APPENDIX N

DEMONSTRATION OF TRANSPORT FROM THE HGA OZONE NONATTAINMENT AREA TO DFW

DALLAS/FORT WORTH ATTAINMENT DEMONSTRATION

APRIL 2000 REVISION

Analysis of Impact of Houston Emissions on Dallas-Fort Worth

Executive Summary
August 30, 1999

We have developed a considerable body of evidence that emissions from Houston affect the Dallas-Fort Worth (DFW) area. The most compelling evidence of transport is based on some special modeling runs where we removed all the anthropogenic emissions from the Houston 8-county area to see what difference it would make in the two Dallas episodes. From these Houston-Zero Out runs we see that if HG emissions are removed from the model, significant ozone reductions occur in a plume downwind of the HG area.

- During the 1995 DFW episode, the ozone reduction plume impacts the Austin area by more than 10 ppb. The largest ozone reductions from this HG-zero run occurs in the afternoon, when ozone is normally at a maximum.

- During the 1996 DFW episode, the ozone reduction plume impacts the Tyler-Longview area by more than 10 ppb. The largest ozone reductions from this HG-zero run occurs in the afternoon, when ozone is normally at a maximum.

- A special episode was created with synthetic winds to carry the HG plume directly towards the DFW area. With the synthetic wind package, the ozone reduction plume impacts the DFW area by 5 ppb during the during the evening and morning hours, and by 10 ppb during the afternoon when ozone is at a maximum.

- Modeling with CAMx and Ozone Source Apportionment (OSAT) analysis during the 1996 episode shows that 3-6 ppb of the Dallas ozone comes from HG sources.

We have also developed other supplementary evidence that emissions from Houston affect the Dallas-Fort Worth area. Some of this evidence comes from surface winds and trajectory data, some comes from satellite and aircraft measurements.

- Back trajectories calculated from wind flow during ozone episodes imply that parcels and pollution are carried from Houston. Our analysis shows that more than 13% of the high ozone days have back trajectories that pass near or through the HG area.

- Review of the DFW back trajectories indicates that parcels that pass closer to Houston have higher ozone, and that this relationship is statistically significant ($p=.0001$)

- Actual measurements from satellite and aircraft missions provide strong evidence of the existence of an urban ozone plume downwind of the Houston area.

- During ozone episodes, surface wind directions in the DFW area shift to a more Southeasterly direction, which implies contributions from both the lignite belt and Houston.

Conclusions:

- The HG urban plume does on occasion contribute to the high ozone that occurs in the DFW area.

- The HG urban plume is transported to other areas in Texas and adds to the background concentrations.

Modeling Results after Removing Houston Anthropogenic Emissions

The strongest case for transport is based on some special modeling runs where all the anthropogenic emissions from the Houston 8-county area were removed to determine the impact of HG emissions on the 1995 and 1996 Dallas episodes. We have developed 'movies' for these special modeling cases which show the effect of removing Houston emissions. A briefing to explain these materials and show the 'movies' may be arranged by contacting Pete Breitenbach at 239-1468.

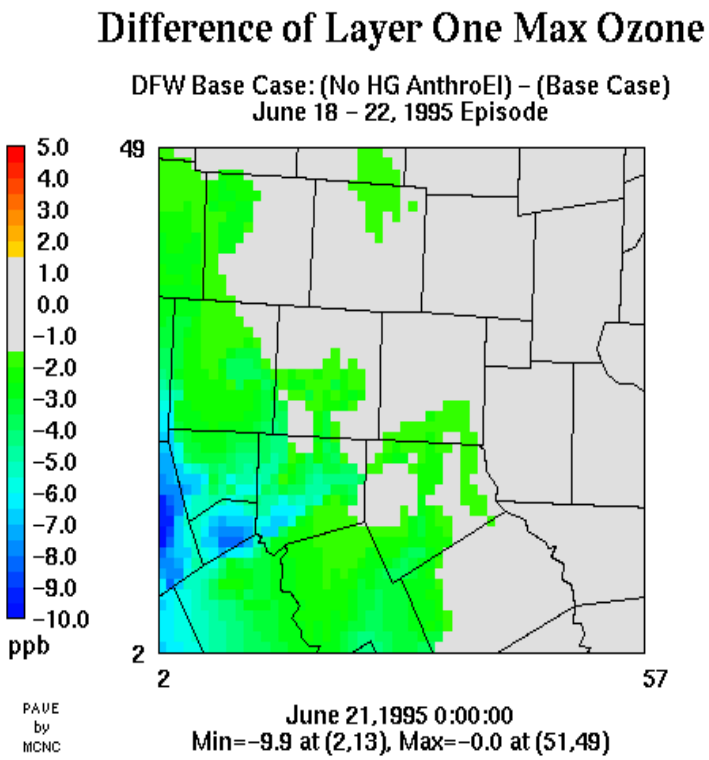
Since we cannot show the movies in this report, we have included some graphic images to illustrate the results of the special modeling test. The left panel on each graphic shows a detailed view of DFW and surrounding counties. The right hand panel includes most of East Texas starting from Houston and covering an area from San Antonio to Dallas to the Tyler-Longview area. Both images are difference plots, with the color indicating the difference in the amount of ozone developed in the area. Red and orange areas indicate areas where ozone is increased because of reduced scavenging in the HG area. Blue and green areas show the ozone reduction plume and the results of removing HG emissions from the transported air mass.

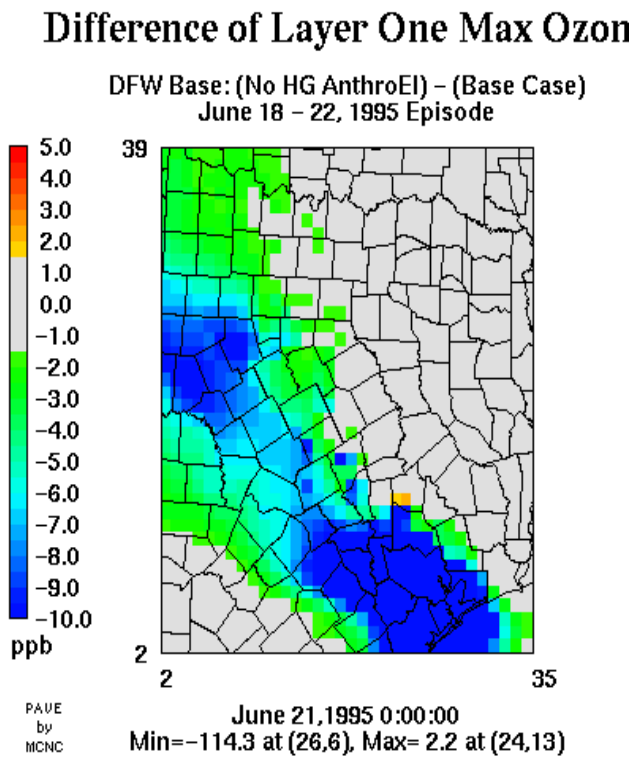
The wind flows differently during the two episodes so the impacts appear in different areas. However, when Houston emissions are removed from the model we see a blue plume indicating an area of reduced ozone concentrations stretching a considerable distance downwind of Houston.

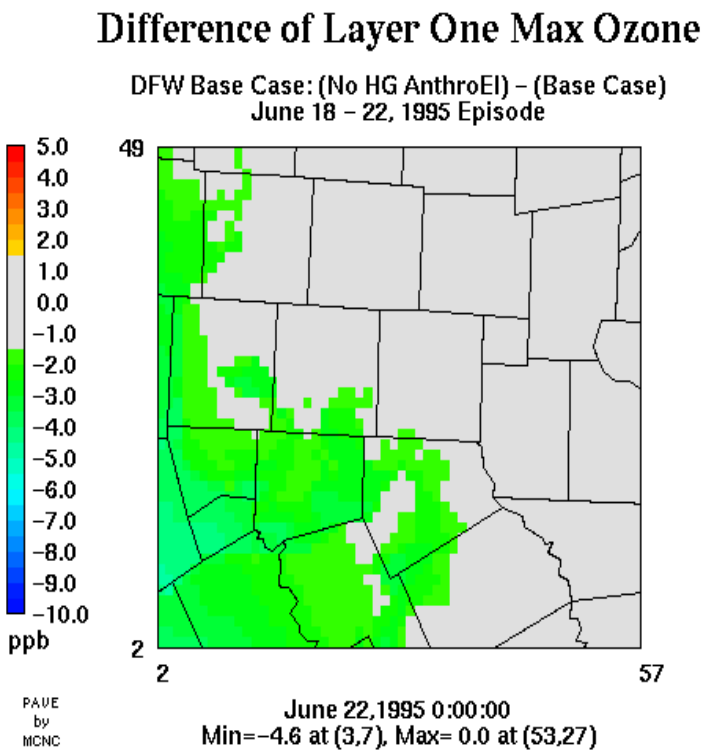
DFW 1995 Episode - During this episode the wind blows from Houston toward Austin on both episode exceedance days (June 21 and 22, 1995). When the Houston emissions are removed, the difference plots show a plume of ozone improvements greater than 10 ppb stretching northwest from Houston to well past Austin.

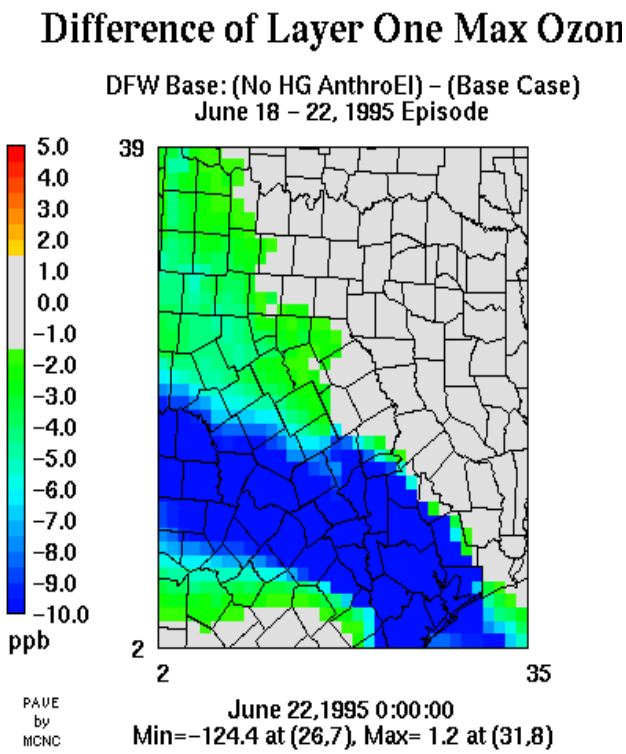
Removal of HG emissions during this episode leads to the following conclusions:

- The afternoon maximum ozone is reduced by 60 - 120 ppb directly downwind of the Houston area.
- Ozone in the Austin area is reduced by as much as 15 ppb depending on time of day.
- Ozone in the Austin area is reduced by 7 ppb during the afternoon ozone peak period.
- There is enough mixing and diffusion during transport that ozone in the DFW area is reduced by approximately 2-3 ppb impact during both days of this episode, even though the wind does not carry the plume directly toward the DFW area.


Difference of Layer One Max Ozone
DFW Base Case: (No HG AnthroEI) – (Base Case)
June 18 – 22, 1995 Episode
5.0
4.0
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
−5.0
−6.0
−7.0
−8.0
−9.0
−10.0
ppb
49
2
2
57
PAVE by MCNC
June 21,1995 0:00:00
Min=−9.9 at (2,13), Max=−0.0 at (51,49)


Difference of Layer One Max Ozon
DFW Base: (No HG AnthroEI) – (Base Case)
June 18 – 22, 1995 Episode
5.0
4.0
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
−5.0
−6.0
−7.0
−8.0
−9.0
−10.0
ppb
39
2
2
35
PAVE by MCNC
June 21,1995 0:00:00
Min=−114.3 at (26,6), Max= 2.2 at (24,13)

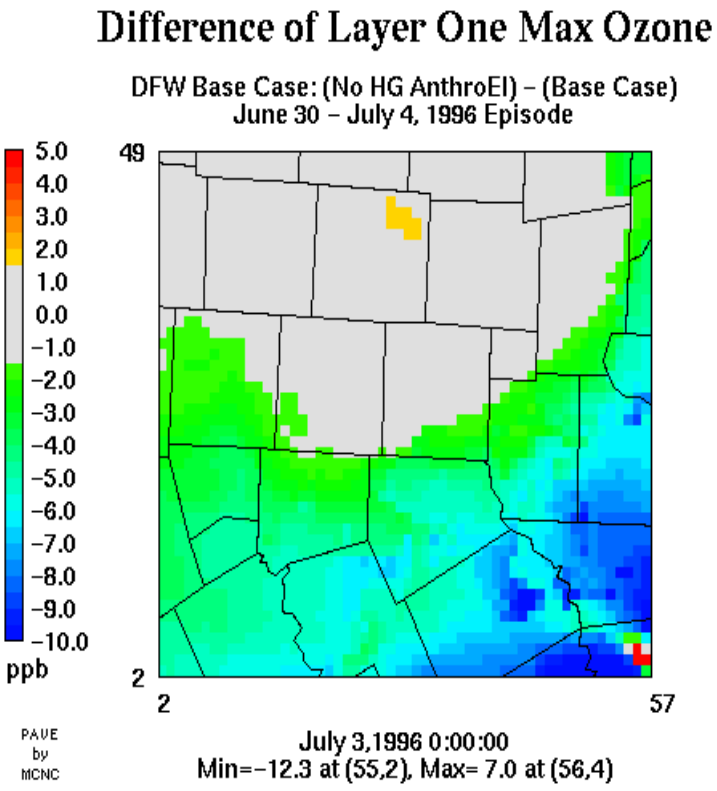

Difference of Layer One Max Ozone
DFW Base Case: (No HG AnthroEI) – (Base Case)
June 18 – 22, 1995 Episode
5.0
4.0
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
−5.0
−6.0
−7.0
−8.0
−9.0
−10.0
ppb
49
2
2
57
PAVE by MCNC
June 22,1995 0:00:00
Min=−4.6 at (3,7), Max= 0.0 at (53,27)

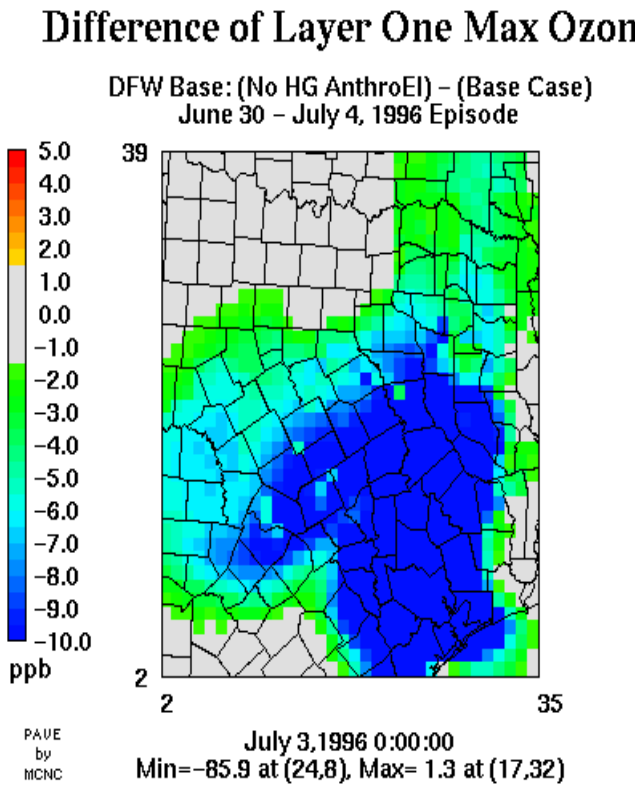

Difference of Layer One Max Ozon
DFW Base: (No HG AnthroEI) – (Base Case)
June 18 – 22, 1995 Episode
5.0
4.0
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
−5.0
−6.0
−7.0
−8.0
−9.0
−10.0
ppb
39
2
2
35
PAVE by MCNC
June 22,1995 0:00:00
Min=−124.4 at (26,7), Max= 1.2 at (31,8)

DFW 1996 Episode - During this episode, the wind meanders slightly but in general blows north from Houston toward Tyler-Longview and Dallas. The difference plots show a plume of ozone improvements greater than 10 ppb stretching from outside of Houston over the Tyler-Longview area. This episode shows significant impacts in the Tyler-Longview area, and minor impacts in the DFW area. During this episode:

Removal of HG emissions during this episode leads to the following conclusions:

- The afternoon ozone is reduced by 80-100 ppb directly downwind of the Houston area.
- Ozone in the Tyler-Longview area is reduced by 2- 22 ppb depending on time of day.
- Ozone in the Tyler-Longview area is reduced by 14-22 ppb during the afternoon peaks.
- The ozone'benefit' plume just touches the Dallas area and shows benefits 2-10 ppb depending on time of day.

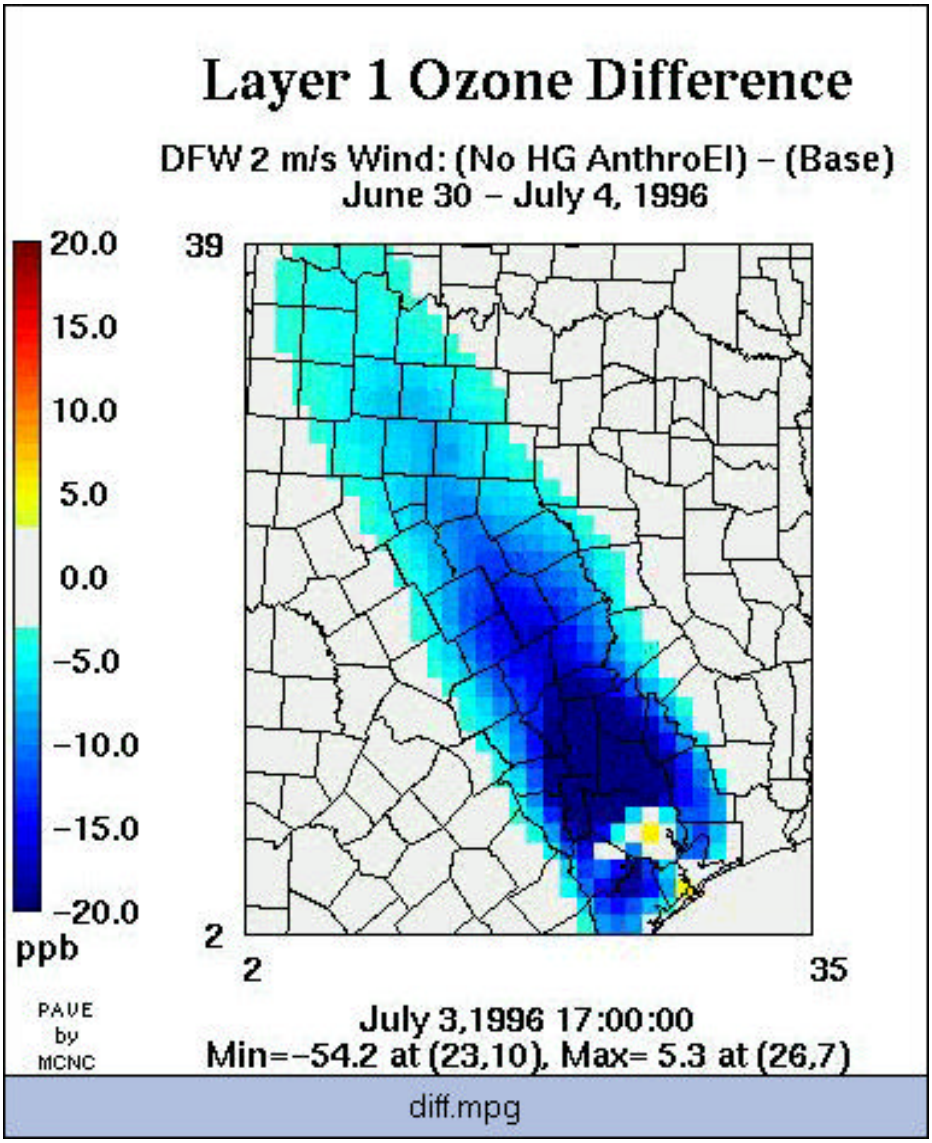




Synthetic Wind - A special case was developed that modified the 1996 episode winds so that they blow directly toward the DFW area. This synthetic wind was combined with the zero Houston emissions and blew steadily at 2 meters/second (approximately 4.5 mph). In this special case the ozone reduction plume stretches directly from Houston toward the DFW area and shows benefits ranging from 5-10 ppb depending upon the vertical mixing, wind shear and time of day.

Removal of HG emissions during this special episode leads to the following conclusions:

- The max ozone is reduced by 50-57 ppb directly downwind of the Houston area.
- A plume of ozone benefits greater than 20 ppb stretches from Houston toward the DFW area.
- Cutting HG emissions during this special episode reduces DFW ozone by as much as 10 ppb during afternoon hours when ozone is normally a maximum.



Ozone Source Apportionment Technology (OSAT) Analysis

The CAMx model includes a module called the Ozone Source Apportionment Technology (OSAT) that allows identifying sources in specific areas and tracking their impact on different areas. This module was used to determine the impact of Houston sources on the DFW ozone concentrations in both the 1995 and 1996 episodes. Overall, the OSAT analysis shows that during the 1995 episode, Houston sources contributed approximately 2 ppb to the Dallas ozone. Similarly, during the 1996 episode approximately 3-6 ppb of the Dallas ozone episode comes from HG sources.

The ribbon plots on the next page show the hourly output from the CAMx/OSAT model run on the 1995 and 1996 Base 4b episodes. The graphs look like a sawtooth since the total ozone varies diurnally during each day of the episode. The colored ribbons identify the amount of ozone produced from each source category. The first three stripes show the impact of initial conditions (red), boundary conditions (green) and biogenic sources (blue). The Houston component is the narrow yellow stripe, and the Beaumont component is orange. The DFW components are brown for Mobile, yellow-green for Area sources and dark green for point sources.

Conclusions from the OSAT runs follow.

The 1995 ribbon plot shows that:

- Houston (yellow) contributes 2-3 ppb to the DFW ozone maximum on days 3, 4 and 5 of the episode.

- Beaumont (orange) contributes 1-2 ppb to DFW on days 2 and 4 of the episode.

The 1996 ribbon plot shows that:

- Houston contributes 2-6 ppb of ozone during the evening hours (when ozone is low).

- Houston contributes 3-6 ppb during the day (when ozone is high) on days 4 and 5 of the episode.

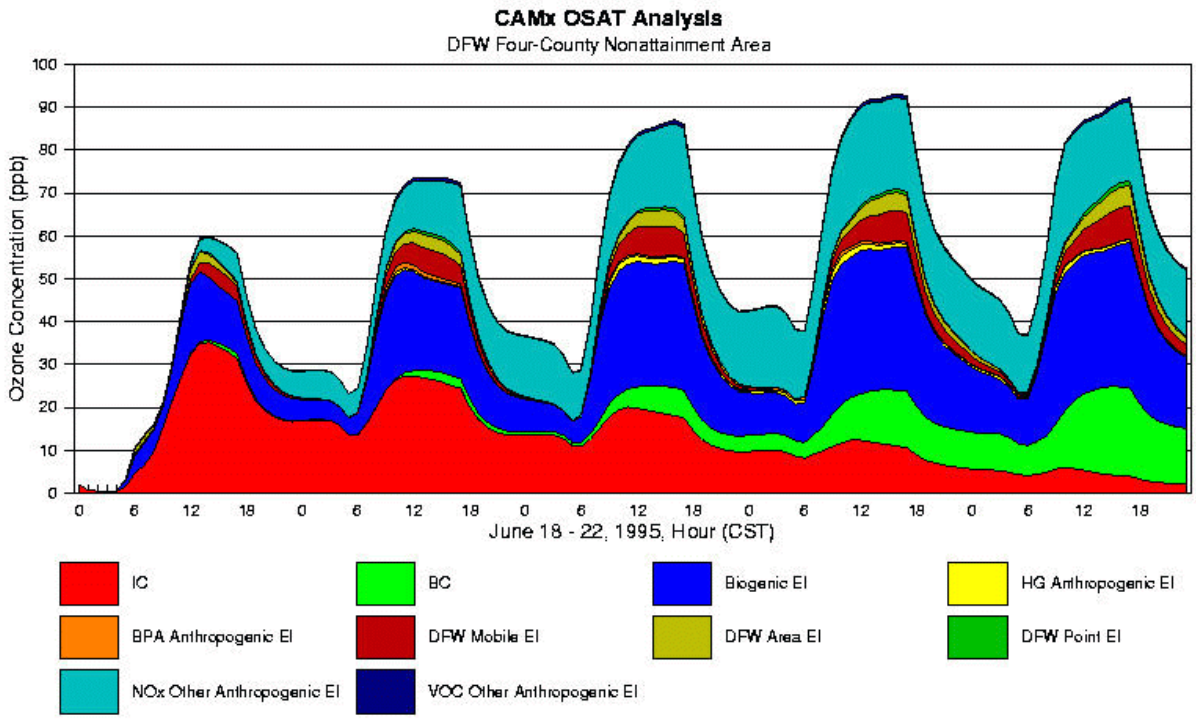
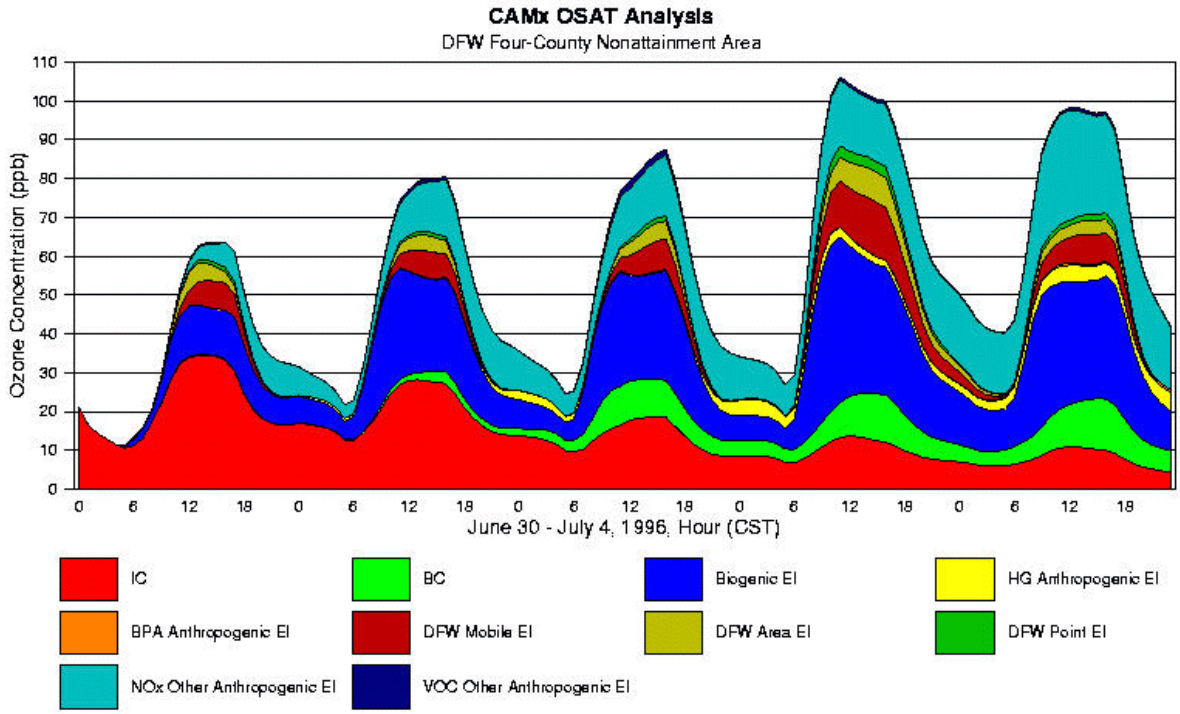

CAMx OSAT Analysis
DFW Four-County Nonattainment Area
Ozone Concentration (ppb)
June 18 - 22, 1995, Hour (CST)
IC
BC
Biogenic EI
HG Anthropogenic EI
BPA Anthropogenic EI
DFW Mobile EI
DFW Area EI
DFW Point EI
NOx Other Anthropogenic EI
VOC Other Anthropogenic EI

Figure 6


CAMx OSAT Analysis
DFW Four-County Nonattainment Area
Ozone Concentration (ppb)
June 30 - July 4, 1996, Hour (CST)
IC
BC
Biogenic EI
HG Anthropogenic EI
BPA Anthropogenic EI
DFW Mobile EI
DFW Area EI
DFW Point EI
NOx Other Anthropogenic EI
VOC Other Anthropogenic EI

Trajectory Evidence of Transport from Houston to Dallas

There is also considerable evidence derived from trajectory analysis indicating the wind blows from Houston toward Dallas in the period leading up to the DFW ozone episodes. Forward trajectories track a parcel from where it starts as it moves forward and determines where the parcel ends up at a later time. In contrast, a back trajectory identifies a final location, and determines where the parcel came from and what path it took to get there.

The first chart shows a map of Texas with 160 back trajectories constructed for all the high 1-hour and 8-hour ozone days that occurred between 1994 and 1998. High ozone was defined as any day on which a monitor in the DFW area recorded a daily one hour maximum at or above 125 ppb or a daily eight-hour average maximum at or above 85 ppb. The chart shows the trajectories of parcels that terminate in DFW at 500 meters which is roughly the middle of the transported layer. This chart shows that air parcels can come from practically any direction, but they generally do not come from the West and NW. Trajectories on high ozone days are much more likely come from the NE through East and South directions.

Initially, 160 DFW exceedance days from the 1994-1998 period (with either an 1-hour and 8-hour at a DFW monitor) were identified and analyzed with back trajectories. Of those 160 days days, 13% (21 of them) passed by or through the upper gulf coast area. This establishes a lower limit to the frequency with which Houston affects DFW high ozone levels of 13 percent. Because transport can extend over a period of several days, the actual frequency may be much higher.

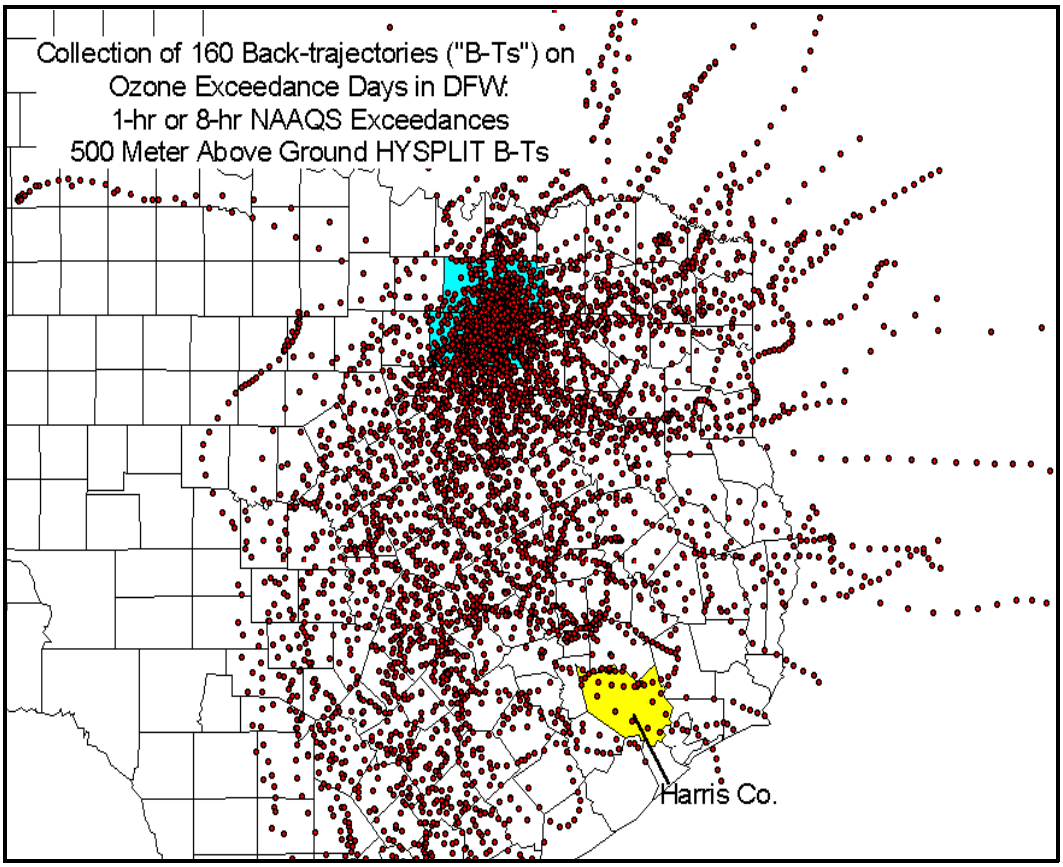
Additional statistical and mathematical analysis has been done to determine the relationship between the HG source region and DFW ozone concentrations. In a study done by Tom Sager at UT Austin, approximately 22% of the trajectories come within 100 miles of Houston. Parcels that spend more time within 100 miles of Houston have higher ozone. A regression equation based on how close the back trajectories approach Houston indicates that parcels that pass nearer to Houston have higher ozone, and that this relationship is statistically significant ($p=.0001$).

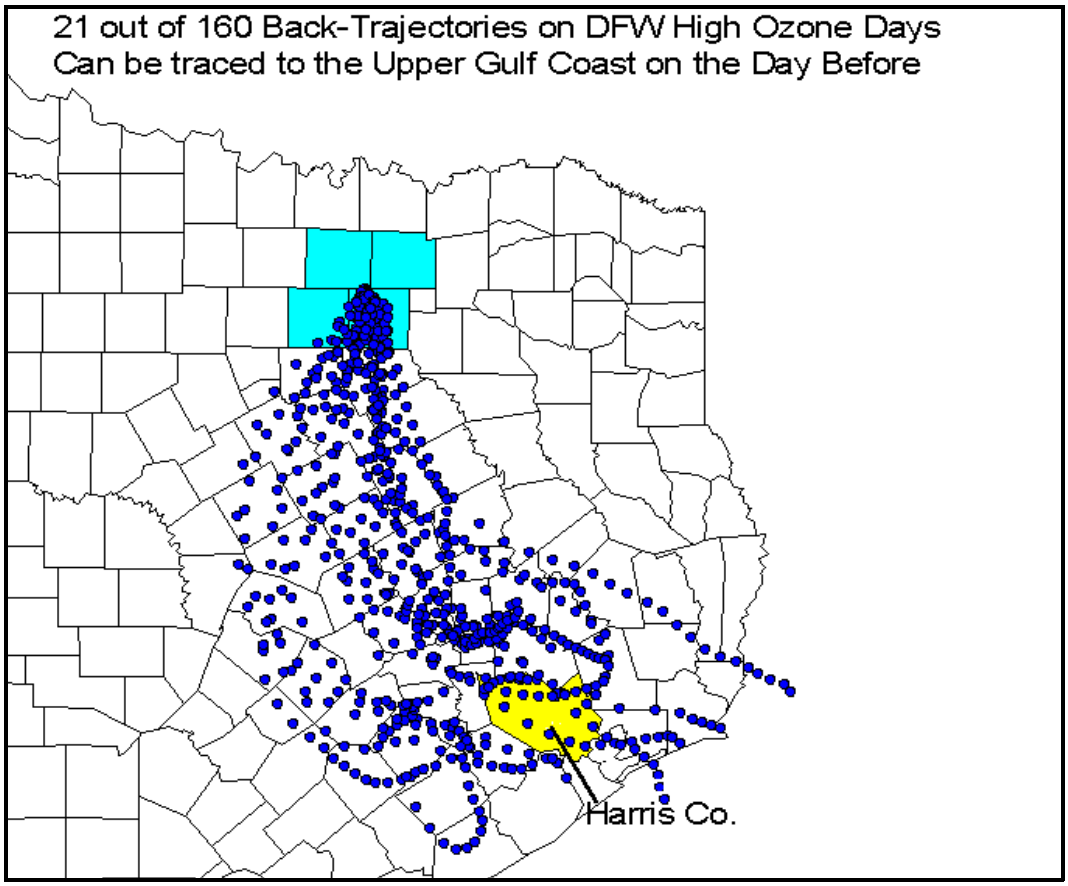
Conclusions from trajectory analysis:

- Back trajectory analysis for ozone episodes and parcels near the DFW area indicates that the air comes most frequently from the NE through East and South directions.

- Between 13% and 22 % of the DFW ozone events can be traced back to the HG area.

- Review of the DFW back trajectories indicates that parcels that spend longer periods and pass closer to Houston have higher ozone.


Collection of 160 Back-trajectories ("B-Ts") on
Ozone Exceedance Days in DFW:
1-hr or 8-hr NAAQS Exceedances
500 Meter Above Ground HYSPLIT B-Ts
Harris Co.

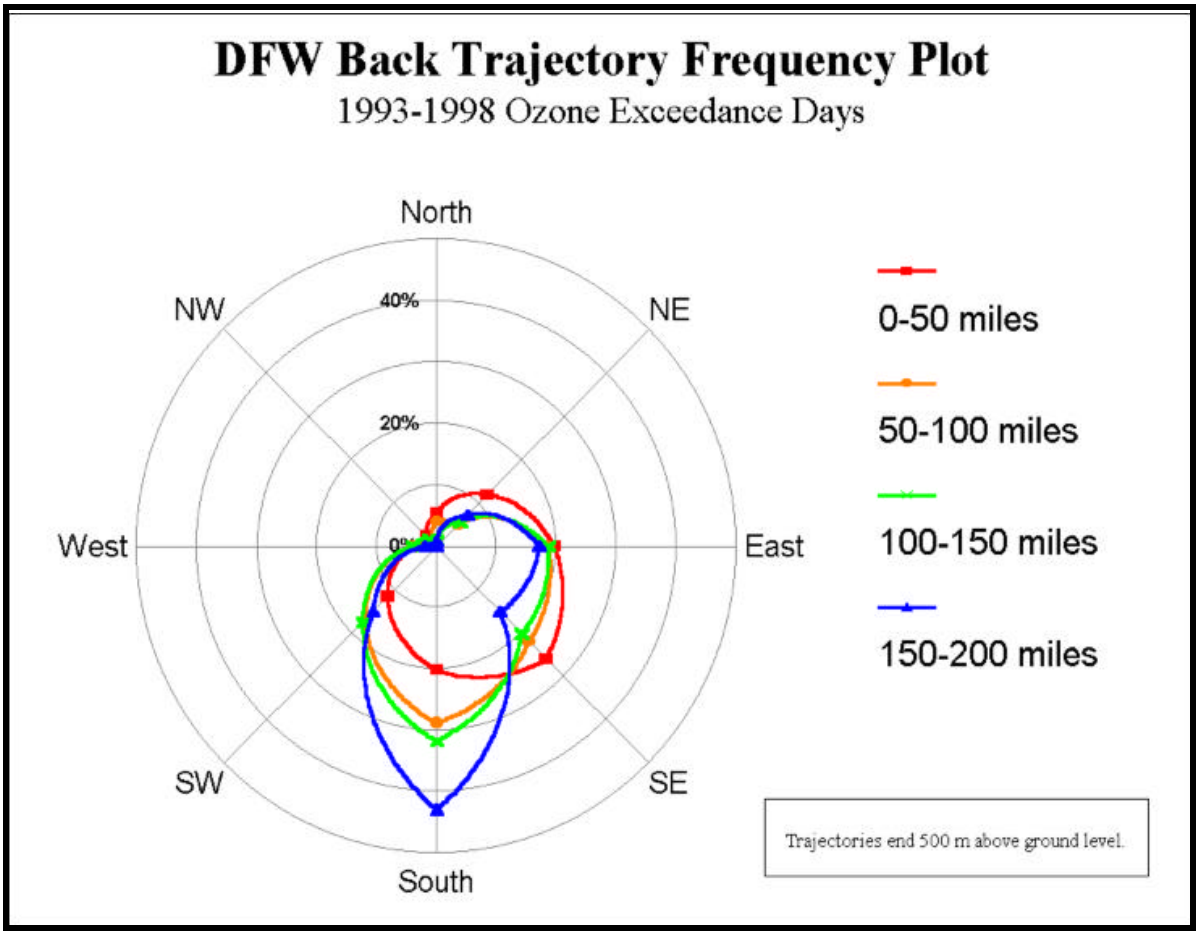

21 out of 160 Back-Trajectories on DFW High Ozone Days
Can be traced to the Upper Gulf Coast on the Day Before
Harris Co.

Additional Back Trajectory Analysis

Another frequency analysis of the same back trajectory data is shown on the bottom of this page. For this chart, the hourly location data was segregated by distance into categories, and then evaluated by direction. The number of points associated with each distance and direction was determined, and the percentages developed into a composite frequency chart. The chart shows that when parcels are within 50 miles of DFW (red) they are most likely to come from the SE. At longer distances 100-200 miles, the trajectories tend to come more frequently from the south. However, even at 100-200 miles (which is well beyond the lignite belt) 15-20 % of the high ozone trajectories come from the SE, implicating the Houston area.

Conclusions:

- At longer distances from DFW the trajectories tend to shift to a more southerly direction.
- However, even at ranges of 100-200 miles 15-20 % of the high ozone trajectories come from the SE, implicating the Houston area.



Satellite and Aircraft Data

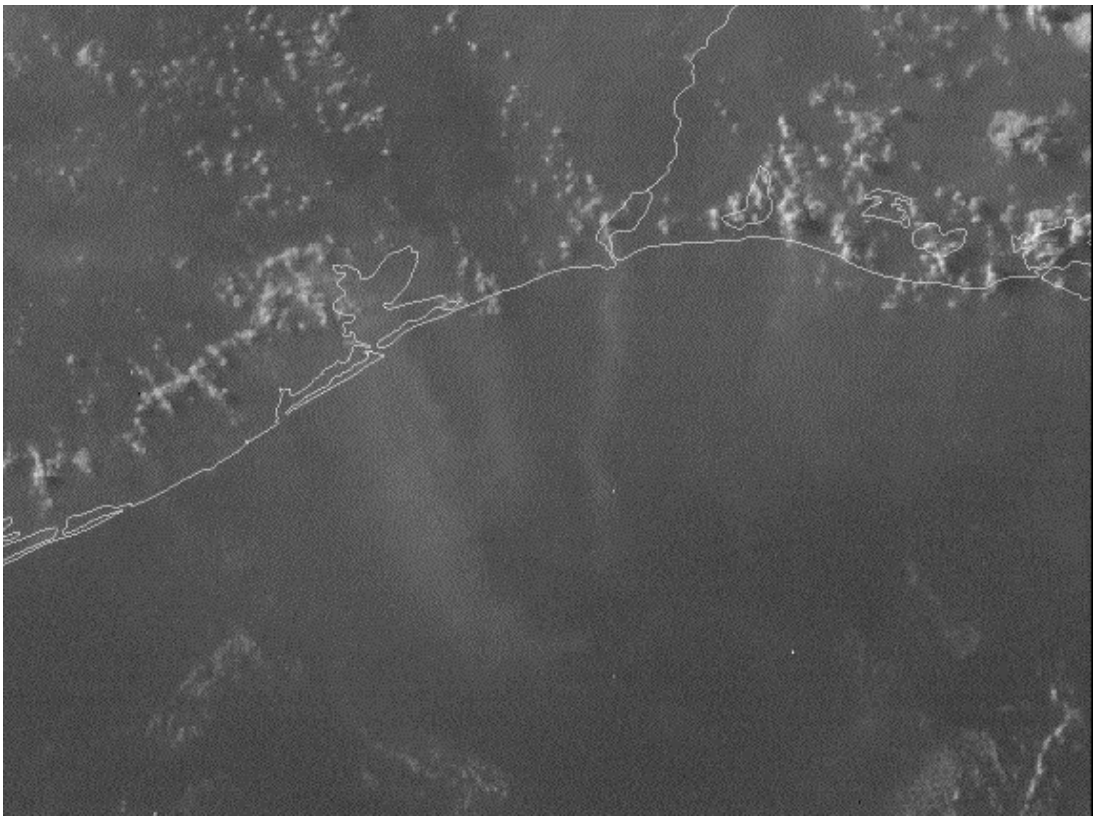
There is considerable evidence in the literature indicating the existence of urban plumes. Both the Southern Oxidants Study (SOS) and the Ozone Transport Assessment Group (OTAG) have concluded that transport of ozone and precursors was a significant factor in regional ozone. Given the amount of mobile source traffic and the size of the petrochemical industry in Houston, it is obvious that an urban plume should exist. So far no formal evidence of a Houston plume has been developed. However, we have strong evidence of such a plume from satellite data and aircraft measurements.

Figure 1 shows a visual satellite image of the Houston area taken on June 11, 1997. On this day the winds blew from the NW, and carried the Houston urban plume out into the Gulf of Mexico. Also visible in this image are plumes coming from Beaumont and Lake Charles. Figure 2 is a photographic enhancement of Figure 1, making the plumes easier to see. Normally, urban plumes over land areas are difficult to see in satellite data because there is little contrast between the plume and the surface underneath. However, since the winds on this day carried the plume out over water, the plumes are quite visible.

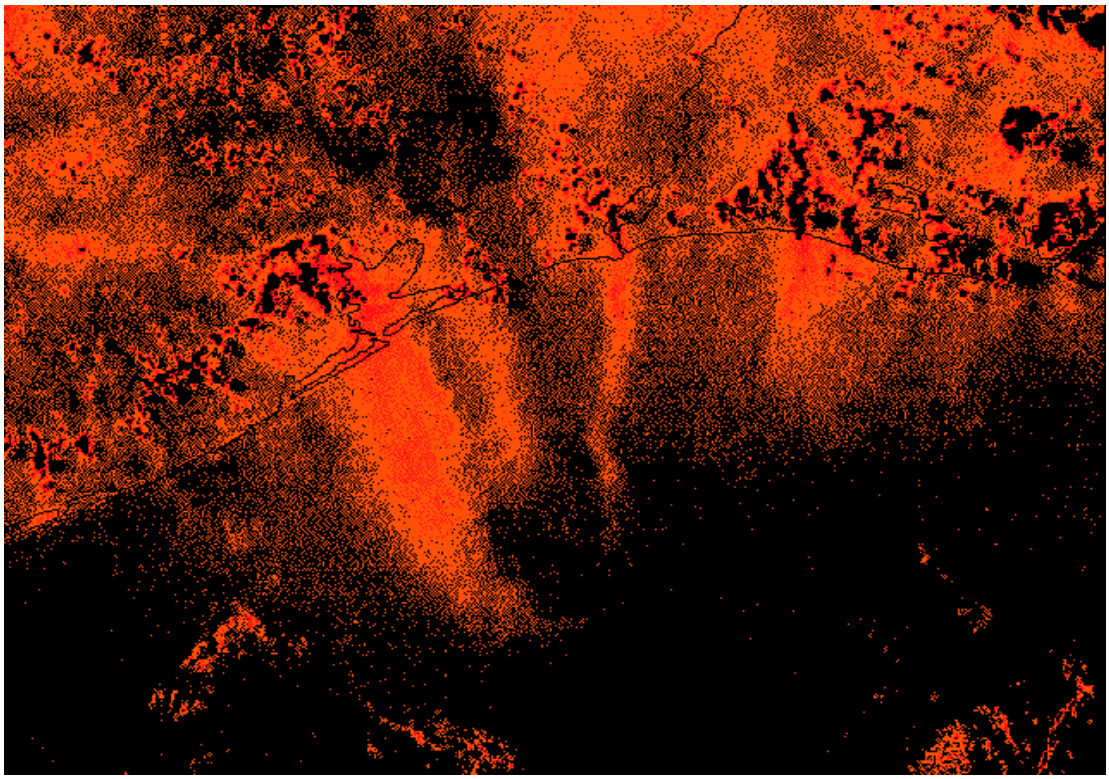
We also have data from a Baylor aircraft mission on the same day, June 11, 1997, which verifies that the visual plume also has high ozone. Figure 3 shows the flight path of the aircraft over land and over water during this mission. The early portions of the mission were flown over land areas, later on the aircraft flew off shore and did a vertical spiral. Data from the early portion of the mission indicate relatively low concentrations (blue and green traces) of ozone over land, and substantially higher concentrations (magenta and red traces) of ozone over the city and offshore. Figure 4 shows the maximum ozone concentrations measured on the surface at Houston CAMS stations that day, corroborating the plume ozone measurements made by the aircraft at 2000 feet. Additional support materials are available showing the ozone concentrations measured during the entire mission, but these are not included in this document.

Conclusions:

- An ozone plume extends downwind of the Houston urban area. The impact on other cities and areas of Texas depends upon the wind direction each day.

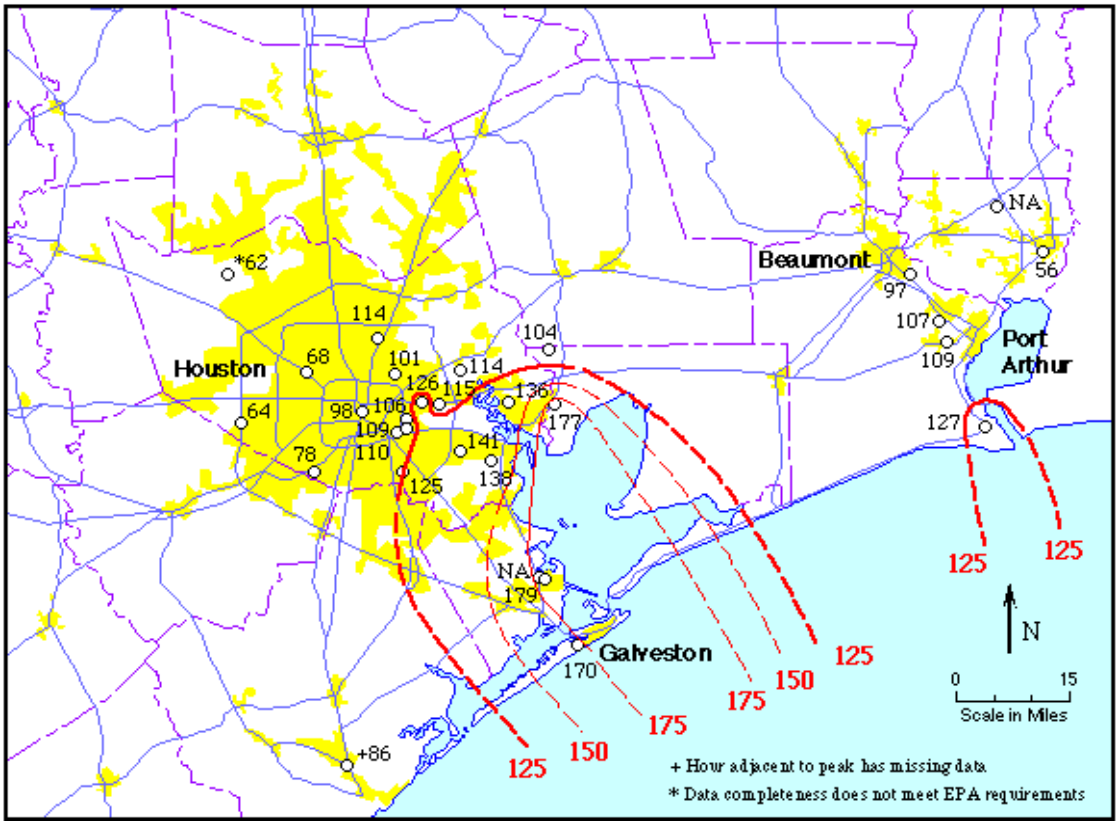


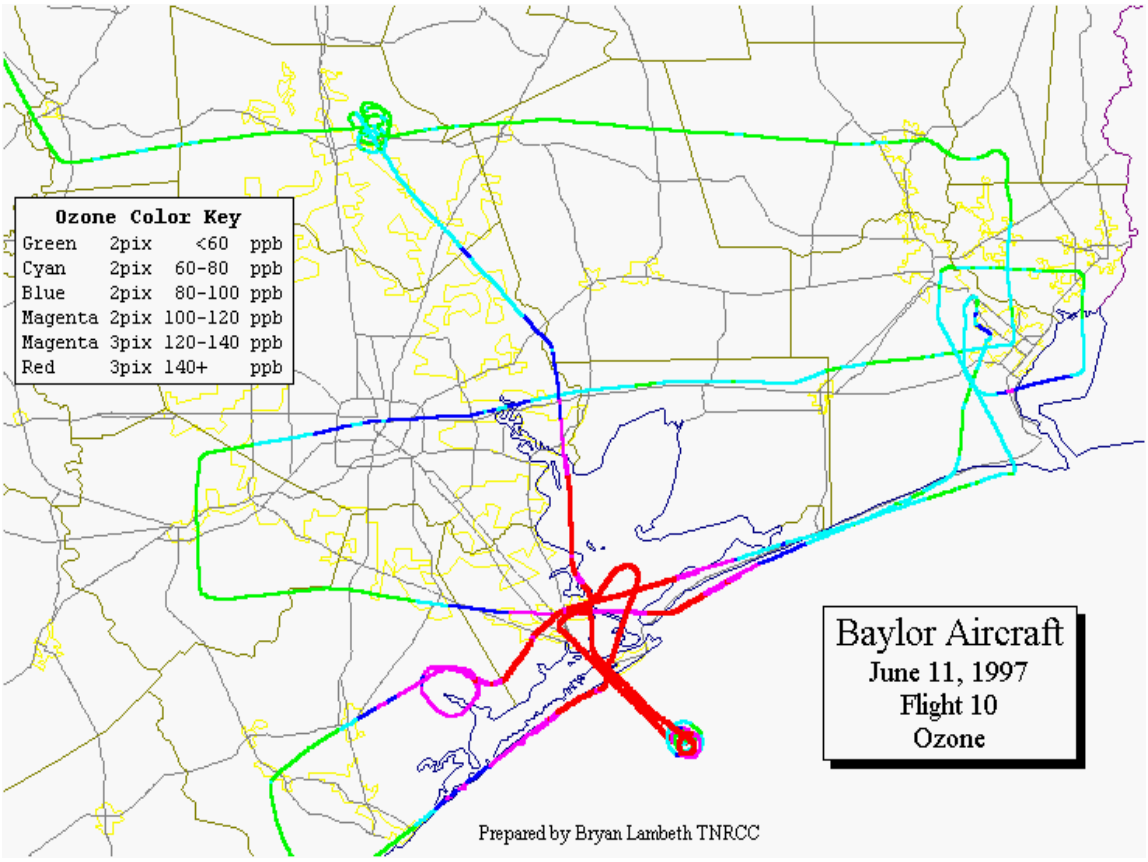
Visual Satellite Image from June 11, 1997



Enhanced Satellite Image from June 11, 1997

Peak One-Hour Ozone Averages (ppb) in the Houston - Beaumont Area 6/11/97





Surface Wind Analysis for DFW Area

Analysis of surface wind data during ozone episodes implies transport from Houston. In his masters thesis, Tim Nobis analyzed the DFW airport winds during both ozone days and non ozone days. His data is presented below in graphical form. The first graph shows a "wind rose" which is the conventional meteorological tool for displaying wind data. The blue trace shows the relative frequency (%) for each wind direction based on everyday winds. It shows clearly that the most frequent wind direction during ordinary days is from the south.

In contrast, the red data and red trace shows the frequency of wind directions during 1-hour ozone episodes. The text indicates that during ozone episodes, calm winds increase in frequency from 10% to 39% of the time. The wind rose indicates that during ozone episodes winds from the East - SE increase in frequency. In contrast, winds from the SSE through south decrease in frequency. Nevertheless, winds from the SSE still occur approximately 10% of the time, which implicates all the sources SSE of Dallas, including Houston.

The second graph shows the same data in bar graph form to make it easier to read the relative frequencies. Clearly, winds from the East-Southeast occur more frequently during ozone episodes, winds from the south decrease, and the number of calms increase dramatically.

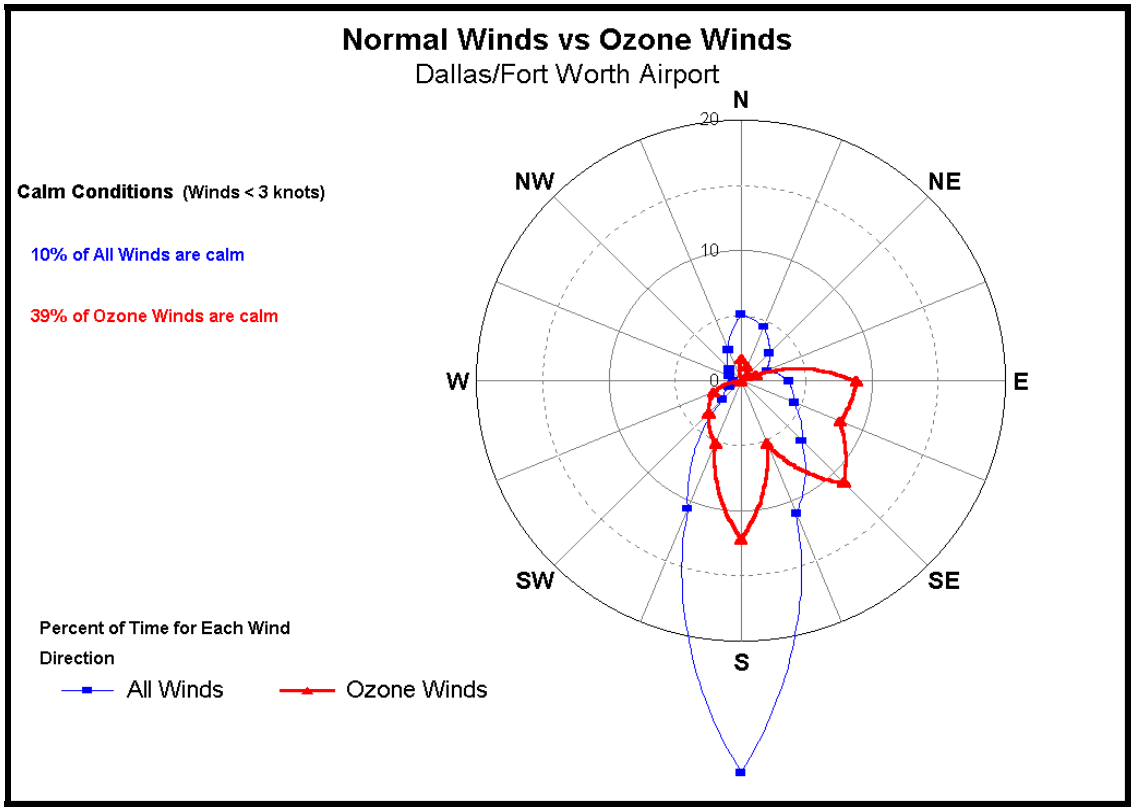
The following page shows a wind direction analysis performed by TNRCC staff for the DFW area for 8-hour ozone exceedance days. The analysis reviewed the morning and the afternoon average wind directions at DFW CAMs stations for both ozone and non-ozone days. The polar chart shows the relative frequency of wind direction in morning and afternoon for both non-ozone and ozone days. For non-ozone days morning winds tend to come from the S and SSW, shifting to the SSE and S in the afternoon.

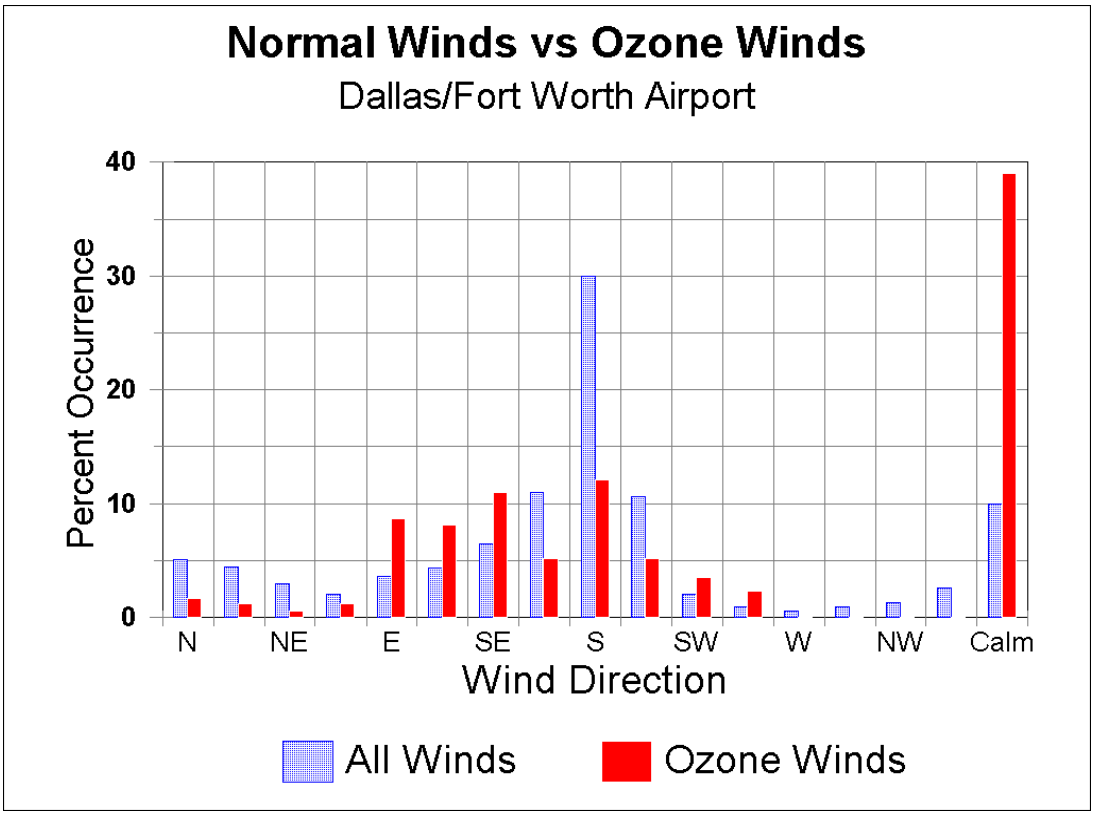
On ozone days, calm winds and light winds (as indicated by the narrow white and blue bars) are much more frequent. Also, during the morning on ozone days the surface winds are more variable in direction, but they almost never come from the north. However, during the afternoon on ozone days, the winds surface winds shift to the SSE and SE.

Conclusions:

- During ozone episodes, calm winds and light winds occur more frequently, and

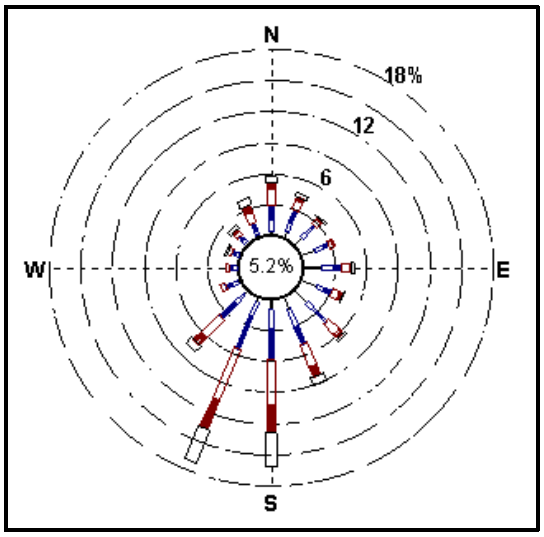
- Surface wind directions in the DFW area shift to a more southeasterly direction, which implies contributions from all the sources SE of DFW, including Houston.


Normal Winds vs Ozone Winds
Dallas/Fort Worth Airport
Calm Conditions (Winds < 3 knots)
10% of All Winds are calm
39% of Ozone Winds are calm
N
NE
E
SE
S
SW
W
NW
20
10
0
Percent of Time for Each Wind Direction
All Winds
Ozone Winds

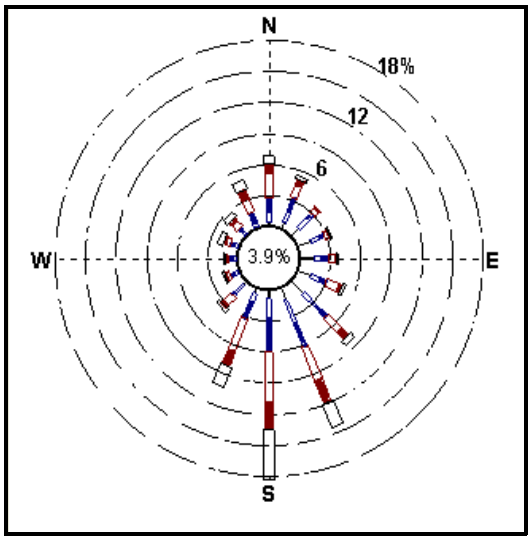

Normal Winds vs Ozone Winds
Dallas/Fort Worth Airport
Percent Occurrence
40
30
20
10
0
N
NE
E
SE
S
SW
W
NW
Calm
Wind Direction
All Winds
Ozone Winds

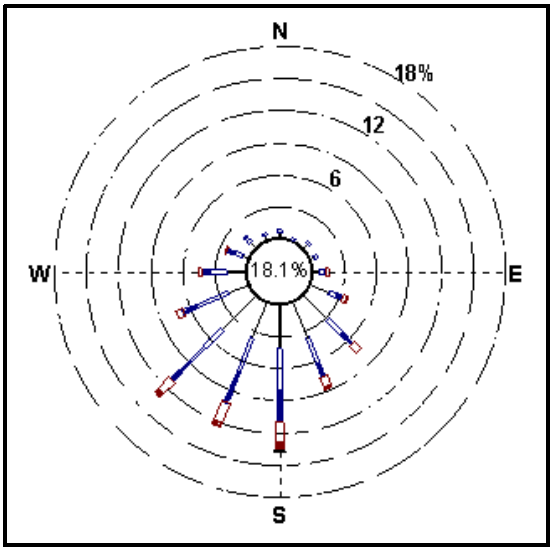
Dallas Wind Roses

Low Ozone Morning

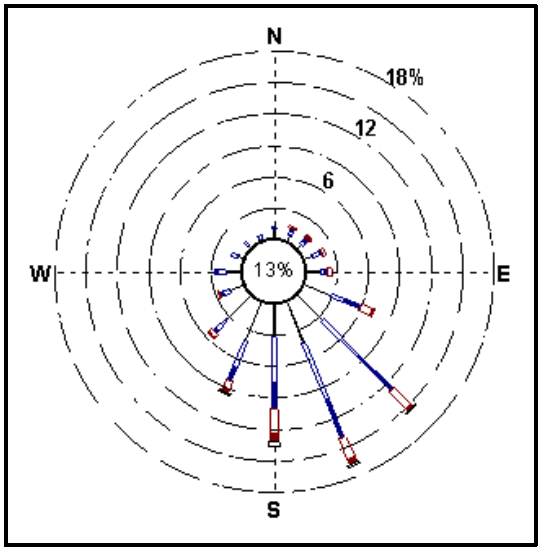


Low Ozone Afternoon





High Ozone Morning



High Ozone Afternoon