A Case Study of Impact of Sea Surface Temperature Variability on Boundary Layer Wind Structure

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1. INTRODUCTION

Sea surface temperature (SST) is one of the most crucial parameters in the coupled ocean-atmosphere system. SST significantly regulates the marine boundary layer (MBL) structure, leading to the feedback from the atmosphere to the ocean. The impact of SST variability is particularly important in the coastal environment where the air-sea coupling is more pronounced due to the similarity of the temporal and spatial scales in the ocean and the atmosphere. As air flows over an abrupt change in SST, an internal boundary layer develops within an existing boundary layer. Consequently, both the wind and thermodynamic structures will respond and adjust to the SST changes (e.g., Mahrt et al., 2003, Skyllingstad *et al*. 2004, McPhaden and Wallace, 1989). The significance of the impact of the SST variability on the MBL flow depends on the intensity and horizontal scale of the variability and the surrounding atmospheric conditions. In this work, we study the impact of local cold SST anomaly on wind speed spatial distribution in the MBL.

Aircraft observations in CBLAST-Low field experiment in August 2003 revealed significant small-scale SST variability and corresponding variability of air temperature and winds. These measurements provide excellent cases for more comprehensive understanding on this issue. This study combines the Naval Research Laboratory Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®) with aircraft *in situ* measurements to simulate and understand the impacts of the variability on the MBL mean and turbulent flow.

2. AIRCRAFT MEASUREMENTS

Fig. 1 shows the aircraft SST measurement to the south of Martha's Vineyard Island (MVI). The cold anomaly has an average width of 8 km in the north-south direction with the maximum temperature change of 6°C over 5km. The wind came from NW (not shown). Air temperature and wind speed at 40m decrease following the SST change with a time lag as shown in Fig. 2. With the SST starting to rise southward, the air temperature and wind speed adjust again and increase.

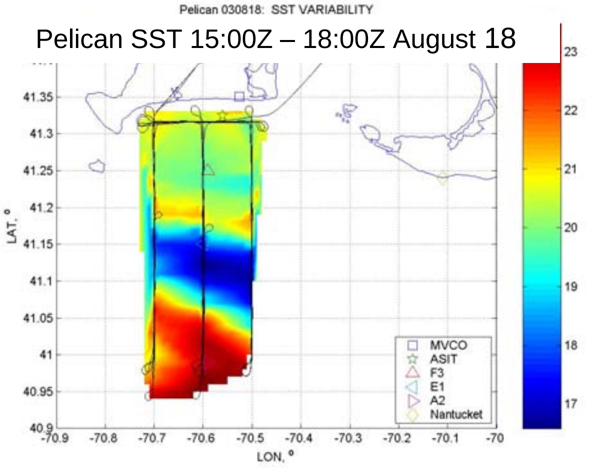

Figure 1: Aircraft measurement of SST during CBLAST.

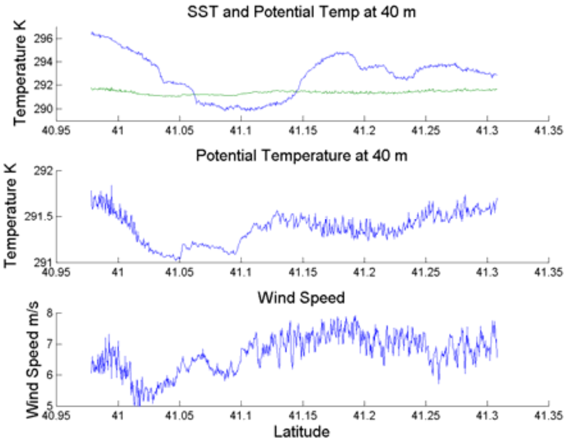

Figure 2: Aircraft measurement of SST, wind and air temperature at 40 m along the leg following 70° W, 15:00-1800 UTC, August 2003

3. COAMPS SETUP

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COAMPS is configured to include four nested grids (27km, 9km, 3km and 1km) with 38 levels in the vertical. The simulation starts at 00UTC, August 16, 2003, and continues through 00UTC, August 19 with 12 hour update cycle and full data assimilation of both atmosphere and ocean at the beginning of each run. To evaluate the sensitivity of the MBL to the SST variability shown in Fig. 1, we apply two different SST datasets in the assimilation process. The first comes from the routine satellite and ship data, which is available at the time of the forecast, which provide a constant (with respect to time) SST field for each of the 24 hour runs. In addition to those used in the first dataset, the second include all available 8-km and 2-km satellite data. More importantly, all available CBLAST SST data including the buoy and aircraft measurements are also utilized in the SST assimilation, which produces SST field every 6 hours. Therefore, the first simulation (control) uses a constant SST field for each update cycle; the second simulation (S2) uses SST field updated every time step based on the 6-hour time varying SST fields.

4. COAMPS SIMULATION RESULTS

We only present the results from the nest 4 on August 18, when the aircraft measurements are available. The S2 SST field clearly has two cold regions compared with that from the control. One is located to the east of Nantucket Island and reflects the influences of more frequent and high-resolution satellite data in the assimilation. The other is to the south of Martha's Vineyard Island and represents the aircraft SST data (Fig. 1). The maximum SST difference between two fields is as large as 6°C. These differences in SST result in different MBL structure over these two cold regions. The difference of the surface wind speed (S2-Control) from two simulations demonstrates that the wind speed from S2 simulation is decreased over the two cold regions with the maximum reduction of 2 ms^{-1}, a 25% change (Fig. 4). Fig. 5 compares SST, air temperature and wind speeds at 30m in the aircraft measurement area. It is clear that the introduction of SST measurements in S2 significantly improves both winds and temperature prediction. As air flow from warm to cold

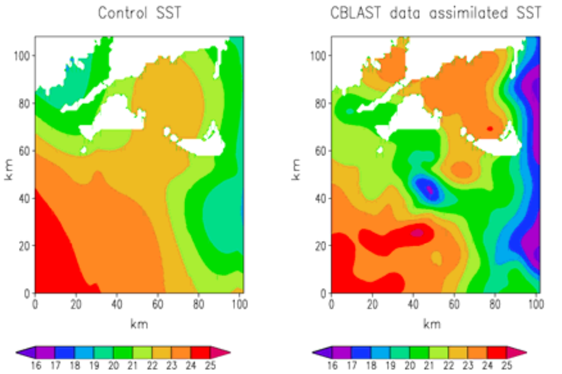

Figure 3. SST fields used in two simulations on 17:00 UTC August 18

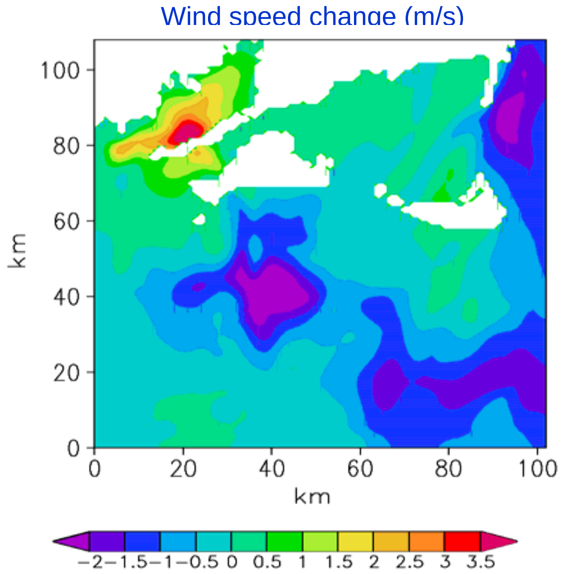

Figure 4. Wind speed difference (S2 – Control) on August 13.

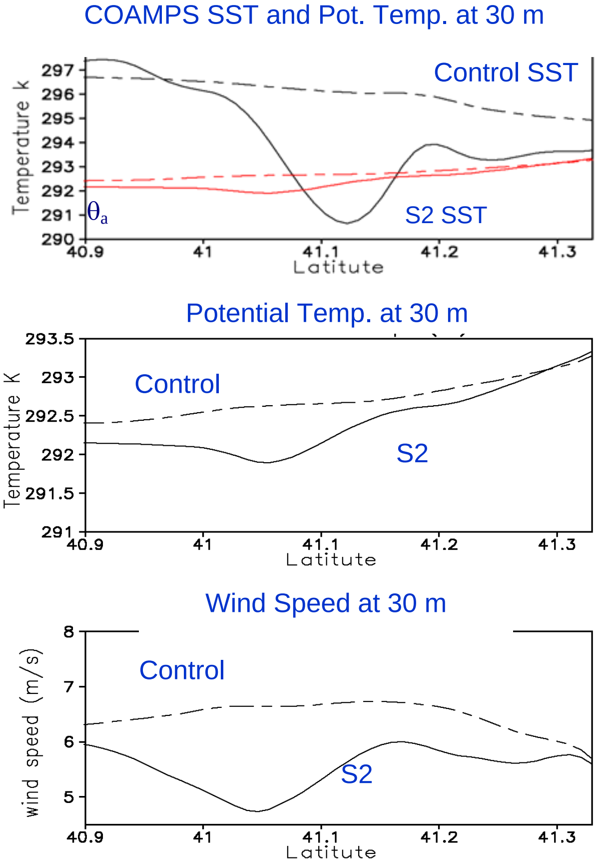

Figure 5. COAMPS results along the longitude 71.6°W. Dashed lines are for Control run, the sold for the S2.

water in S2, both air temperature and wind speed are reduced, being consistent with the observations shown in Fig. 1. The stable stratification in the surface layer significantly weakens the turbulence intensity, resulting in a negative sensible heat flux and reduced surface stress (not shown here).

The change in the surface layer stability regime inevitably changes the MBL structure, which is shown in Fig. 6. The wind speed is considerably reduced; while it is slightly enhanced aloft. An internal stable layer near the surface is developed and it severely weakens the turbulence intensity and limits the turbulence length scale. Consequently, the MBL height is only about 100 m.

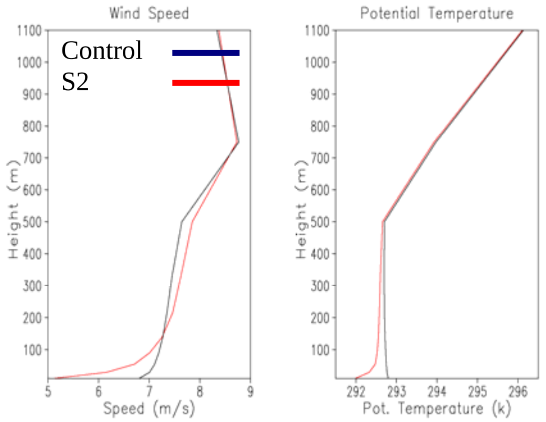

Figure 6. Wind speed and potential temperature profiles averaged over the cold SST area near MV from the two runs.

Due to the change of SST, the surface pressure field is also changed, which surely affects the wind distribution. To evaluate the effects of turbulent mixing and pressure gradient force on the wind speed, we calculate two main source terms of the wind speed budget, which can be written as

$$\frac{\partial\sqrt{\bar{u}^2+\bar{v}^2}}{\partial t}=-\frac{1}{\sqrt{\bar{u}^2+\bar{v}^2}}\left(u\frac{\partial\overline{w'u'}}{\partial z}+v\frac{\partial\overline{w'u'}}{\partial z}\right)$$

$$-\frac{1}{\sqrt{\bar{u}^2+\bar{v}^2}}\left(\bar{u}\frac{\partial\bar{p}}{\rho_0\partial x}+\bar{v}\frac{\partial\bar{p}}{\rho_0\partial y}\right)+Advection$$

where the first term on the right-hand-side represents the turbulence mixing effect, the second the pressure gradient. We average both terms over the cold SST area near MVI and present the results in Fig. 7. The turbulent mixing term is constant in the MBL for Control run, reflecting the well-mixed condition driven by the surface heating. The same term for S2 run shows large negative values and strong gradient in the internal stable layer and it becomes zero at 100 m. This occurs because the downward turbulent momentum transport diminishes due to the weak turbulence and because the internal stable layer is very shallow, leading to a very strong gradient of the total wind stress near the surface. The pressure gradient term is negative for S2 run, and its value is considerably smaller than that of the turbulence term. Consequently, it is the turbulent mixing term that plays a dominant role in reducing the MBL wind speed for this simulation.

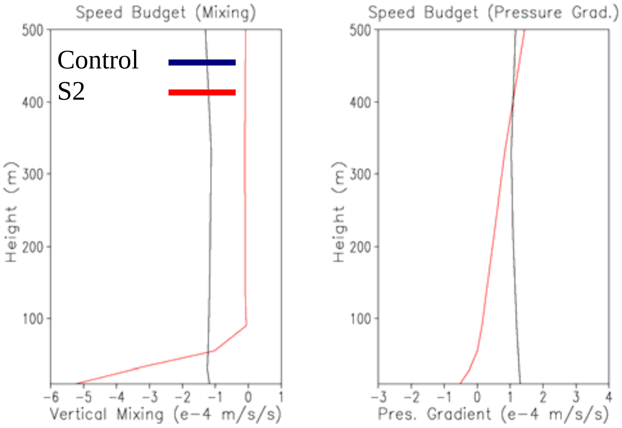

Figure 7. Turbulent mixing and pressure gradient terms from the speed budget.

5. SUMMARY

This study focuses on the impact of SST variability on the wind speed in the MBL. Using COAMPS simulation and aircraft measurements, we identify the turbulence mixing as the main mechanism in the adjustment of the wind speed. Our work continues on issues of turbulence response to the SST anomaly and its effects on the mean fields in the MBL.

Reference

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