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EFFECTS OF SPATIAL VARIABILITY OF SST ON THE MARINE BOUNDARY LAYER

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1. INTRODUCTION

Predicting the structure of the atmospheric boundary layer requires accurate estimates of the surface temperature and roughness. Over land, changes in surface properties can cause large variations in heat and momentum flux. Therefore, most mesoscale models employ a land surface model that provides some measure of actual land fluxes. Over the ocean, variations in sea-surface temperature (SST) and roughness are usually assumed to have a small effect over distances of 10-100 km, and are often prescribed using satellite derived observations. However, recent observations during the CBLAST low wind field experiment suggest that SST in coastal waters may have a more significant impact, with variations in SST of 2-3 degrees over distances of ~5 km.

Two examples from the CBLAST-low field study are shown in Fig. 1 representing near-neutral and convective upstream flow passing over a cold patch. These observations were taken from an aircraft flying at 10 m above the surface. In the near-neutral case, turbulence decreases slightly while passing over the cold patch and winds show a small (~0.5 m s^{-1}) reduction about 4 km from the coldest SST. Temperature variance increases slightly over the cold patch relative to the upstream and downstream air mass.

In the convective case, turbulent temperature variations are much stronger over the warm water upstream from the cold patch in comparison with the near-neutral case. Vertical velocities, however, are nearly the same in magnitude. The effects of the cold SST on all fields in this case are more abrupt than the near-neutral example; winds drop from ~4 to ~2 m s^{-1} and vertical velocity magnitude is reduced to ~0.2 m s^{-1}.

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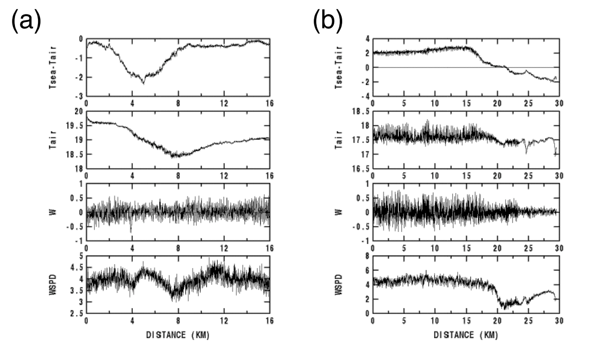

Figure 1. Time series data taken from aircraft flying at 10 m above sea level for (a) near-neutral and (b) convective conditions upstream conditions.

As Fig. 1 shows, the structure and behavior of the marine boundary layer depends on both the local surface heat flux forcing and the upstream conditions proceeding changes in SST. Features with these scales are typically much smaller than the resolution of mesoscale models and currently are not accounted for in boundary layer parameterizations. In addition, it's not clear how changes in surface heating affect the vertical momentum budget. For example, the convective case displays a much greater momentum response in comparison with the near-neutral example, even though the upstream winds have about the same value.

To address these questions, we apply a large-eddy simulation (LES) model that has been adapted to simulate changes in surface forcing. The model is based on Skyllingstad (2003) with modifications to allow for a recirculating boundary for inflow conditions and open boundaries for outflow conditions. The recirculation part of the model domain is essentially a periodic LES embedded within an open-ended channel. Using this structure, we can examine how changes in surface forcing affect the boundary layer over downwind distances of ~10 km.

2. Experiment Design

Simulations were conducted for a 16 km long channel with a depth of 200 m and a width of 640 m. Grid spacing in all directions was set to 5 m. An initial potential temperature profile was prescribed having a 125 m mixed layer with potential temperature of 25 °C capped by a stable layer with a vertical gradient of 3.5 °C/1000 m. Winds were initialized in geostrophic balance with a speed of 4 m s^{-1}. Surface heat flux was set using a prescribed SST and the Louis (1979) surface layer parameterization, modified to follow Fairall et al. (1996), which includes a wind speed dependent surface roughness.

Four preliminary simulations are presented in this paper. In the first two cases, we examine the differences between upstream near-neutral versus convective conditions by applying an upstream SST of 25.5 and 29.0 °C, respectively, for the first 3.5 km. The first 2 km of the domain recirculate as discussed above. Downstream SST in both cases is set to 23 °C over a distance of 5.5 km, followed by a return to the upstream temperature over the remaining 7 km. We refer to these experiments as the cold patch cases. In the second set of experiments, an average SST is applied representing the temperature that would be used if the boundary layer was being modeled in a mesoscale model with ~10 km grid spacing. These experiments are referred to as the uniform cases.

3. Results

Our first task in analyzing the LES output was to compare the model behavior with observations as shown in Fig. 1. Plots of model fields for the cold patch cases are presented in Fig. 2 using a range of scales similar to the observations. Noticeable differences are evident in both cases. In the convective case, the LES shows more variation in potential temperature over the cold water and almost no change in the horizontal velocity across the domain. In contrast, the observations indicate a large decrease in temperature variability and a significant drop in wind speed over the colder water. Vertical velocity from the model agrees with the observations, showing a marked decrease over the cold patch. Overall cooling in the model is about 1 °C, which is similar to the observed case.

(a)

(b)

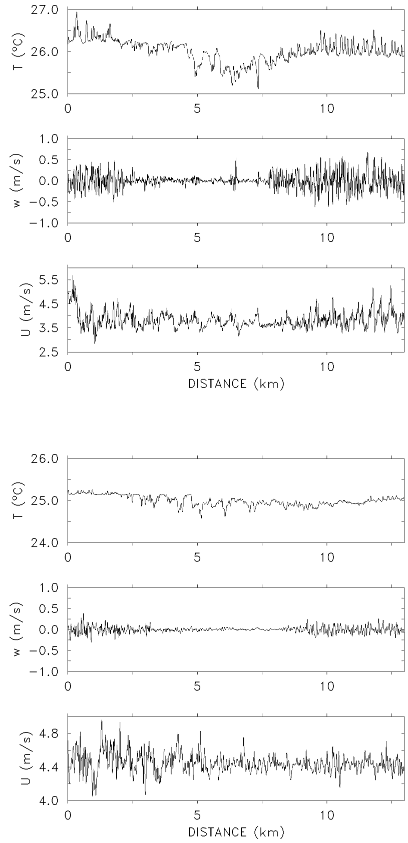

Fig. 2. Spatial data of potential temperature, vertical velocity, and horizontal velocity taken from the LES model for (a) convective and (b) near neutral upstream conditions. Data are from a height of 10 m.

Better agreement is indicated in the near neutral simulation. In this case, the model predicts potential temperature variance that is too high over the cold patch in comparison with the measurements. Overall cooling in the model is similar to the observations, which show less temperature change in response to the cold patch than the convective case. Cooling is decreased in the near neutral case in comparison with the convective case because overall mixing is reduced causing weaker vertical transport of cool surface air. Vertical velocity values are uniformly too small in the model, although they exhibit the same trend as the measurements with a decrease over the cold patch.

Differences between the model and measurements could result from a number of factors. In the model, we assumed a particular mixed layer height, which could be much different from the observed cases. We also assumed the air flow was perpendicular to the SST gradient, which was most likely not the case in the measurements. Our coarse model resolution of 5 m could also introduce errors because the observations were taken so close to the lower boundary. We plan to address these issues in future experiments.

One of the basic questions we wanted to answer through our simulations was determining how isolated SST patches affect vertical fluxes of heat and momentum. Our second set of experiments address this issue by simulating an ocean surface having a constant SST that is the same as the average SST from the patch cases. Plots from these experiments are shown in Fig. 3 representing the domain averaged potential temperature.

Differences between the cold patch and uniform cases are evident in both the convective and near neutral cases. In the convective case, the boundary layer temperature is slightly warmer except at the surface, where the local affect of the cold patch is dominant. The average results from this case yield a profile with a slightly super-adiabatic layer at the surface, consistent with a convective boundary layer. The difference in temperature in the near neutral case is smaller than the convective case. Again, the cold patch forces a colder near surface temperature in comparison with the average forcing example, but in this case the average SST does not force not convection so the profiles do not differ as greatly.

4. Conclusions

Preliminary LES results suggest that small scale SST variability can cause significant differences in the boundary layer average temperature when not included in mesoscale models. These differences are likely produced by nonlinear changes in the surface flux forced by the flux parameterization. For example, surface heat flux is not linearly related to the difference in SST and near surface air temperature.

5. References

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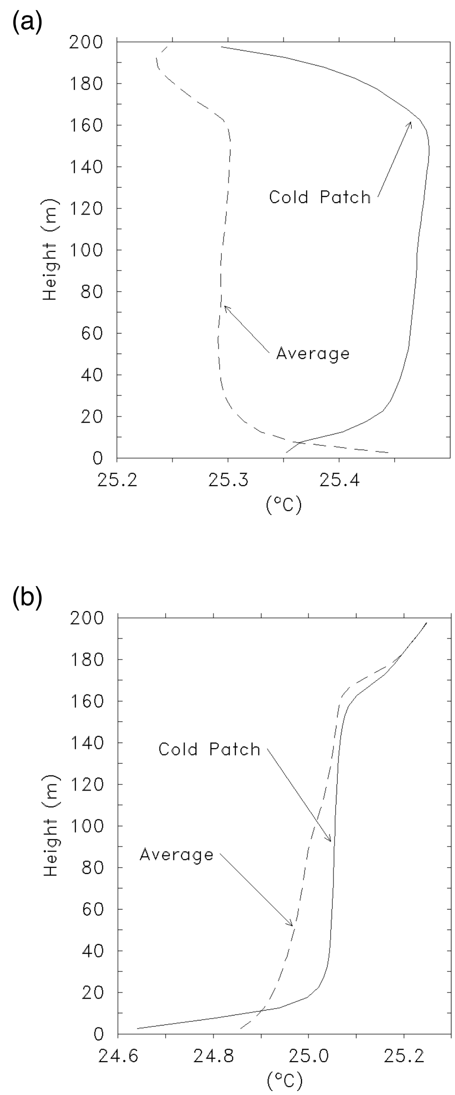

Fig. 3. Horizontally average potential temperature from the (a) convective case and (b) near neutral case. Solid lines are for simulation with a cold patch, dashed lines are for uniform SST forcing.