and “x” are observed boundary layer top and cloud base, respectively. Values in red denotes the maximum observed cloud liquid water.

IMPACT/APPLICATIONS

Our analyses of observational and model results for JES and DECS revealed the model weaknesses associated with the existing boundary layer parameterizations. The results points to the need of improved mixing length and entrainment parameterizations in COAMPS.

TRANSITIONS

The implementation of explicit entrainment parameterization in COAMPS, after testing and further examination, will be submitted to NRL for possible transition to operational use.

RELATED PROJECTS

Related projects are Award #N0001403WX20542 and Award #N0001403WR20195 for *Advanced Surface Flux Parameterization*.

PUBLICATIONS

- Khelif, D., C. A. Friehe, H. Jonsson, Q. Wang, and K. Rados, 2003: Wintertime Boundary-layer structure and air-sea interaction over the Japan/East Sea. Accepted by *Deep Sea Research*.
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- Whisenant, M. K., 2003: Boundary Layer Parameterization in High-resolution Mesoscale Models, Ph. D. Thesis, Meteorology Department, Naval Postgraduate School, Monterey, CA.