J6.2 MIXING HEIGHTS, MIXING STRENGTH, AND SURFACE FLUXES OVER GALVESTON BAY AND THE GULF OF MEXICO: IMPLICATIONS FOR MODELING OF POLLUTION EPISODES

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1. INTRODUCTION

Coastal areas have large contrasts in mixing height which affect the transport of pollutants. Water warms and cools more slowly than land as the diurnal cycle proceeds. This also leads to sea breeze circulations. In the Houston/Galveston area, the large, shallow Galveston Bay intrudes into the otherwise northeast-southwest coastline. At times, a "Bay breeze" pattern distinct from the larger scale "Gulf breeze" can be distinguished. Because the most intense pollutant sources are near the Bay, this has important effects on concentrations of ozone and aerosol.

During the second Texas Air Quality Study (TexAQS II) in 2006, measurements of mixing heights, mixing strength, and surface fluxes were made from the NOAA Research Vessel Ronald H. Brown. During its deployment from 1 August – 12 September, the ship made several transects of the dredged channel running roughly north-south in Galveston Bay. It also transited the Houston Ship Channel between the Bay and downtown Houston several times, spent time in the Gulf of Mexico along the Texas coast, and tied up or kept station in dock areas. The primary meteorological instruments were the NOAA High Resolution Doppler Lidar (HRDL), radiosondes, and a surface flux package. The ship also carried a comprehensive package of gas-phase and aerosol chemistry instruments.

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On land, the study was supported by radar wind profilers operated by several agencies, chemistry ground sites, and radiosonde launches. The airborne component included several aircraft.

Here, we present some of the measurements of boundary layer structure from Brown. We also describe our experiments in modeling one case with WRF, comparing the model results to the measurements. We found that the land surface behavior and initialization of the model were the most important items in producing realistic simulations.

2. OBSERVATIONS

Buoyancy flux observations for the entire ship deployment are shown in figures 1 and 2, separated according to whether the ship was in the Gulf or in the Bay. In both places, the flux is almost always positive but small. We might have expected to see negative fluxes in the afternoon and evening, when warm air may be advected off the land, but in fact the water temperatures (not shown) have a distinct diurnal cycle in phase with the sun, so the time of warmest air over land corresponds approximately to the time of warmest water. There is a hint of stronger positive fluxes when the wind is from the north, which most often occurred at night. Over the Bay, there are some larger fluxes in the daytime, which could be due to the influence of land, or to warmer water, since the Bay is quite shallow (about 2 m). Most of the data in the Bay were taken when the wind was easterly or southeasterly, giving a reasonable fetch (at least 10 km) over the water.

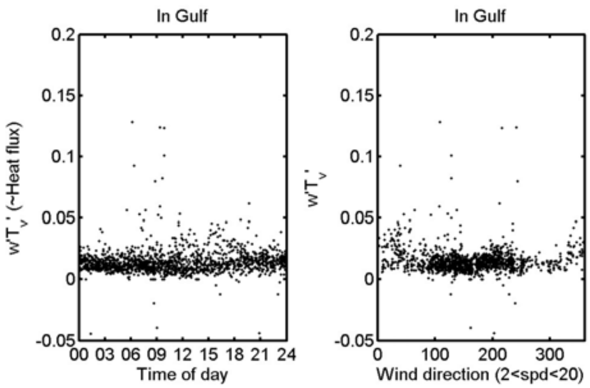

Figure 1: Buoyancy flux over the Gulf, by time of day (local standard time, left) and wind direction at the ship (right).

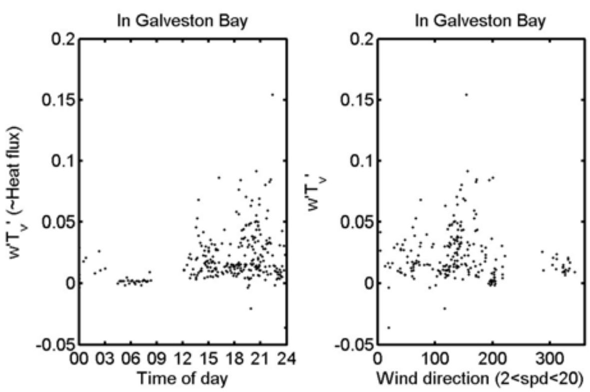

Figure 2: Buoyancy flux over the Bay, by time of day (local standard time, left) and wind direction at the ship (right).

Soundings taken over the Gulf, and especially over the Bay, usually show multiple layers. Finding a clearly-defined boundary layer is difficult. Often a change of wind direction is the clearest indication of a change of layer. The Doppler lidar (HRDL) provides more complete information that allows for greater confidence in defining the boundary layer. The availability of turbulence intensity information, in the form of velocity variances, is the most important addition. It allows us to distinguish between layers that *have been* mixed and layers that are *currently being* mixed.

A technique combining backscatter intensity, wind speed and direction, and vertical velocity variance yields the average mixed layer heights shown in figure 3. Over the Gulf, there is no diurnal cycle, and the mixed layer averages about 600 m deep. In the Bay, there is a weak diurnal cycle in the mean, and the average depth is 400 – 800 m. There is little data at night because the ship was not able to be in the Bay at night. In areas very near or surrounded by land (Barbour's Cut and the Houston Ship Channel), a more or less normal diurnal cycle of mixed layer height is seen.

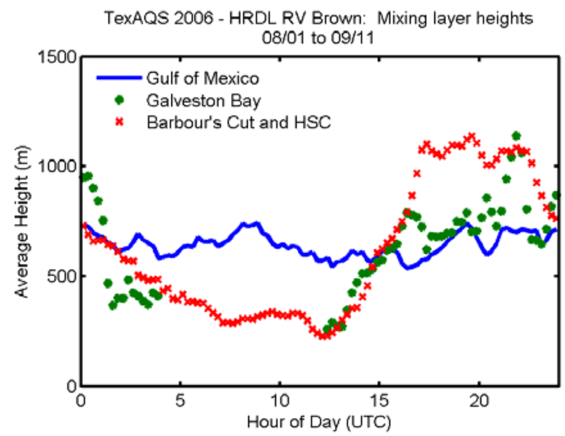

Figure 3: Average mixed layer heights from HRDL by time of day and location.

3. SEPTEMBER 1, 2006 CASE STUDY

The strongest ozone measured during the TexAQS II campaign, and during the 2006 ozone season in Houston, was on 1 September 2006. The ship saw over 180 ppbv in the northern Bay around 1200 LST (1800 UTC). Pollutants were emitted from the industrial concentration around the Ship Channel, advected to the east by light morning winds, and reacted in the fairly shallow mixed layer over the Bay. After noon, the winds shifted, first to east (from the Bay) and then to southeast (from the Gulf), pushing the ozone blob back over Houston.

To simulate the key features, we used a WRF –ARW model setup with nested 15, 5, and 1.67 km grid spacing. The inner grid was 180 points square, centered over Houston. Sixty vertical levels were used. Data from three radar wind profilers was assimilated using FDDA.

Selecting the "best" analysis to initialize the model turned out to be important. We experimented with NAM, GFS, and ECMWF analyses at various analysis times. The 1 September case has non-trivial synoptic forcing, and all the analyses have slightly different synoptic-scale fields, which make important differences in the small-scale features produced by our WRF runs. We settled on the ECMWF analysis at 0Z as the best choice for this case.

The other very important item was the land surface. The default settings gave temperatures that were too cool over the land by several degrees at midday. This completely prevented the development of a sea breeze. After much experimentation, we used the 5-level "slab" land surface scheme, and arbitrarily reduced the soil moisture parameters for most land use types to tune the land surface temperatures.

Figures 4 and 5 show the simulated 10 m winds at noon LST (1800 UTC) and 1700 LST (2300 UTC). The simulation captures the key features, the divergence over the Bay, bay breeze, and gulf breeze. The bay breeze does not penetrate quite far enough to the west into the metropolitan area, nor does the gulf breeze penetrate quite far enough north. The winds in the northern Bay veer somewhat too much compared to observations.

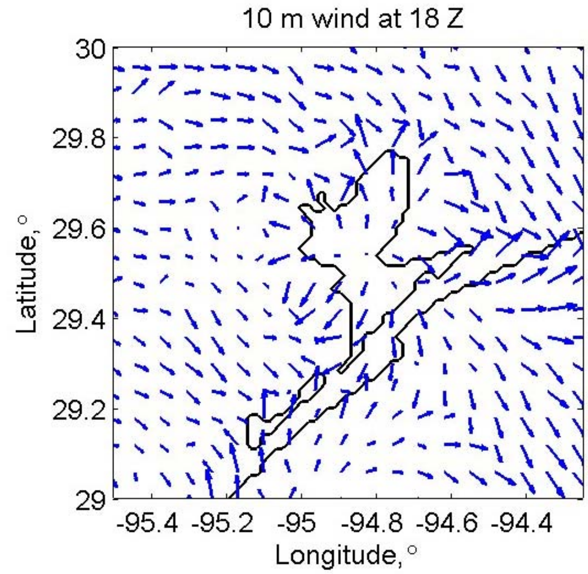

Figure 4: Winds at 10 m AGL in the WRF simulation at 18Z (1200 LST).

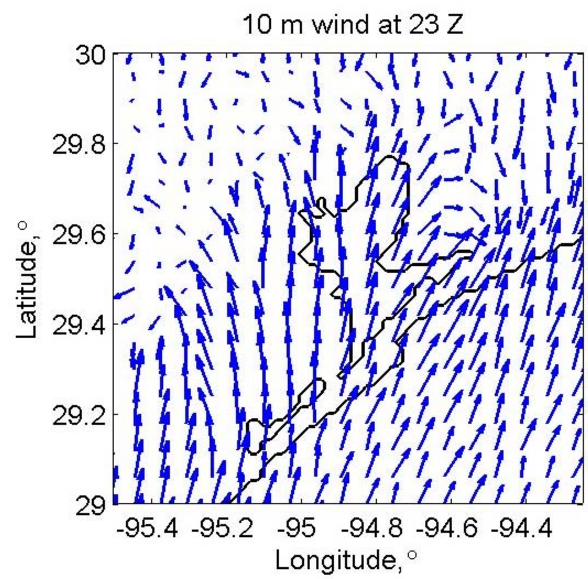

Figure 5: Winds at 10 m AGL in the WRF simulation at 23Z (1700 LST).

Sea surface temperatures in the model are taken by default from the initial analysis and not changed in the course of the run. The SST from the ECMWF analysis was slightly too cool in the Bay and slightly too warm offshore. An experiment forcing the SST everywhere to match the observations from buoy 42035, offshore of Galveston, made only small differences in the wind field. The warmer SST increases the latent heat flux over the Bay. Sensible heat flux is increased slightly during the night, and remains (small but) positive during the day, instead of going negative as it does in the baseline run (figure 6). The boundary layer height, diagnosed by looking for the lowest height with Richardson number >0.25, is nearly unchanged. The ship observations show even warmer SST in the Bay than in these forced simulations, and it's likely that warming up the Bay further would increase the daytime BL height. However, it would probably also decrease the divergence over the Bay and the inland penetration of the bay breeze.

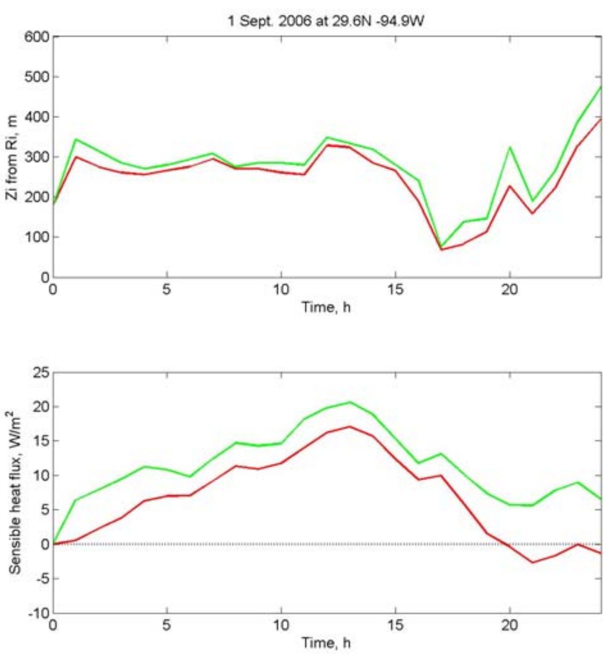

Figure 6: Boundary layer height from bulk Richardson number (top) and sensible heat flux (bottom) for baseline run (red) and run with forced SST (green). Time is UTC on 1 September.

4. SUMMARY

The boundary layer over Galveston Bay and the Gulf of Mexico near the Texas coast during August and September 2006 was almost always weakly mixed, with small positive buoyancy flux night and day. Mixed layer depths were 300-600 m most of the time, with no diurnal cycle in the Gulf and a small average diurnal cycle in the Bay. The lower and more weakly mixed boundary layer over the Bay plays a role in strong ozone events in Houston by keeping morning emissions confined.

Simulations of 1 September, the strongest ozone day of the 2006 season, with WRF captured the key features of the wind field, including the divergence over the Bay, bay breeze, and gulf breeze. The initial analysis and land surface behavior were the most important items in getting good simulations. More realistic water surface temperatures made only small differences in this region of the parameter space.

ACKNOWLEDGEMENTS:

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