Evaluating Surface Flux and Boundary Layer Parameterizations in Mesoscale Models Using Aircraft Measurements

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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 the surface flux and boundary layer parameterizations currently used in COAMPS. In particular, we emphasize intercomparisons between model results and observations in order to understand the model discrepancies. Our work in FY02 had two specific area: one is to evaluate COAMPS using the measurements of Japan/East Sea Experiment (JES), the other is to evaluate and improve the prediction of stratocumulus topped boundary layers in COAMPS with emphasis on entrainment and entrainment parameterization using measurements from the Dynamics and Chemistry of the Marine Stratocumulus (DYCOMS-II).

APPROACH

My 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. Dr. Kostas Rados, visiting scientist at NPS worked on JES project. Ms. Lisa Chang, a visiting Ph. D student, worked on the stratocumulus and entrainment project. Dr. John Kalogiros, research associate at NPS, assisted in observational data analysis as well. Direct 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 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.

WORK COMPLETED

1. We analyzed the Twin Otter measurements from all available flights of JES experiment to understand the observed boundary layer mean and turbulence structure under a variety of meteorological conditions during January/February 2000. These measurements of the CIRPAS Twin Otter include

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intensive near-surface flux measurements at a 'flux center' and multiple soundings along a horizontal track across the Japan/East Sea. These measurements made possible a thorough evaluation of the model's surface and boundary layer parameterization. The high-rate data were provided by the UC Irvine (Carl Friehe) and specially processed at NPS for model evaluation purposes.

2. We developed new coding in MATLAB environment to extract and interpolate the COAMPS three-dimensional and time variant output to the time and location of the available observation. This work was necessary due to the large amount of observations involved in our work.

3. We performed COAMPS simulations for all dates when aircraft observations were available during JES. All COAMPS simulations were setup to be compatible with the operational COAMPS. The basic control simulation used the Mellor-Yamada (Mellor and Yamada, 1982) mixing length in the boundary layer parameterization, and original Louis scheme (Louis, 1982) for surface parameterization.

4. We analyzed COMAPS simulated boundary layer properties against the observational data with emphasis on surface fluxes and Turbulent Kinetic Energy (TKE). Statistical analysis was made to these evaluations. We also made TKE budget analysis for the modeled COAMPS JES boundary layer to better understand the behavior of the simulated boundary layer, especially the modeled TKE at different grid resolution.

5. We analyzed all C-130 measurements of the stratocumulus-topped boundary layers from DYCOMS-II experiment, focusing on quantities needed for COAMPS evaluation and improvement. In particular, we obtained vertical profiles of mean thermodynamic and cloud liquid water quantities from all vertical soundings of the C-130 flights and calculated turbulence fluxes and variance from all level legs of the C-130 DYCOMS-II measurements. These observational data are ready to use for model evaluation.

6. Initial attempts were made to use the MPI version of COAMPS at NPS for simulations of the stratocumulus regime, but were unfortunately failed. All simulations were then used the vectorized version of COMAPS. We performed various COAMPS simulations for the first three flights of DYCOMS measurements. These simulations were designed to understand the COAMPS simulations for the stratocumulus regime and understand how the current COAMPS responses to changes in entrainment specifications.

RESULTS

COAMPS evaluation using JES observations: Using turbulence measurements from 9 Twin Otter flights from JES, we were able to understand the behavior of COAMPS surface flux parameterization and its simulations for the low-level atmosphere. Figures 1 shows the model-observation comparison for surface stress, sensible heat, and latent heat, and TKE. The COAMPS simulated surface fluxes show qualitative consistency with the aircraft observations. However, quantitatively, there is a trend that surface stress is under predicted and surface sensible heat flux is under-predicted. These relatively large differences were founds in cases when the strong wind prevails in both the modeled and simulated atmosphere. The TKE at 50 m were consistently under-predicted. We found this bias a result of an unrealistic turbulence dissipation rate imposed in the model to prevent TKE from becoming negative.

We examined the model simulated mean quantities in order to understand the general model behavior and to understand the cause of discrepancies in parameterized surface fluxes shown in Figure 1. Figure 2 shows a comparison of the mean quantities and the sea surface temperature (SST). COAMPS seems to under-estimate the mean wind speed, which is the main reason for the underestimated surface stress. The COAMPS also underestimates air temperature while slightly overestimates water vapor. Since the SST is in general overestimated, it compensates the overestimated water vapor so that latent heat flux does not show significant bias. This is not true for the sensible heat flux, since the combination of biases in both air temperature and SST resulted in rather significant overestimates of the sensible heat flux in the moderate to high wind conditions.

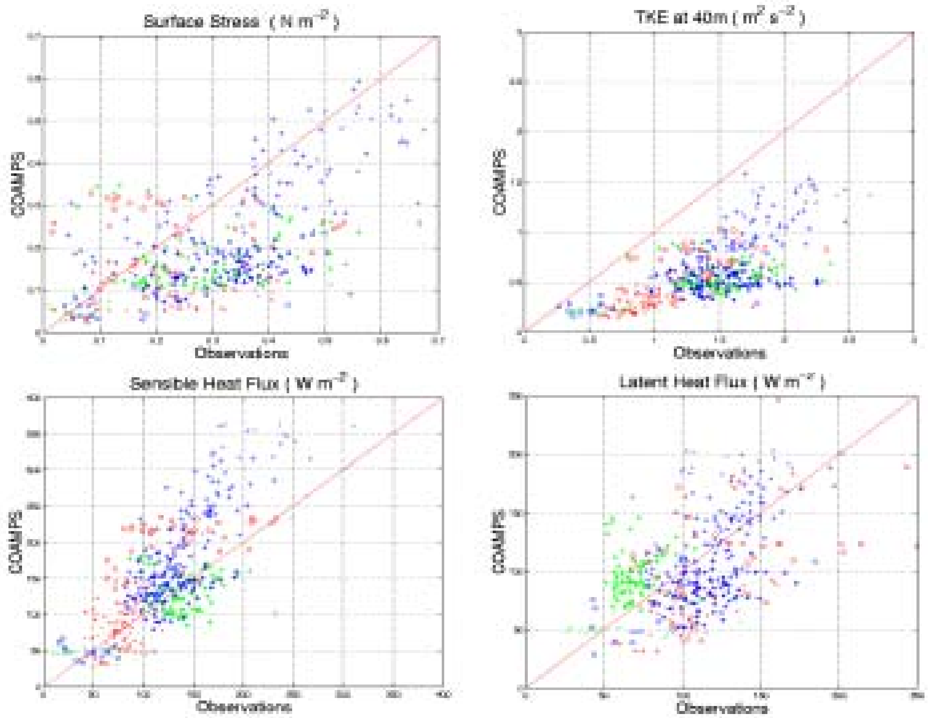

Figure 1. Observed and COAMPS simulated surface fluxes and TKE.
[Symbols denotes results from different flights (days).]

It is worthwhile noting that the simulated mean and turbulence quantities for each flight can be rather significantly different from the observations although the biases for the overall comparison are small. This points to the limitation of evaluating a single component of a mesoscale model using a limited amount of cases.

COAMPS simulations of the stratocumulus cloud regime: Simulations of the DYCOMS-II cases from the operational COAMPS showed very patchy cloud, if any, compared to satellite and aircraft observations. In collaboration with Shouping Wang at NRL, we found that the mixing length was set to be irrelevant to the thermo-stability in the cloud layer in the current operational COAMPS, which is not physical but maybe practical in an operational model to avoid frequent crashed. This was corrected in our test run for the DYCOMS-II cases (the first three cases), and we found significant improvements in the model cloud field.

We have simulated the first three cases of DYCOMS-II using the Navy's mesoscale model (COAMPS) and performed sensitivity test on changes of the lower limit of minimum mixing length for the first measured case. Our results suggest that COAMPS does reasonably well for predicting the low-level water vapor and wind field, although the boundary layer height was significantly under predicted. However, temperature was underestimated by 2-4 ^{o}C (Figure 3). The cold bias may have to do

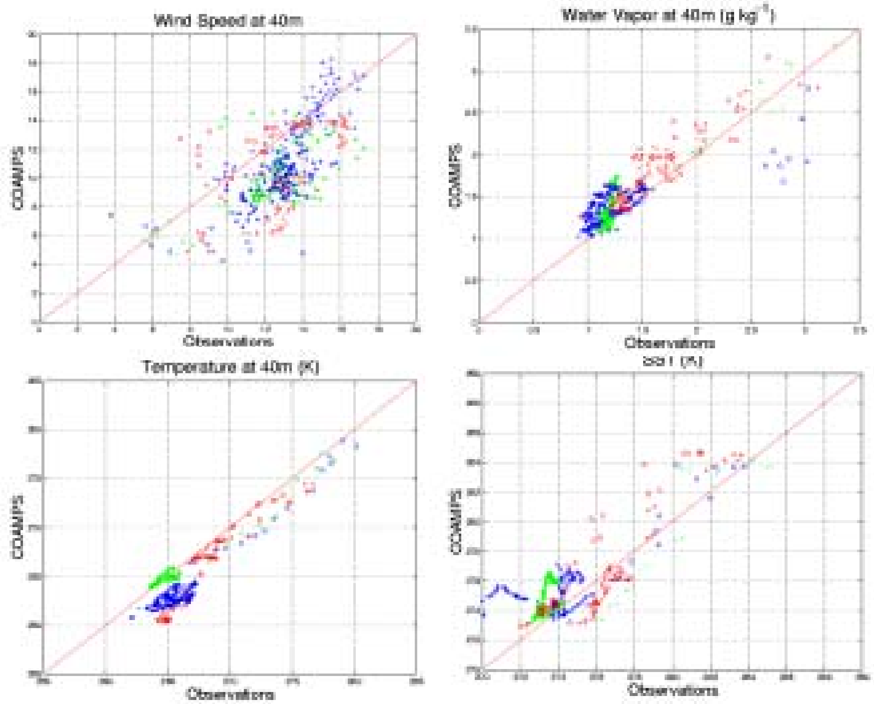

Figure 2. Observed and COAMPS simulated mean wind speed, water vapor, air temperature, and SST. [Symbols denotes results from different flights (days).]

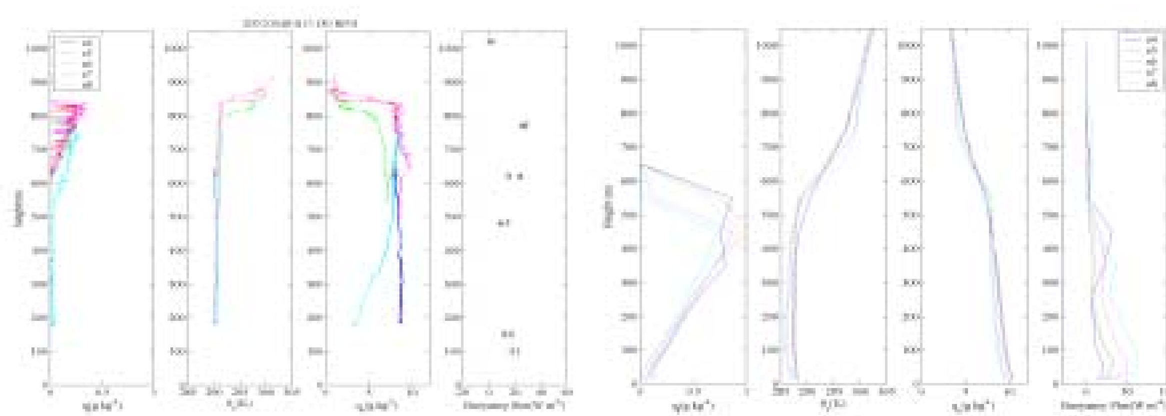

Figure 3. Observed (left 4 panels) and COAMPS simulated (right 4 panels) vertical profiles of liquid water content, virtual potential temperature, specific humidity, and buoyancy flux. Profiles from different soundings are shown to illustrate spatial variability. COAMPS soundings were taken at the time and location where the C-130 soundings were made.

with insufficient entrainment mixing, as seen from our sensitivity test. The sensitivity test runs indeed illustrate the depletion of liquid water and weakening of the inversion strength due to enhanced entrainment (not shown). However, some of the results in the sensitivity test are not physical due to the decoupling of the imposed increase in entrainment (or in mixing length) and the rest of the boundary layer processes. These results suggest further study on appropriate representation of the entrainment process in mesoscale models, which will be our future focus.

IMPACT/APPLICATIONS

Our analyses of observational and model results for JES revealed the model weaknesses associated with the surface flux parameterizations. The results points to the need of improved roughness length used in Louis scheme in order to improve the representation of surface flux in COAMPS. Our COAMPS study of the DYCOMS-II cases showed the inadequacy of the current COAMPS in dealing with the stratocumulus regime. Our sensitivity test also suggests improvements of the model representation on cloud-top entrainment as a direction for future model development, which will be the focus of my FY03 effort.

TRANSITIONS

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

RELATED PROJECTS

Related projects is N001400WX20757(B), for *Advanced Surface Flux Parameterization.* Another related award (N0001402WR20210) to this project was intended to support the additional ground-based measurements at Nantucket, MA as part of the CBLAST-LOW project, which is reported in the annual report for award N001400WX20757(B).

SUMMARY

We have performed systematic evaluation of the COAMPS simulations for 9 cases observed during JES in various meteorological conditions. The multiple cases allow us to connect the model deficiencies to the surface flux component of the model. We also performed sensitivity study that provided direction of future model development. Problems in current COAMPS in simulating the stratocumulus cloud regime were also identified using aircraft observations from DYCOMS-II. Our sensitivity tests reveal the needs of incorporating a physically based entrainment parameterization that effectively represent the entrainment processes.

PUBLICATIONS

Khelif, D., C. A. Friehe, and Q. Wang, 2002: Wintertime Boundary-layer structure and air-sea interaction over the Japan/East Sea. Submitted to *Deep Sea Research*.

Rados, K., Q. Wang, J. A. Kalogiros, S. Wang, D. Khelif, and C. Friehe, 2002: Evaluation of Marine Boundary Layer Parameterizations in COAMPS using the JES Experiment data set, *15th Symposium on Boundary layers and Turbulence*, American Meteorological Society, 15-19, July 2002, Wageningen, The Netherlands. 632-635.

Wang, Q., K. Rados, J. A. Kalogiros, S. Wang, D. Khelif, and C. Friehe, 2002: Evaluating surface flux and boundary layer parameterizations in a mesoscale model using aircraft measurements. In preparation for submission to *Mon. Wea. Rev.*.