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3-D DISTRIBUTION OF OZONE DURING THE MAJOR POLLUTION EVENT OF 30 AUGUST 2000 DURING TEXAQS 2000

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1. INTRODUCTION

Air pollution in the Houston, Texas area is a product of strong emissions and specialized meteorological conditions. The emissions are from the Houston urban area, from power plants, and, to the east and southeast of the city, from the many refineries and petrochemical plants along the Ship Channel and the western shore of Galveston Bay. The specialized meteorology consists of interactions of the local sea-breeze circulations with larger-scale geostrophic or gradient flows. During the Texas Air Quality Study (TexAQS) from mid August to mid September 2000, many days had onshore or weak ambient flow, and the sea breeze, generated by the temperature contrast between the land and the Gulf of Mexico, moved inland by early afternoon. However, conditions where the larger-scale flow was offshore and opposed the sea breeze (Fig. 1) were especially conducive to pollution events, because the sea-breeze front stalled over the sources, and the pollutants remained in the area and accumulated. Stalled *synoptic* fronts have also previously been identified as preferred locations for high-pollution episodes (McNider et al., 1995).

One especially dramatic example of these processes was 30 August 2000 during the Houston air quality experiment (TexAQS 2000). 30 August was a day when the bay and gulf breezes did not begin along the western shore of Galveston Bay until late in the afternoon, as a result of large-scale offshore flow in the atmospheric boundary layer (ABL). In the following study we present a detailed analysis of this event, emphasizing how the chemistry and airborne ozone lidar profile measurements provide insight into the meteorological processes beyond that available from the meteorological instrumentation alone, which included rawinsondes, tethersondes, surface flux sites, surface mesonets, and radar wind profilers.

2. INSTRUMENTATION

Many aircraft and ground-based instruments were deployed to characterize the meteorology and chemistry of the atmosphere over the Houston-Galveston area during TexAQS 2000. One of these instruments was a downward-looking ozone-profiling differential-absorption lidar (DIAL) operated by the Environmental Technology Laboratory (ETL) of the National Oceanic and Atmospheric Administration (NOAA), mounted in a DC-3 airplane (Alvarez et al., 1998). This lidar mapped out the distribution of ozone and aerosol backscatter in a 2-d vertical curtain along the flight track, and thus was capable of showing the 3-D distribution of these pollutants by flying back and forth over a region.

3. RESULTS

The flow for most of the day on 30 August was offshore in the Houston-Galveston area, as indicated by the surface measurements and vertical profiles of the horizontal winds determined from conical scans of the Doppler lidar sited at La Porte (Darby et al., 2002). This offshore flow resulted in low pollution concentrations over land, up to the shore of Galveston Bay, because the pollution from the Houston urban and Ship-Channel areas was carried offshore to the southeast over the Bay. High concentrations of these pollutants remained over the water from near the surface to ~300 m ASL as determined by airborne ozone lidar flights (as depicted in Fig. 2a), because the air in contact with the cooler water surface of the Bay was relatively stable. The sea breeze began weakly in the afternoon, and the sea-breeze front only penetrated a few kilometers inland by late afternoon (Fig. 1). As shown, the stronger offshore flow and the weaker

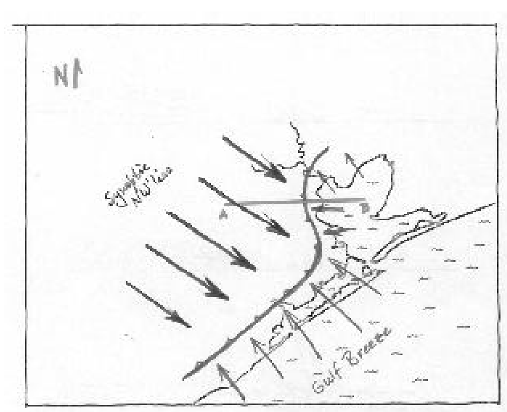

FIGURE 1: Map of the Texas coastline along the Gulf of Mexico (lower right of figure) and Galveston Bay (B at the right end of line AB), showing the Bay and Gulf breezes in mid to late afternoon forming into larger-scale offshore flow, similar to the conditions on 30 August 2000. The line AB shows the location of the vertical cross sections in Fig. 2.

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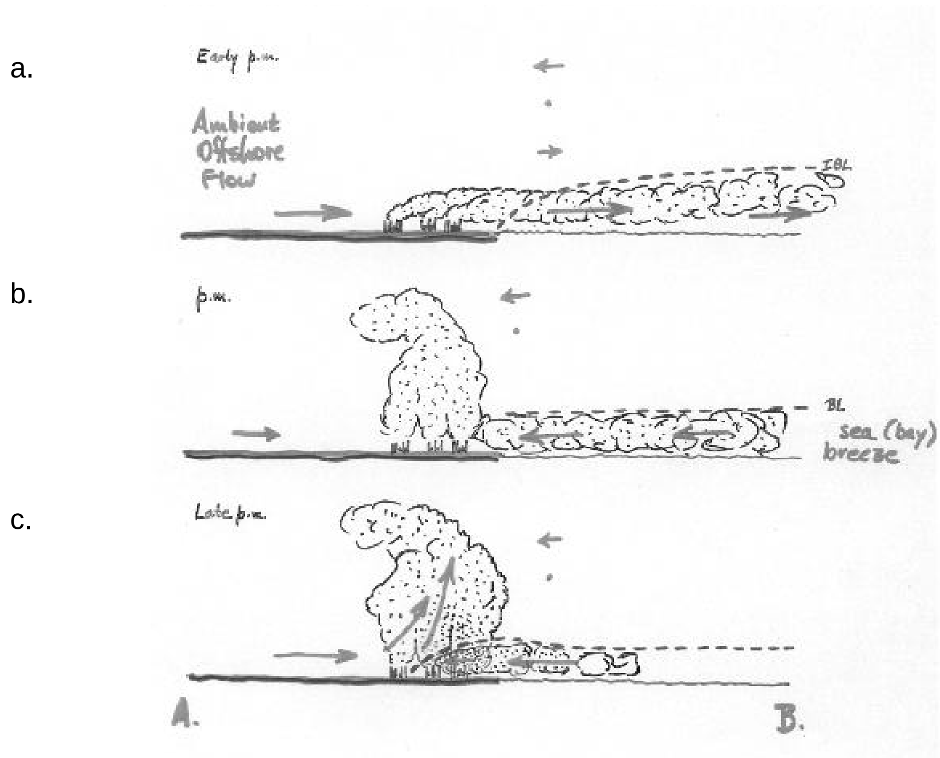
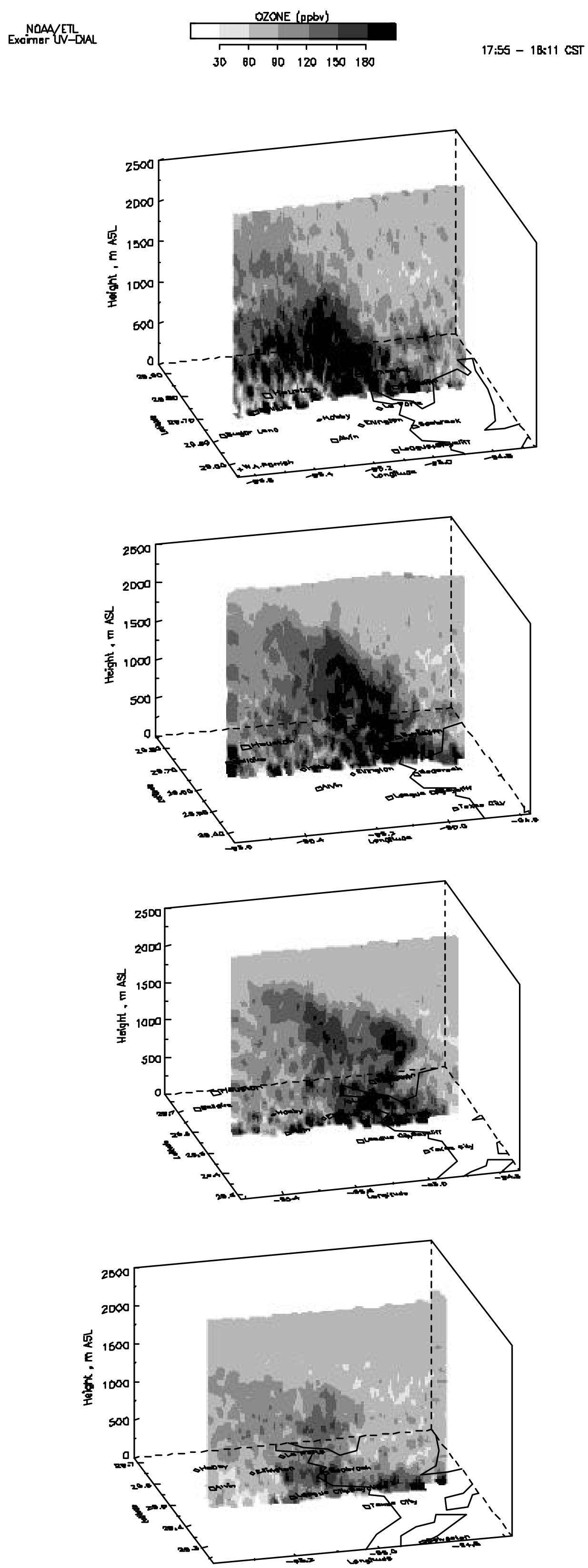


FIGURE 2: Vertical cross sections of the winds (arrows), stable-layer base (dashed line), and pollution distribution (dotted areas) across the shore of Galveston Bay along the line AB in Fig. 1: a) Late morning through early afternoon, b) mid-afternoon, approximately 1500 CST, and c) late afternoon, after 1700 CST.

onshore sea-breeze flow behind the front produced a north-south region of strong convergence just inland and parallel to the western shore of Galveston Bay. This flow pattern also produced optimum conditions for high pollution concentrations, because the onshore flow brought pollution released earlier in the day, which had drifted out in a shallow layer over the bay, back over the sources for a double dose (Fig 2b,c). Although this has been hypothesized to happen, it has been very difficult to obtain documented occurrences.

In addition to revealing how bad the pollution situation became, the airborne-ozone-DIAL measurements also revealed how strong and deep the convergence was over the linear north-south sea-breeze front along the west shore of the Bay. The DC-3 flew several parallel east-west cross sections across the shore from south to north, thus painting a 3-D picture of the ozone distribution (Fig. 3). The pollution formed a spectacular hedge of ozone reaching more than 2 km high, with very high concentrations of 200 ppb occupying much of this volume. Thus the strong updrafts in the sea-breeze convergence zone lofted these excessive pollution concentrations high into the atmosphere. Airborne air-chemistry measurements during mid afternoon suggest the primary sources of the ozone-rich air were industrial facilities along the Ship Channel and the western shore of Galveston Bay.

The lofting of significant concentrations of pollutants to high altitudes in the ABL also has implications for the region. This area source affected not only the local air quality, but significant concentrations of pollutants were available for transport by the winds aloft. The tall hedge of pollution formed late in the day, and the winds aloft during the night of 30-31 August measured by 915-MHz radar wind profilers show 3 layers: 1) a low-level jet (LLJ) below 500 m AGL that veered from southwest to west throughout the night, 2) a 300-400-m deep light-wind layer of variable direction above the LLJ layer, and 3) a layer of northeasterly flow above these layers starting at ~1 km AGL is indicated, but may be related to migrating bird contamination of the radar signal. Trajectories constructed from the profiler data show the LLJ in the lower layer carrying pollution toward Beaumont and the Louisiana coast, material in the light wind layer remaining over the Houston area, and the upper layer being carried toward Corpus Christi, according to the profiler data. The following day this pollution would mix down to the surface at its location and become part of the buildup of rural background, as found by Banta et al. (1998) near Nashville, Tennessee.



4. DISCUSSION

The question of whether the lofting of pollutants in the bay-breeze convergence zone was unique to this day or occurred on other days can be addressed with data from the airborne O_3 DIAL. 30 August was part of a 9-day pollution episode, which included days investigated by Senff et al. (2002). Other days with stalled bay-breeze fronts did show this effect, including 26, 29, and 31 August. Because the strength and direction of the large-scale flow varied from day to day, the location and strength of the highest O_3 concentrations also varied, and the >200 ppbv measured on 30 August was the highest surface concentration recorded during the project.

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FIGURE 3. Airborne DIAL vertical cross sections (from west [left] to east) of O_3 concentrations, with the black shading starting at 180 ppbv. Cross sections move from south (bottom) to north (top), each superimposed on a map of the Galveston Bay coast.