3-Dimensional Distribution and Horizontal Transport of Ozone in Southeast Texas Measured With an Airborne Lidar During TexAQS 2006

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Introduction

In the summer of 2006, many scientists in the Earth System Research Laboratory (ESRL) / Chemical Sciences Division (CSD), including the Optical Remote Sensing (ORS) Group, participated in the 2006 Texas Air Quality Study (TexAQS) in southeast Texas, which lasted from early August thru mid October of 2006. CSD/ORS deployed its newly developed TOPAZ ozone and aerosol airborne lidar, primarily to map out the 3-dimensional distribution of ozone and aerosol pollutants in the Houston and the general southeast Texas areas. For many of the ESRL/CSD researchers, it was their second time investigating air quality in the greater Houston area after a first deployment in the summer of 2000. A key objective of the 2006 study was to determine whether any of the regulatory measures implemented by the State of Texas in the meantime had resulted in lower ozone levels in southeast Texas.

TOPAZ Ozone Differential Absorption Lidar

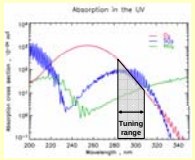
For the TexAQS 2006 study, CSD/ORS developed TOPAZ (**T**unable **O**ptical **P**rofiler for **A**erosol and **O**zone), a new-generation airborne ozone and aerosol lidar. This new lidar is light-weight and compact, so it can be flown on a rather small research aircraft, such as the NOAA Twin Otter. It incorporates the latest solid-state laser technology and its transmitter is tunable in the UV spectral region.

TOPAZ specs:

- 3 channels (285 – 310 nm, tunable)
- Pulse energy: 0.2 to 0.4 mJ
- Rep rate: 1 kHz
- Nadir-looking

TOPAZ measurements:

- Ozone & aerosol backscatter profiles
- Altitude coverage: surface up to 3.5 km
- Resolution: 10 s or 650 m horizontal, 100 m vertical (O3), 6 m (aerosol)
- Precision: 3 – 15 ppb

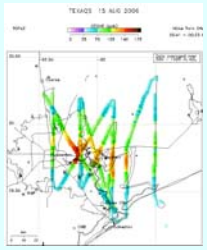


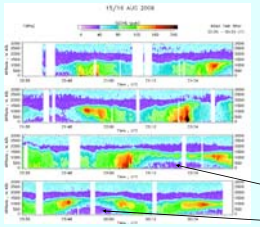
TOPAZ lidar mounted in NOAA Twin Otter

NOAA Twin Otter N46RF

3-D Distribution of Ozone in Houston,TX Area

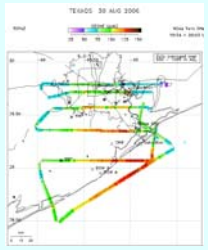
Houston, TX is characterized by a unique and very dense concentration of refineries and other petrochemical facilities, which are mostly concentrated along the Houston Ship Channel and the western shore of Galveston Bay near Texas City. VOC emissions from these plants combined with NOx emissions from co-located power plants and vehicle traffic provide a potent mix of ozone precursors that often lead to very rapid and efficient ozone formation, resulting in violations of the 125 ppb 1-hour and 80 ppb 8-hour ozone standards. During TexAQS 2006, high ozone concentrations were observed with the TOPAZ lidar in the Hoston area, both under light-wind conditions when the complex land-sea breeze flow pattern dominates and the ozone pollution plume tends to stay close to the pollution sources and under synoptic flow conditions when the Houston / Ship Channel plume is carried downwind of the Houston metro area.

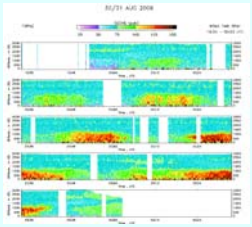




On Aug 15, through early afternoon winds in the Houston area were light from a WSW direction. This allowed the buildup of high ozone concentrations just to the northeast of the main source in the Ship Channel area (upper panel).

In the early afternoon, the bay breeze developed and the flow switched to a SE direction and accelerated. The LaPorte wind profiler (LPT – just south of the Ship Channel) detected the flow reversal around 2030 UTC (14:30 LST). As the bay breeze front moved inland it pushed the ozone plume to the NW across the northern half of the Houston metro area. In its wake it replaced polluted air with clean maritime air with ozone concentrations below 40 ppb. Since the bay breeze layer is only several hundred meters thick, high ozone concentrations remain aloft and are available for long-range transport and downward mixing the next day (bottom panel).





On Aug 30, the Houston / Ship Channel ozone plume is transported downwind in moderate northerly flow. The largest ozone concentrations (> 125 ppb) were observed about 100 km downwind. This illustrates that under steady synoptic flow conditions high ozone concentrations in the greater Houston area are likely to be missed by the surface monitoring network. Most stations are located in the Houston metro area with few stations in surrounding rural areas. Thus, the surface network may indicate no violations of the ozone standards. However, the TOPAZ measurements indicate that even under well-ventilated conditions ozone exceedances are likely to occur downwind of the Houston metro area.

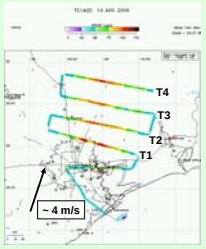
Ozone Flux Emitted by Houston and Dallas Metro Areas

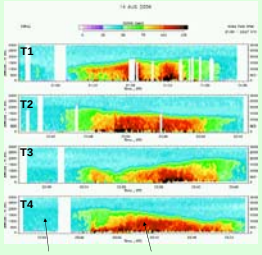
Objective:
Compute total horizontal flux of ozone emitted by Houston and Dallas/Fort Worth metro areas to estimate export of ozone in rural areas in SE Texas

Approach:
Use TOPAZ data from flight transects downwind of metro areas and calculate ozone flux in plume for each transect

Meteorological Conditions:
Steady synoptic flow at speeds of several m/s

Additional Analysis (in the future):
Determine ozone production rates if multiple downwind transects are available

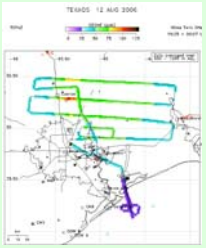




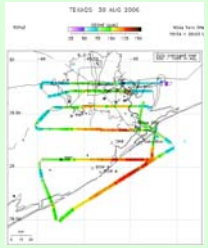
Flux calculation:
Integrate excess ozone in plume (plume O_3 – background O_3) between surface and top of boundary layer and between horizontal plume edges. Then multiply with horizontal wind speed to yield flux in molecules O_3 / sec for each transect.

Three additional cases:

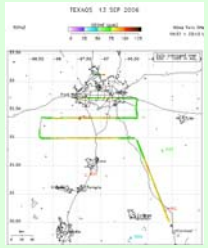
Houston: Southerly flow: Aug 12



Houston: Northerly flow: Aug 30



Dallas: Northerly flow: Sep 13



Metro area	Date	Wind direction	Wind speed , m s^{-1}	Time, UTC	Back-ground O_3, ppb	Flux, molec O_3 s^{-1}
Houston	8/12	S	4.8	2304 - 2334	~30	$4.0*10^{26}$
Houston	8/14	S	4.0	2259 - 2326	~35	$4.6*10^{26}$
Houston	8/30	N	4.4	2218 - 2250	~60	$4.4*10^{26}$
DFW	9/13	N	4.1	2150 - 2230	~60	$1.4*10^{26}$

Preliminary conclusions:

- Above-background ozone flux emitted by Houston metro area is very similar for the 3 case studies (4.0 to $4.6 * 10^{26}$ molec/s).
- A flux of $4.3 * 10^{26}$ molec O_3 / s emitted over 1 hour is equivalent to a 10-ppb increase in ozone over a 1200 square mile area, assuming a 2-km deep mixed layer.
- Export of ozone from DFW metro area is about a factor of 3 less than from Houston ($1.4 * 10^{26}$ molec/s).