TCEQ Ozonesonde Project Update

Dave Westenbarger
Engineering Specialist, Air Quality Division

Presented to Southeast Texas Photochemical Modeling Technical Committee
August 23, 2011
TCEQ Partners

- This work is performed under Proposal for Grant Activities (PGA) #582-5-64594-FY10-11 under a grant umbrella from TCEQ to the University of Houston.

- Since 2004, TCEQ and others have funded a data collection effort in the Houston-Galveston-Brazoria (HGB) area using ozonesondes. The work is carried out by scientists and students at these institutions:
  
  Valparaiso University (Indiana)
  - Dr. Gary Morris – Co-Principal Investigator

  University of Houston (U of H)
  - Dr. Barry Lefer – Co-Principal Investigator
  - Student technicians who perform launches

  Oklahoma State University (OSU) / Kiamichi Forestry Research Station in Idabel, OK
  - Dr. Robert Heinemann

- We also rely on citizens who return landed equipment for a $30 reward. This equipment can sometimes be re-used, reducing project costs by allowing more flights.
What is an ozonesonde?

- An ozonesonde (*sonde is French for "probe") is a weather balloon with instruments for measuring ozone concentrations and meteorological parameters (radiosonde).

- As the sonde ascends, it continuously measures ozone and other parameters:
  - Wind speed and direction
  - Temperature
  - Relative humidity
  - Barometric pressure
  - Location

- This data is radioed back to a receiver.

- Balloon ascends at ~5m/s for ~90 minutes.

- When the balloon bursts at high altitude (~20-30km) the equipment descends and sometimes is recovered and returned (about 10% are returned).
Purpose of the Project

The primary intent of the project is to:

1. Measure, characterize, and explain differences in the lower free troposphere (LFT) ozone profile throughout the year, though especially spring and late summer; and
2. Study the resultant impact on planetary boundary layer (PBL) ozone in eastern Texas.

Since 2004, TCEQ and partners have measured and analyzed atmospheric conditions in Houston using ozonesondes.
- This project is the largest urban ozone profile database in the U.S.
- As sample size increases with more years of data, statistical reliability of the results and conclusions improves dramatically.

April 2010, launches began at Idabel, Oklahoma, near the northeast corner of Texas, where Texas, Oklahoma, and Arkansas meet.
- These launches help characterize air parcels transported into Texas from the north and northeast, sometimes representing background conditions that affect Dallas-Fort Worth, Tyler-Longview and other potential non-attainment areas in Texas.
- Other sites were considered but Idabel was chosen due to logistics--the need to have people nearby to conduct launches on short notice.
- Staff of the Kiamichi Forestry Research Station of Oklahoma State University in Idabel agreed to perform these launches.
Why Are These Measurements Needed?

- Ozone and precursors that remain **overnight** in the residual layer can impact ozone the next day. Vertical profiles from sondes help explain:
  - ozone seasonality
  - transport
  - PBL behavior
  - source partitioning (local vs. transport); and
  - other questions.

- Surface monitors are **limited**.
  - Surface monitors cannot measure ozone aloft.
  - Surface monitors cannot distinguish local from transported ozone.

- Sondes are relatively **inexpensive** and provide a lot of data.
  - They are a cost-effective method of characterizing atmospheric columns above ground-level. Each launch costs ~$1,000-$1,500 depending on equipment.
  - Other methods (airplanes, LIDAR, etc.) are expensive.
  - TCEQ spent $135,000 in Fiscal Year 2011 for about 65 launches. Proposed funding for FY 2012 is identical.
How Are These Measurements Used?

• Analyses of the data contribute to **photochemical modeling** for ozone State Implementation Plan (SIP) development for the Houston-Galveston-Brazoria area.

• Additional analyses will provide support to photochemical modeling efforts that may be needed for future SIP development for regions of **northern, eastern** (and possibly central) **Texas**.

• The data collected can help address important scientific questions including:
  - Do we observe **subsidence** of high ozone from the Upper Troposphere/Lower Stratosphere (UT/LS) behind cold fronts, which enhances surface layer concentrations, resulting in a larger probability of **ozone exceedance**?
  - How do spring biomass burning and **transport** from the south add to Houston ozone levels?
  - What factors influence the ozone profile over Houston in each **season**?

• A final report analyzing data collected through 2011 is due **December 23, 2011**.
Locations of Launch Sites

1. University of Houston campus
   2004-2011
   ~375 launches, continuing

2. Idabel, Oklahoma
   2010-2011
   ~30 launches, so far
Number of Launches

Houston

- Most launches occur in spring (Apr-Jun) and summer (Jul-Sep).
- Decision to launch depends on forecast weather conditions.
- Total launches each year depends on available funding.
Number of Launches

Idabel, OK

- Launches began April 2010.
- The decision to launch depends on forecast arrival of synoptic weather systems from the north, northeast, or east.
- Launches occur mid-morning when systems are forecast to arrive that day.
Data is Available On-Line

- Flight data and other information for all flights since 2004 is available at the project Web site:

  www.imacs.uh.edu/ozone/ourdata.htm

  - Date & time of flight
  - Raw data (X files)
  - Plots including:
    - Partial pressure (P)
    - Mixing ratios (MR)
    - Wind speed & direction (W)
    - Potential temp, theta
    - Trajectories (Traj)
    - Skew-T
  - Notes on flights (e.g., lost data, software crash)

- Data are currently being updated (please be patient!).
Example Launch Trajectory: U of H

06-Jun-2011 flight from University of Houston campus

On this flight, the sonde flew west from U of H campus as it ascended. After about 35 minutes, it turned sharply southeast, crossing above Texas 35, before turning west-southwest. After 20 more minutes, it began its descent, still heading west, and landed near Sienna Acreage Estates.
Example Launch Trajectory: Idabel, OK

04-Jun-2011 flight from Idabel, OK

On this flight, the sonde flew due north and northeast for 30 minutes as it ascended, then turned east. A small eddy sent it circling for 20 minutes until it began descending. The sonde descended east, then north-northeast before landing about 50 minutes later, east of Hochatown State Park.
This graphic depicts ozone and relative humidity during five flights in August 2010 from U of H and Idabel. Notice the variability as the sondes ascend in altitude. On August 26, an extremely dry parcel of air (very low humidity) was detected at Idabel above 2.5 km altitude. A flight the next day from U of H also detected dry air above 2 km altitude. Careful inspection can distinguish the boundary between the mixing layer (ML) and lower free troposphere (LFT).

Note: flights occurred on different days in the two locations.
Max on 8/11/10: 142 ppb @ Moody Tower C695
Results: Meteorology on June 6, 2011

- Left panel – ozone and relative humidity.
  - Two layers of high relative humidity (green) can be seen at about 3 km and 6 km altitude.
  - Extremely high ozone (blue and red) is observed above 10 km altitude. Note change in scale from blue (ppmv) to red (ppbv).

- Right panel – ozone, temperature and pressure.
  - High surface ozone (blue) drops sharply above 2 km.
This graphic shows spring launches over Houston from 2005 to 2010. Each curve color represents a particular year from 2005 to 2010. In this case, ozone at the surface increases from 40-50 ppb up to 50-70 ppb, then levels off, up to about 6 km altitude. In most years, ozone increases or is variable above 6 km until about 11 km altitude, where it increases sharply. In spring, 11 km altitude is roughly the beginning of the tropopause.
This graphic shows how late summer ozone above Houston varies as altitude increases. Each curve color represents a particular year from 2004 to 2010. For all years, a pattern is observed of ozone increasing at the surface up to about 200 m. From 1 km to about 2 km altitude, roughly the top of the mixed layer, ozone drops considerably, on average, before beginning to increase again. Above about 14 km altitude, roughly the beginning of the tropopause, ozone increases sharply.
Ozone Profiles by Season

Average ozone by season – all flights from U of H
mean (thick) and one standard deviation (thin)
ozone profiles, 2004-10

Here, all years have been aggregated by season. The spring (April-June) profile shows more ozone aloft, with a small vertical ozone gradient (about 1 ppbv/km) from the surface up to 10 km, suggestive of downward mixing of ozone from the UT/LS due to more frequent passages of cold fronts during this season. The summer (July-September) profile shows a strong negative gradient of ozone (about -5 ppbv/km) from the mixing layer (ML) to the lower free troposphere (LFT), with a nearly constant positive vertical gradient in ozone (about 3.5 ppbv/km) from 2.5 to 9 km altitude.
This graphic shows ozone concentrations as altitude increases, grouped by wind direction. All years (2004 to 2010) are averaged together. The highest surface ozone is observed when winds are from the east (about 70 ppb) or north (about 60 ppb), or are calm (about 65 ppb). Ozone averages about 55 ppb when winds are from the west, but drops sharply up to 2 km altitude. Ozone averages about 40 ppb when winds are from the south and remains constant up to about 3 km.
Ozone Profiles by Wind Direction

Average ozone by wind direction – all flights from U of H mean (thick) and one standard deviation (thin) ozone profiles, Apr-Jun 2004-10
As only one year of Idabel data is available so far, comparisons across years are not yet possible. Also, the small sample size requires caution in interpretation. Surface ozone was observed to be about 45 ppb from all directions except south, where it was lower, around 35 ppb. In all cases, ozone aloft increased up to 1 km, above which it dropped sharply for calm and easterly winds. Westerly winds brought the highest ozone from 1-4 km altitude, which could be associated with plumes from the DFW area, although this is preliminary.
Average Ozone – Late Summer 2010

Average ozone, summer and fall 2010 – U of H and Idabel
mean (thick) and one standard deviation (thin)
ozone profiles, Jul-Oct 2010

Average (thick) and one standard deviation (thin) profiles for Houston (red) and Idabel (blue) from fall 2010. Houston shows increases from the surface to about 1 km altitude, a sharp drop to about 2 km, and steady increase above 2 km. Idabel shows a sharp increase just above the surface to about 1 km altitude, generally increasing above 1 km up to about 12 km. Both sites show sharp increases above about 12 km altitude.
Morris (2011) suggests a method to estimate the relative influence of transport versus locally-produced ozone.

1. For each day, find max(ozone) in the 1 km layer above the ML (the free troposphere, or FT).
2. Also find max(ozone) in the ML.
3. Subtract max(ozone_{ML}) from max(ozone_{FT}).
4. The sign of this difference suggests the relative importance of:
   - Transported ozone
   - Locally-produced ozone
Transport Influences by Season

- Plotting the differences between max(ozone_{FT}) and max(ozone_{ML}) for all days reveals seasonal patterns:
  - Jul-Aug: higher ozone more often found near the surface than aloft.
  - Nov–May: higher ozone more often found aloft than at the surface.

Red lines signify one standard deviation variability from monthly mean values (grey).
Three cases of interest are indicated by the colored points—(1) low ozone/low humidity in the FT (blue), (2) high ozone/high humidity in the FT (green), and (3) high ozone/low humidity in the FT (orange).
## Three Transport Cases of Interest

<table>
<thead>
<tr>
<th>Case</th>
<th>ozone</th>
<th>rh</th>
<th>description</th>
<th>likely influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;75 ppb</td>
<td>&lt;10%</td>
<td>low ozone, very dry air</td>
<td>UT/LS air transported to LFT</td>
</tr>
<tr>
<td>2</td>
<td>&gt;75 ppb</td>
<td>&gt;40%</td>
<td>high ozone, moist air</td>
<td>anthropogenic, biomass burning</td>
</tr>
<tr>
<td>3</td>
<td>&gt;75 ppb</td>
<td>&lt;10%</td>
<td>high ozone, very dry air</td>
<td>UT/LS descending into ML</td>
</tr>
</tbody>
</table>

### Influence by Season

<table>
<thead>
<tr>
<th>Case</th>
<th>UT/LS Transport</th>
<th>Influence*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flights</td>
<td>1</td>
</tr>
<tr>
<td>Winter (JFM)</td>
<td>29</td>
<td>48</td>
</tr>
<tr>
<td>Spring (AMJ)</td>
<td>76</td>
<td>13</td>
</tr>
<tr>
<td>Summer (JAS)</td>
<td>155</td>
<td>3</td>
</tr>
<tr>
<td>Fall (OND)</td>
<td>31</td>
<td>52</td>
</tr>
</tbody>
</table>

*Totals may not sum exactly due to rounding.

---

Air Quality Division • TCEQ Ozonesonde Project Update • DAW • August 23, 2011 • Page 24 of 29
### Three Transport Cases of Interest

<table>
<thead>
<tr>
<th>Case</th>
<th>ozone</th>
<th>rh</th>
<th>description</th>
<th>likely influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;75 ppb</td>
<td>&lt;10%</td>
<td>low ozone, very dry air</td>
<td>UT/LS air transported to LFT</td>
</tr>
<tr>
<td>2</td>
<td>&gt;75 ppb</td>
<td>&gt;40%</td>
<td>high ozone, moist air</td>
<td>anthropogenic, biomass burning</td>
</tr>
<tr>
<td>3</td>
<td>&gt;75 ppb</td>
<td>&lt;10%</td>
<td>high ozone, very dry air</td>
<td>UT/LS descending into ML</td>
</tr>
</tbody>
</table>

### Influence by Season

<table>
<thead>
<tr>
<th>Season</th>
<th>Flights</th>
<th>UT/LS Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># 1 2 3</td>
<td>1+3 2+3</td>
</tr>
<tr>
<td>Winter (JFM)</td>
<td>29 48 3 3</td>
<td>52 7</td>
</tr>
<tr>
<td>Spring (AMJ)</td>
<td>76 13 7 18</td>
<td>32 25</td>
</tr>
<tr>
<td>Summer (JAS)</td>
<td>155 3 19 7</td>
<td>10 25</td>
</tr>
<tr>
<td>Fall (OND)</td>
<td>31 52 3 7</td>
<td>58 10</td>
</tr>
</tbody>
</table>

*Influence* |

- Winter: 60%
- Spring: 58%
- Summer: 40%
- Fall: 20%

*Totals may not sum exactly due to rounding.*
### Flights With 8-Hour Ozone Measured Above Different Cut Points

<table>
<thead>
<tr>
<th>Case</th>
<th>84 ppb</th>
<th>75 ppb</th>
<th>60 ppb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. All*</td>
<td>1.5</td>
<td>3.8</td>
<td>15.1</td>
</tr>
<tr>
<td>2. LFT &gt; BL</td>
<td>0.3</td>
<td>0.5</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. rh &lt; 10%</td>
<td>0.8</td>
<td>1.7</td>
<td>5.1</td>
</tr>
<tr>
<td>all UT/LS (case 3 – almost all natural ozone)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. LFT &gt; BL and rh &lt; 10%</td>
<td>0.2</td>
<td>0.3</td>
<td>2.0</td>
</tr>
<tr>
<td>UT/LS that could lead to exceedances</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Based on only the subset of days which had launches.

- “All” is fraction of flights with LFT ozone > indicated 8-hour ozone level.
- Currently, at least **1.5 flights** per year (actual samples by ozonesondes, not extrapolated) observe eight-hour ozone over 84 ppb which could be due mainly to **transport**.
- Row 3 (case 3) is the minimum number of flight days we would expect to observe exceedances of the 84 ppb 8-hour ozone NAAQS, or other proposed cut points, due to naturally transported ozone alone.
Preliminary Findings

- Seasonal mean profiles suggest local ozone production is more important in summer (JAS) than other seasons, while transport behind frontal passages may be more important in other seasons, particularly spring (AMJ).

- About ~1.5 flights/year, on average, observe ozone aloft that exceeds 84 ppb, which could contribute to elevated BL ozone if it were mixed down to the surface layer. On ~4 days/year, the LFT contains ozone over 75 ppb. Of these, roughly half are associated with UT/LS (natural) ozone.

- In summer, when winds are from the north or east, ozone < 3 km is higher than when winds are from south or west. From 5–10 km, ozone is lower with winds from the west. The strongest vertical gradient in ozone of ~7 ppbv/km from 2.5 – 8.5 km is found for winds from the south. Except for southerly winds, higher ozone is seen in the ML (< 2 km) than just above the ML.

- In spring when winds are calm or from the east, ozone < 2 km is higher than when winds come from south or west.
Further reading


• …and so many more…
Resources

- TCEQ Interim Report:

- Project data: www.imaqs.uh.edu/ozone/ourdata.htm

- Project manager: Dave Westenbarger
dwestenb@tceq.texas.gov
  512/239-0835

- Principal Investigator: Dr. Gary Morris
  Gary.Morris@valpo.edu

- Sponsor at University of Houston: Dr. Barry Lefer
  blefer@uh.edu

Questions?