

ENCLOSURE 4

ENVIRON

MEMORANDUM

To: NETAC Technical Committee

From: Till Stoeckenius, Greg Yarwood, Sue Kemball-Cook

Date: December 29, 2004

Subject: Analysis of high ozone events in NE Texas during 2004.

INTRODUCTION

NE Texas (NE Texas), while no longer in violation of EPA's ambient air quality standard for ozone, continues to experience days during the warm weather season on which ozone concentrations exceed levels designated by EPA as "unhealthy for sensitive groups". In addition, recent data indicate that a violation of the ozone standard remains a possibility if the area were to experience a string of unfavorable weather conditions during upcoming ozone seasons. As a result, understanding the conditions associated with, and likely causes of, recent high ozone events in this area remains of central importance to state and local air quality planners.

This memo presents our analysis of factors contributing to nine high ozone events observed in NE Texas during the 2004 season. For each day, we analyzed hourly ambient air quality and meteorological data, computed back trajectories and collected day-specific emissions data from major sources in the region. We begin with a brief summary of recent ozone trends and a summary of peak ozone concentrations during the nine days included in our analysis. This is followed by a detailed discussion of the conditions during each day. A summary of results and our conclusions are presented in the final two sections of this memorandum.

Recent Ozone Trends

Trends in 8-hour average ozone concentrations relative to the National Ambient Air Quality Standard for the past ten years at the Longview and Tyler air monitoring sites in NE Texas are illustrated in Figure 1. Relative to historical levels, ozone concentrations have remained relatively low in NE Texas since 2001 with no obvious trend over the past four years in either the number of exceedance days or the annual fourth highest concentration.

Recent 8-hour ozone design values (defined by EPA as the average, over a three year period, of the annual fourth highest daily maximum 8-hour average ozone concentration) at monitoring sites in NE Texas are listed in Table 1. The last violation of the standard occurred during the 2000 – 2002 period; the most recent monitoring data show the area to be in attainment for the 2002 – 2004 period.

Table 1. Eight-Hour ozone design values (ppb) at monitoring sites in N Texas.

Period	Longview	Tyler	Karnack
2000-2002	88	84	NA
2001-2003	82	81	84 ¹
2002-2004 ²	83	80	81

OVERVIEW OF HIGH OZONE EVENTS IN 2004

Despite the fact that NE Texas remained in attainment of the ozone standard in 2004, some instances of elevated ozone were observed in the area on several days during the past season as has been the case in previous years. The daily maximum 8-hour and 1-hour ozone concentrations during June – September 2004 are illustrated in Figures 2 and 3, respectively. Of particular note are the nine high ozone days listed in Table 2, which include five days on which the 8-hour standard was exceeded.³ The 8-hour exceedances (concentrations greater than or equal to 85 ppb) were recorded only at Longview, Karnack and Tyler but relatively high values were also recorded at Panola where the 1-hour ambient standard level was nearly exceeded on 3 August. The 3 August event at Panola represents the maximum 1-hour ozone concentration recorded in NE Texas in 2004: there were no actual exceedances of the 1-hour ozone standard (a 1-hour exceedance requires a concentration of 125 ppb or higher).

This memo presents a descriptive analysis of the air quality data, meteorological conditions and point source emissions during the nine days listed in Table 2.

Table 2. High ozone events in NE Texas in 2004 (as of 4 November 2004; data from <http://www.tnrcc.state.tx.us/air/monops/index.html>).

Date	Max 8-hr Avg		Max 1-hr Avg	
	Value (ppb)	Location	Value (ppb)	Location
23 June	71	Longview (C19)	118	Longview (C19)
19 July	85	Longview (C19)	112	Longview (C19)
20 July	83	Longview (C19)	107	Longview (C19)
3 August	104	Longview (C19)	120	Panola (C627) ⁴
10 August	86	Longview (C19)	107	Longview (C19)
17 August	85	Karnack (C85)	89	Karnack(C85)
10 September	91	Tyler (C82)	103	Tyler (C82)
29 September	84	Tyler (C82)	98	Longview (C19)
1 October	81	Tyler (C82)	90	Karnack (C85)

¹ Based on annual fourth highest for 2002 – 2003.

² 2002-2004 design values are preliminary pending data QA by TCEQ.

³ Exceedances shown in red in Table 2 are the only recorded exceedances of the National Ambient Air Quality Standard for ozone in NE Texas in 2004 (as of 4 November).

⁴ Max 1-hour at Longview was 116 ppb.

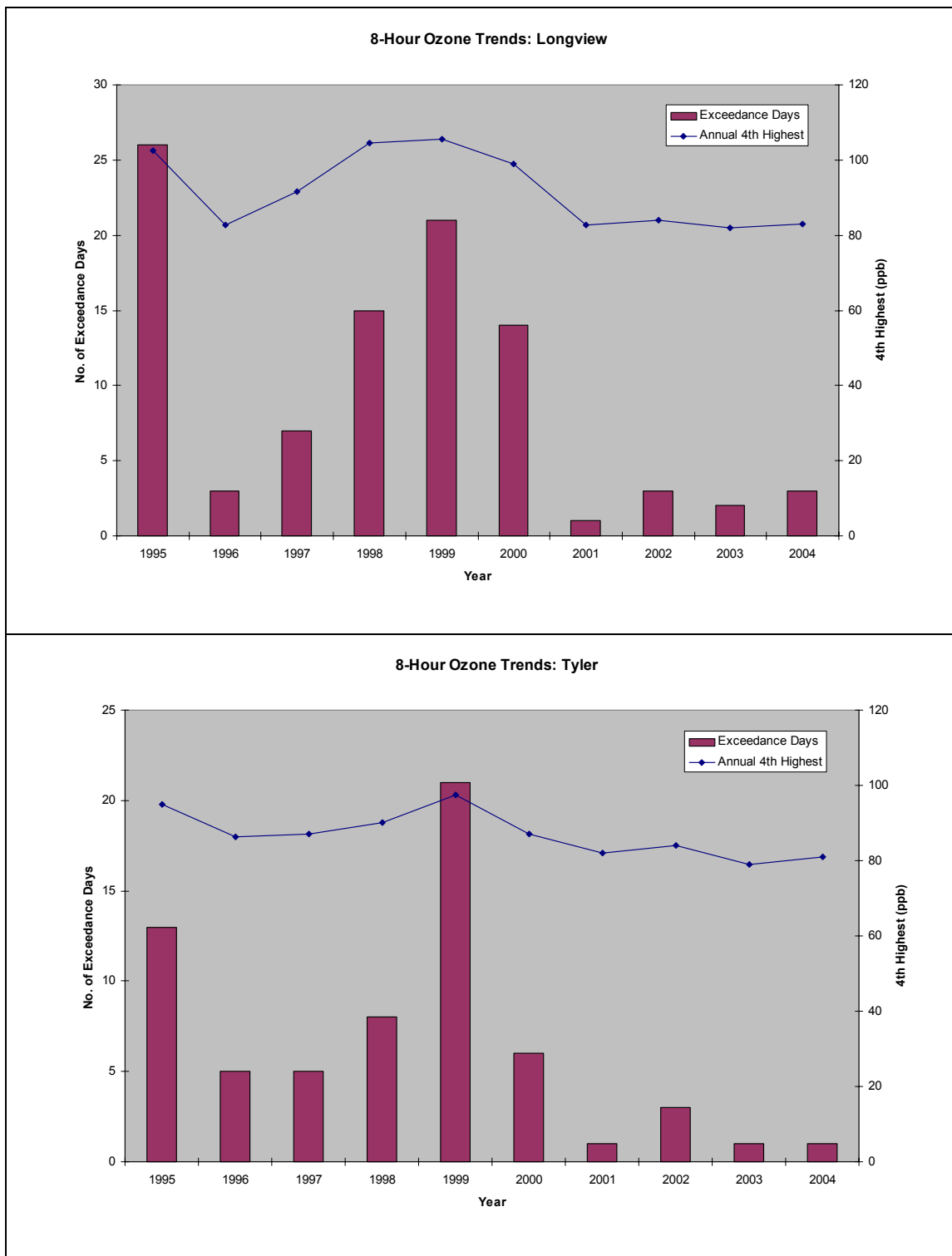


Figure 1. Trends in the number of recorded days on which the daily maximum 8-hour average ozone concentrations exceeded the level of EPA’s ambient standard (bars) and in the value of the annual fourth highest daily maximum 8-hour average (line) at Longview (top) and Tyler (bottom).

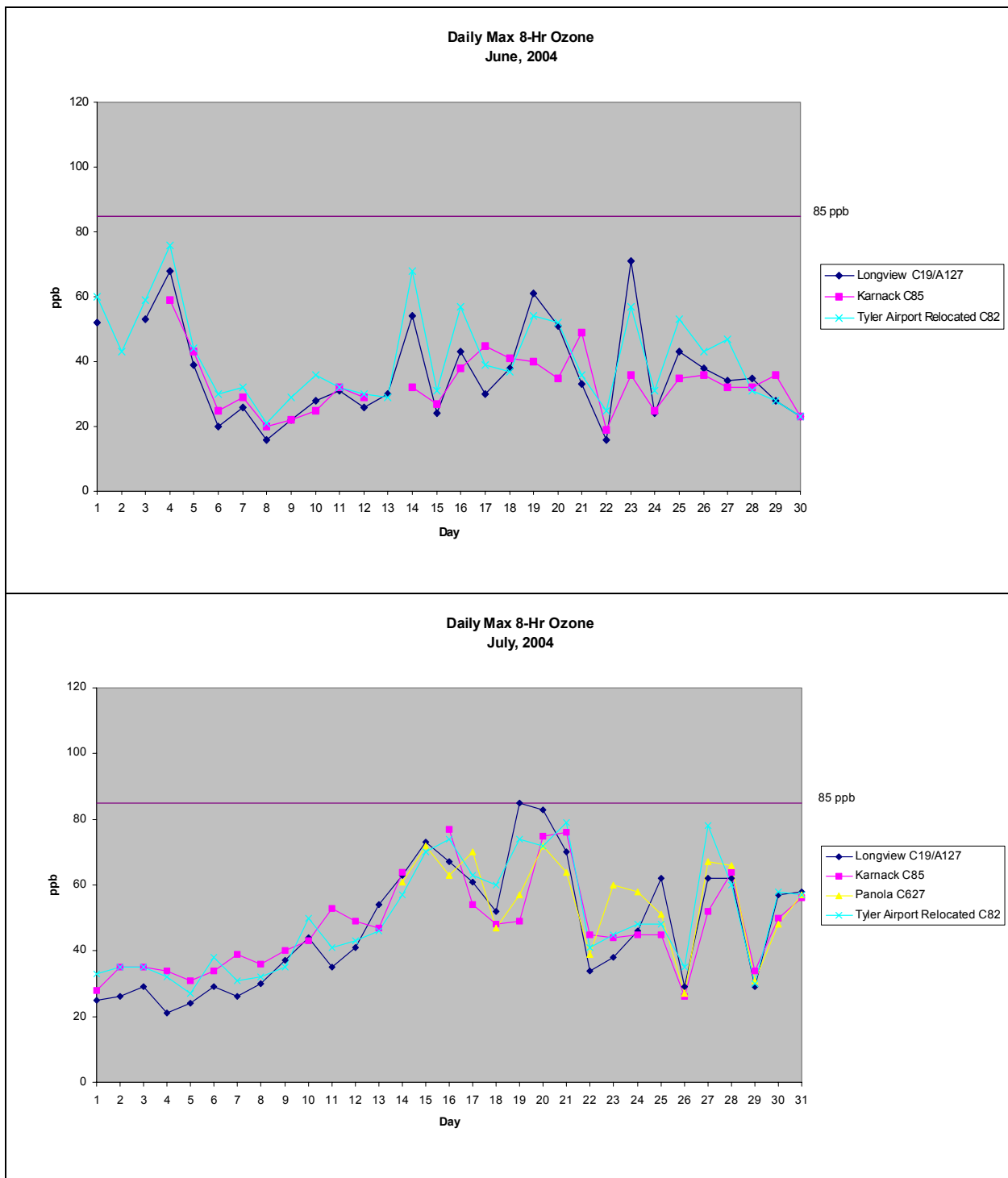


Figure 2(a). Daily maximum 8-hour ozone concentrations in June and July, 2004.

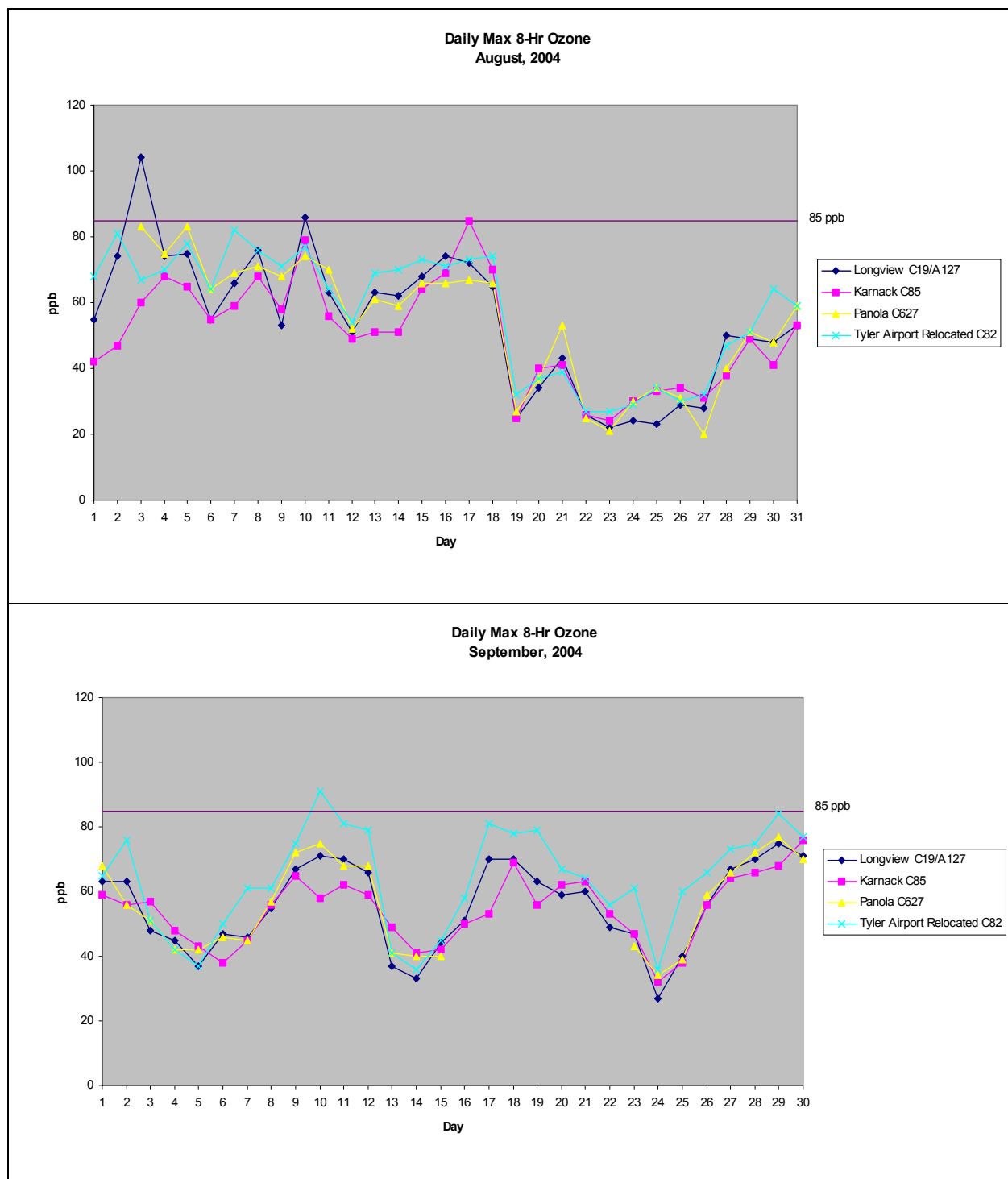


Figure 2(b). Daily maximum 8-hour ozone concentrations in August and September, 2004.

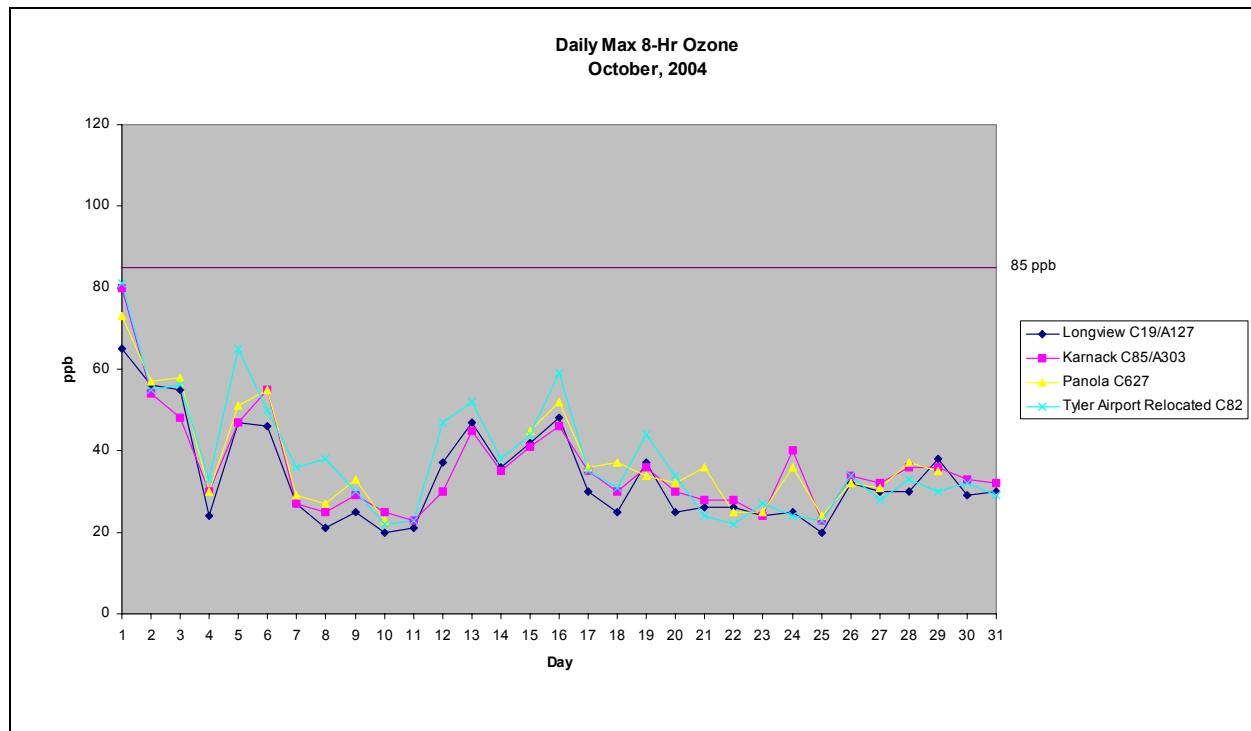


Figure 2(c). Daily maximum 8-hour ozone concentrations in October, 2004.

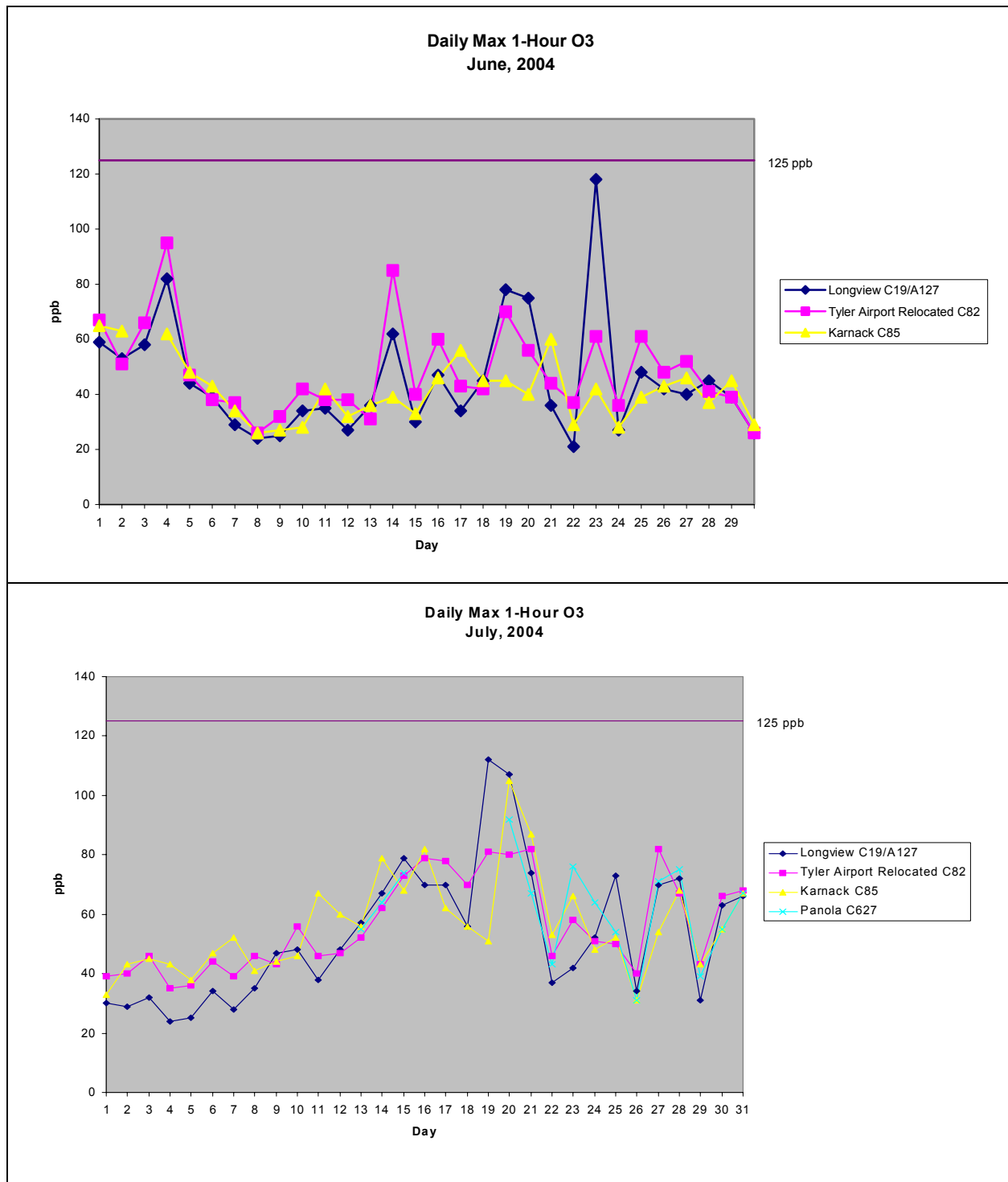


Figure 3(a). Daily maximum 1-hour ozone concentrations in June and July, 2004.

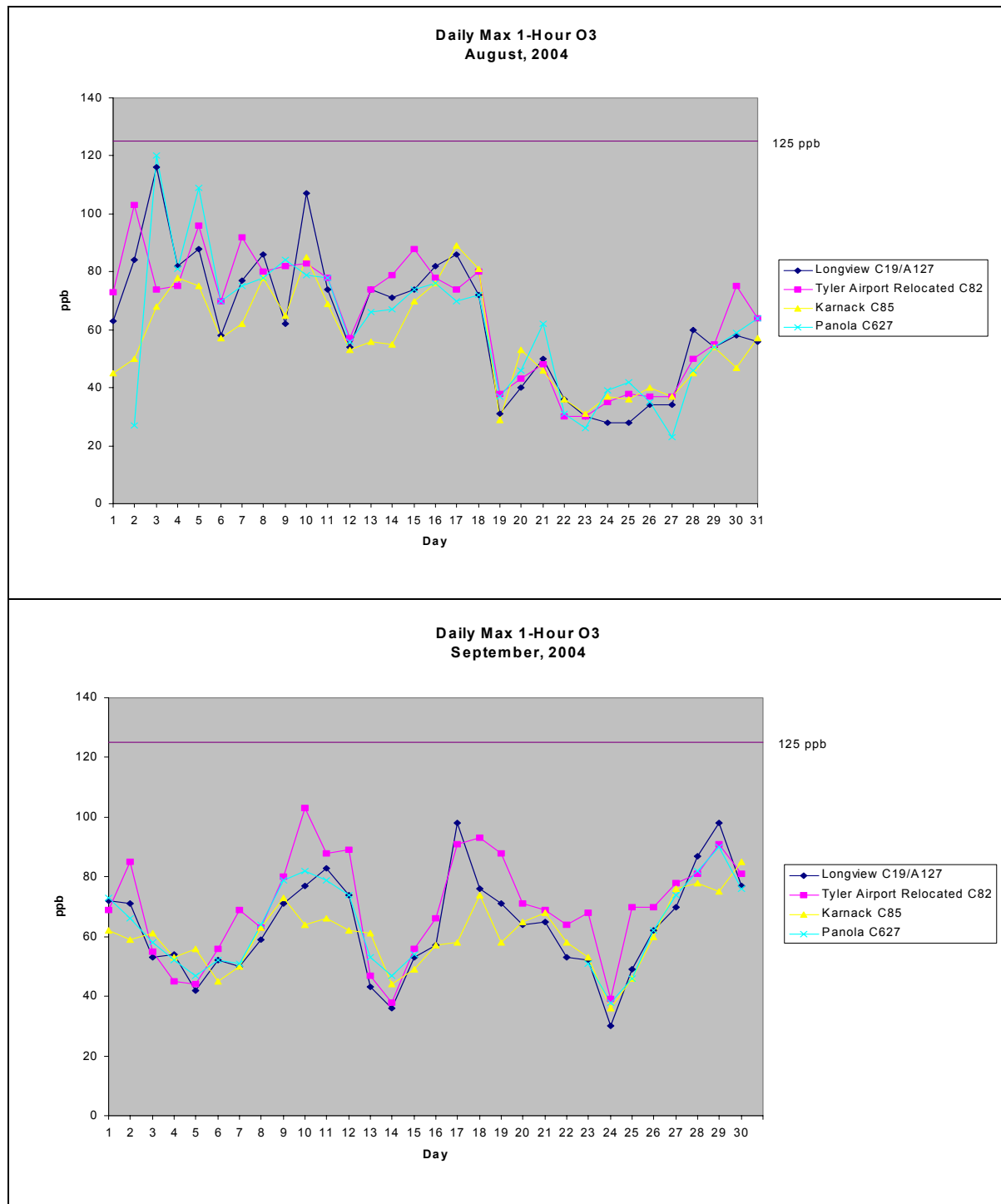


Figure 3(b). Daily maximum 1-hour ozone concentrations in August and September, 2004.

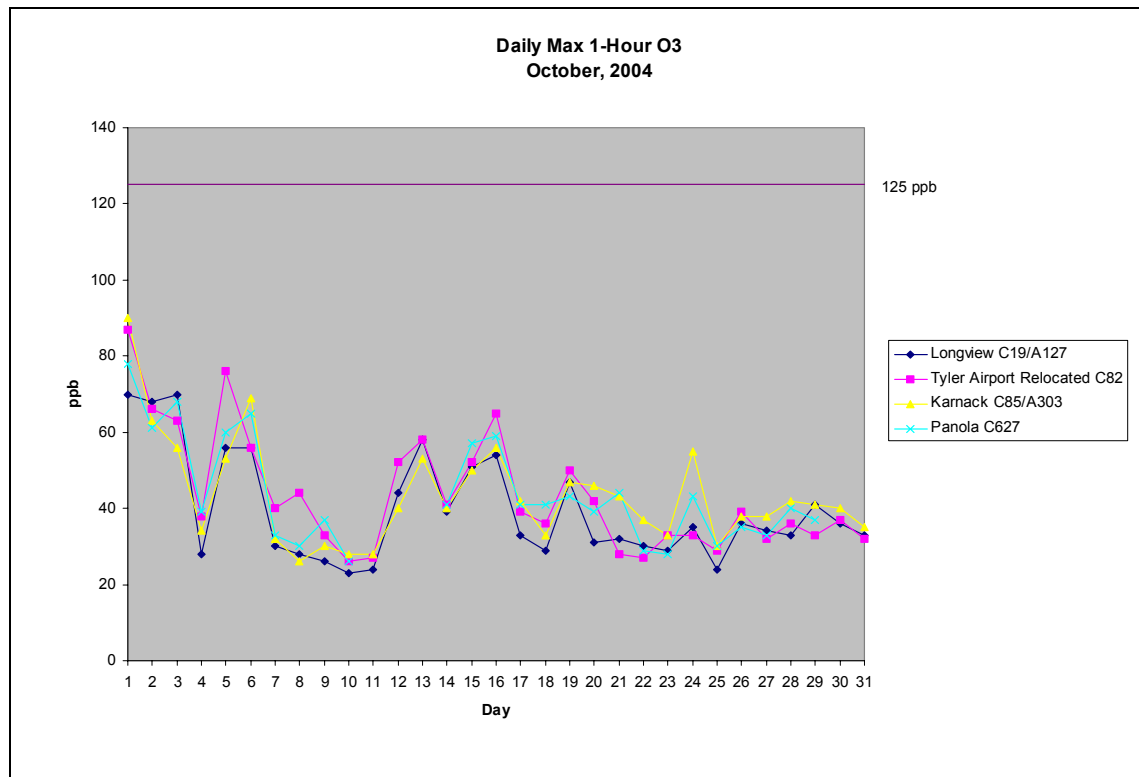


Figure 3(c). Daily maximum 1-hour ozone concentrations in October, 2004.

DESCRIPTION OF 2004 HIGH OZONE EVENTS

In the following subsections, we describe the meteorological and air quality conditions associated with each of the nine NE Texas high ozone days listed in Table 2. For each day, we display and describe the:

- diurnal patterns of hourly ozone concentrations at all NE Texas monitors,
- the time series of hourly wind direction and ozone and ozone precursor concentrations at the monitoring site which experienced the highest 1-hour ozone value,
- regional-scale and local-scale back trajectories tracing the approximate path taken by air parcels during the hours prior to arrival in NE Texas at the time of maximum ozone concentration
- additional key observations such as satellite photographs, etc. which illustrate significant features associated with each high ozone event.

Because of the large number of graphical displays, we have grouped together figures for each day and inserted them immediately following the descriptive text for that day.

23 June 2004

Hourly O₃ concentrations at all monitoring sites in NE Texas on 23 June are shown in Figure 4. A maximum 1-hour average ozone concentration of 118 ppb was recorded at Longview; the maximum 8-hour average on this day was 71 ppb, also at Longview. Figure 4 shows that the Longview monitor experienced 48 - 68 ppb more ozone than the regional background level suggested by the Tyler and Karnack readings.

Hourly O₃, NO_x, SO₂, wind speed (WS) and wind direction (WD) at Longview for the period 22 - 24 June are shown in Figure 5. Elevated SO₂ and one-hour lagged O₃ is evident on 23 June; the period of elevated concentrations followed a wind shift from NW to ENE. A sharp SO₂ and NO_x peak occurred at 13:00 CST on 24 June but was not associated with an increase in O₃ or any apparent wind shift.

Regional scale back trajectories computed with the Hy-Split model (Draxler and Rolph, 2003)⁵ for air parcels arriving at Longview during the hour of peak ozone on 23 June are shown in Figure 6. The trajectory originated over the Gulf of Mexico and traveled due north to Longview; this trajectory path is not normally associated with elevated ozone in NE Texas. The trajectory paths for 22 June and 24 June (not shown) are similar.

Back trajectories from the Hy-Split model discussed in the previous paragraph show trajectories extending over a 48-hour period calculated from a gridded wind field at 40 km resolution and are only suitable for examining approximate movement of air parcels on a regional scale. A local-scale back trajectory can be calculated from interpolated surface wind data collected at a height of 10 m above ground level at monitoring sites in NE Texas using TCEQ's plume animation software.^{6,7} Figure 7 displays such back trajectories over an 8-hour period ending at 15:00 CST at the Tyler, Longview, and Karnack monitoring sites (locations of air quality monitoring sites and major point sources are shown in Figure 8). Of interest in this case is the trajectory for the air parcel which arrived at Longview from the NE and was very slow moving; the wind shift which occurred earlier in the day is clearly evident. This trajectory indicates that the air parcel arriving at the Longview monitor on the afternoon of 23 June was located in southwestern Harrison county during the morning hours. This is in contrast to the Hy-Split trajectory (Figure 6) which shows the air parcel moving faster and arriving from the south. There are a number of likely factors contributing to these differences. The spatially and temporally averaged wind fields used to generate the Hy-Split trajectory may not properly reflect the local scale surface wind direction change which occurred earlier in the day. In addition, the surface winds used to generate the trajectory in Figure 7 are typically much slower than the winds used to drive the Hy-Split trajectories, especially during the early morning hours. In general, transport over the mid-morning to early evening period within NE Texas is probably better described by local scale trajectories such as those in Figure 7 than by the Hy-Split trajectories which are more suitable for analysis of regional, overnight or multi-day transport.

⁵ Draxler, R.R. and Rolph, G.D., 2003. HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model access via NOAA ARL READY Website (<http://www.arl.noaa.gov/ready/hysplit4.html>). NOAA Air Resources Laboratory, Silver Spring, MD.

⁶ Software and data used to plot trajectories and plume positions was provided courtesy of Bryan Lambeth, TCEQ.

⁷ Some caution must be exercised in interpreting the local-scale trajectories, however as the wind field interpolation is based on just a handful of monitoring sites in NE Texas (at most 3 or 4 sites depending on data availability).

Although local-scale trajectories are more appropriate for representing air parcel locations within the first few hours prior to arriving at a monitoring site, one must nevertheless be aware of the fact that these local-scale trajectories are based on spatial interpolation of wind data from at most 3 or 4 local monitoring sites (i.e., the currently operating air quality monitoring sites). This relatively sparse monitoring network is not likely sufficient to fully characterize spatial variations in the local wind field such as may be associated with lake breezes, terrain effects, and urban heat islands. Small-scale effects on the wind field associated with these sorts of forcing phenomena are likely to be particularly important under stagnant, light wind conditions characterized by weak meso and synoptic scale forcing. These types of conditions occurred on 23 June and on several other high ozone days as described below. For this reason, local scale back trajectories such as those shown in Figure 7 which depict generally stagnant, light wind conditions, at best provide only a very rough indication of the actual paths air parcels are likely to have traveled prior to reaching their destination. As one moves along a back trajectory to points representing parcel locations farther back in time and farther away from the monitoring site, the greater the uncertainties become regarding the actual air parcel positions.

The plume plotting package used to produce Figure 7 can also be used to calculate and display for any given hour the positions of plumes released at some previous time from selected major point sources.⁸ Figure 9 shows the positions of plumes at 16:00 CST on 23 June; plumes shown here were released from major sources in the Tyler-Longview area starting at 8:00 CST. Examination of this figure shows that plumes from the Knox Lee and Pirkey power plants pass over or near the Longview monitoring site at about the time of the afternoon ozone peak. Passage of these plumes near the monitor is consistent with elevated NO_x and SO₂ levels noted in Figure 5 although the SO₂ peak shown in Figure 5 occurred 1 – 2 hours prior to the estimated time at which the plumes appear to be closest to the monitor in Figure 9. Unfortunately NO_x data are missing at the time of the ozone peak. It is not unreasonable to expect that material from these elevated sources may have traveled more quickly towards the monitoring site than predicted by the surface level winds used to generate the plume positions shown in Figure 9. It must be recognized, however, that the above discussion regarding significant uncertainties in local-scale back trajectories under near stagnant, light wind conditions applies equally to the plume positions shown in Figure 9. It is therefore not possible to be certain that the elevated NO_x and SO₂ levels observed at Longview are the direct result of emissions from Knox Lee or Pirkey.

⁸ A sequential series of such hourly plume position plots can be compiled into a movie or “plume animation” showing the approximate movement of the plumes over the course of the day. TCEQ routinely generates such plume animations for high ozone events (see http://www.tnrcc.state.tx.us/updated/air/monops/airpollevents/2004/sigevents_2004.html).

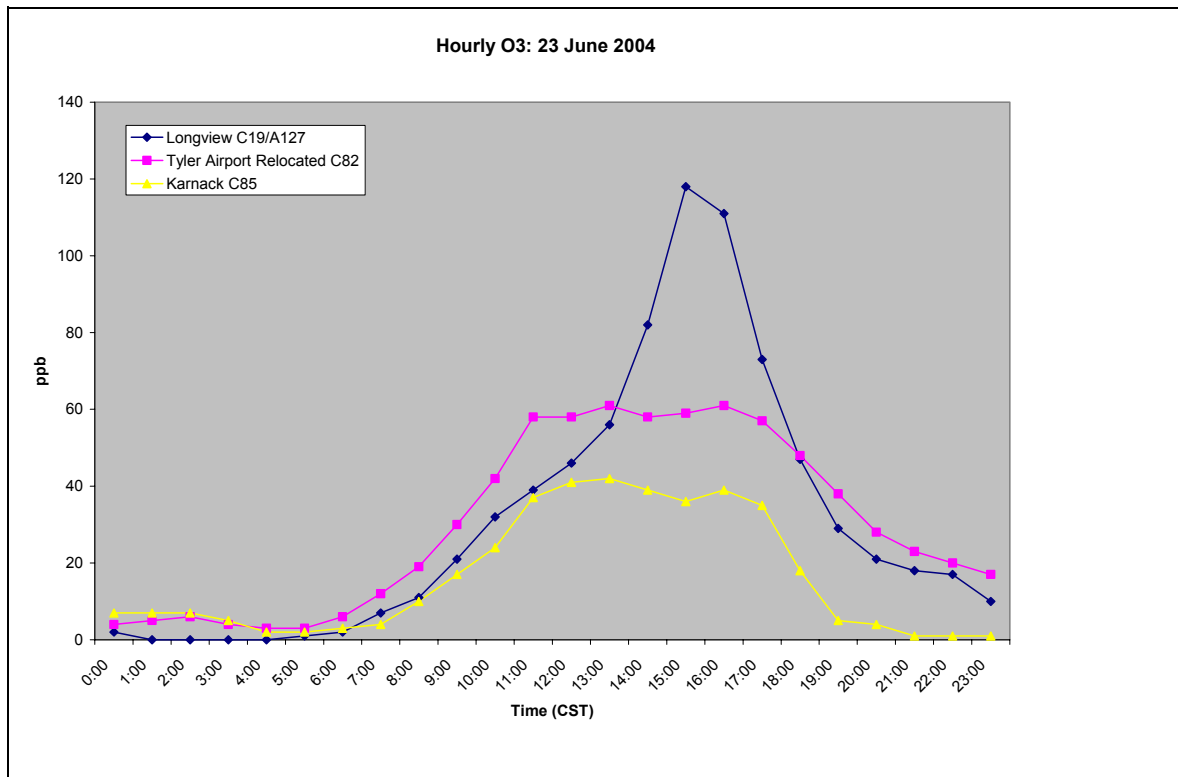


Figure 4. Hourly average ozone concentrations at monitors in NE Texas on 23 June 2004.

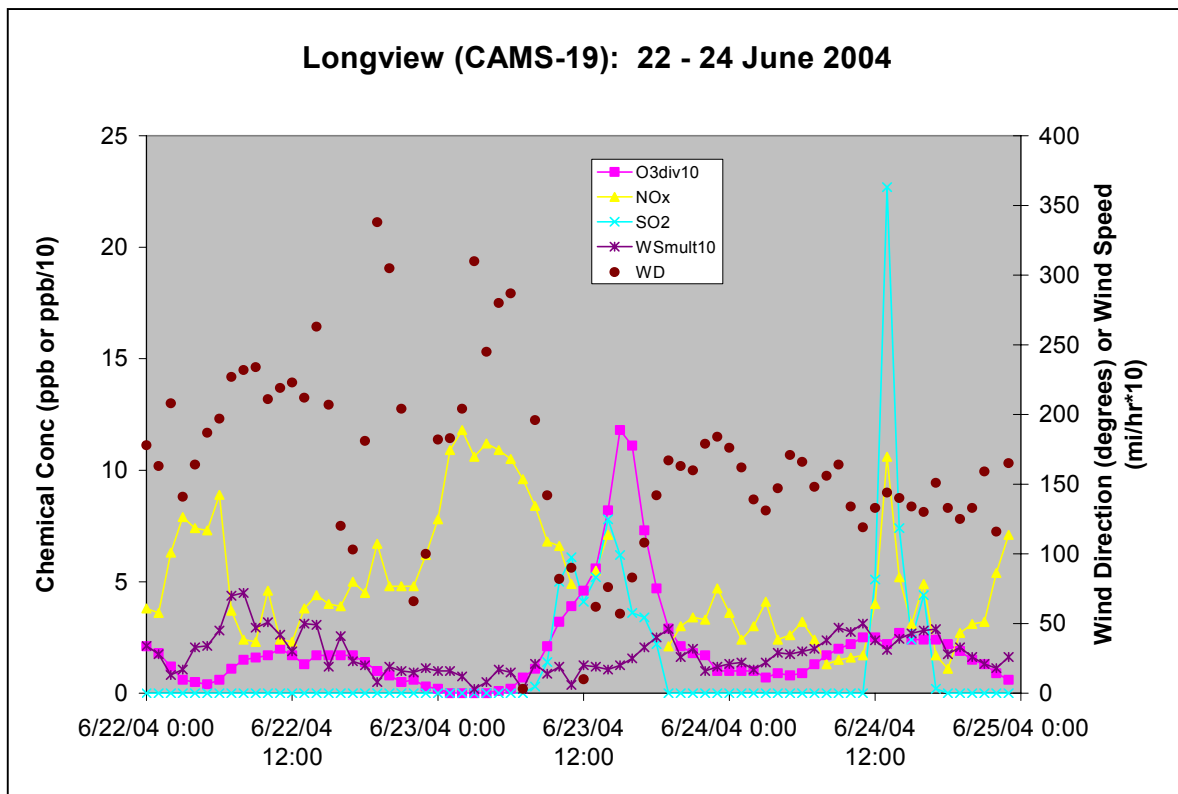


Figure 5. Hourly average O₃, NO_x, SO₂, wind speed (WS) and resultant wind direction (WD) for 22 – 24 June 2004 at Longview (CAMS 19).

NOAA HYSPLIT MODEL
 Backward trajectory ending at 21 UTC 23 Jun 04
 ETA Meteorological Data

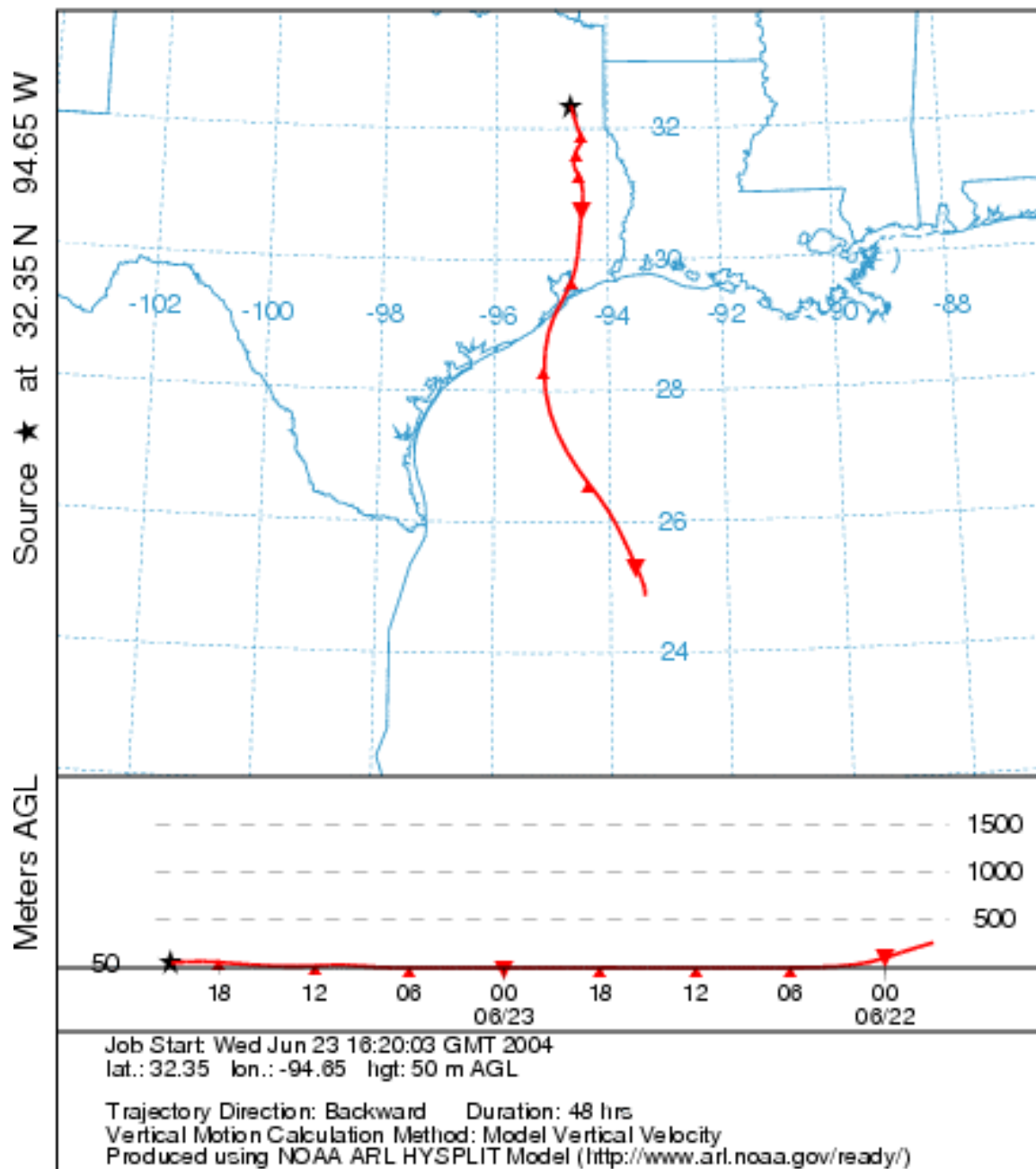


Figure 6. Hy-Split back trajectory for air parcel arriving at Longview at 15:00 CST on 23 June 2004.

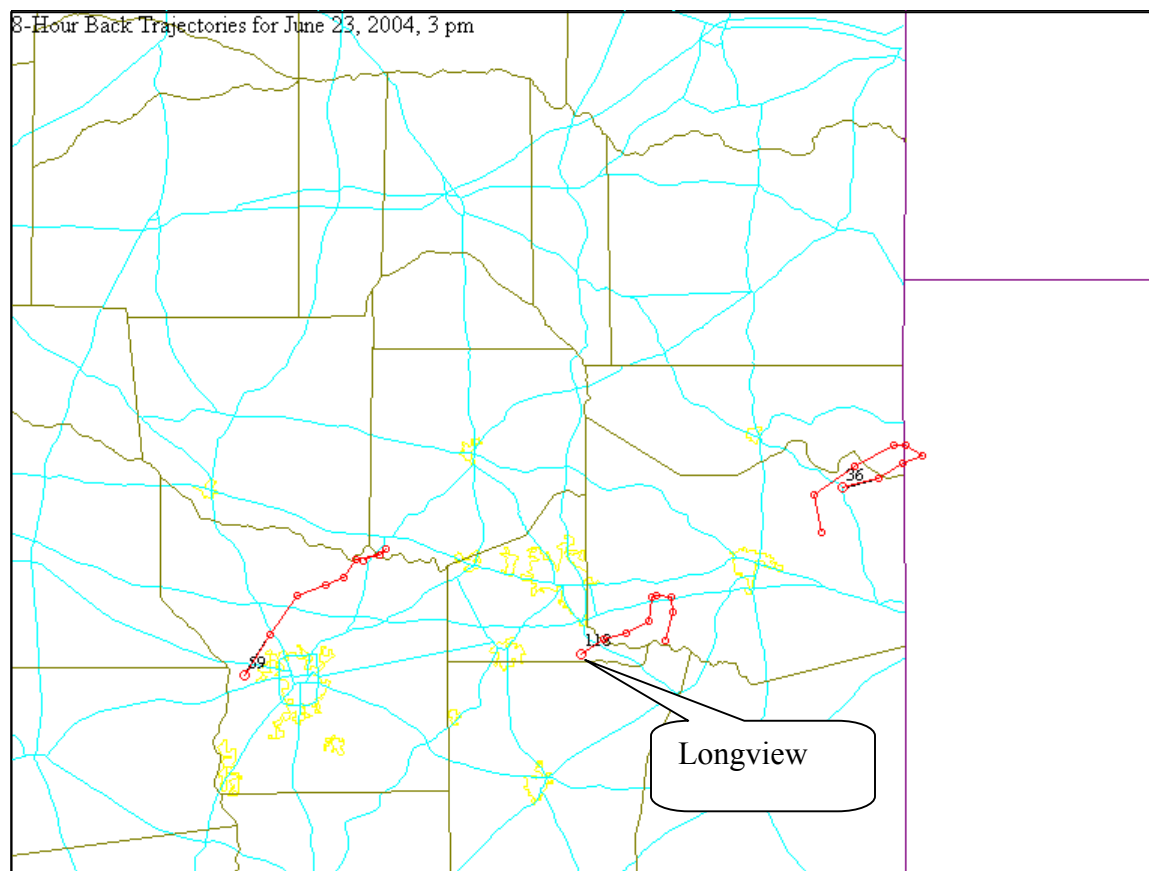


Figure 7. Back trajectories for 8-hour period ending 15:00 CST on 23 June 2004 (ozone concentrations for the hour beginning 3:00 pm CST are shown in ppb just to the upper right of each monitoring site).

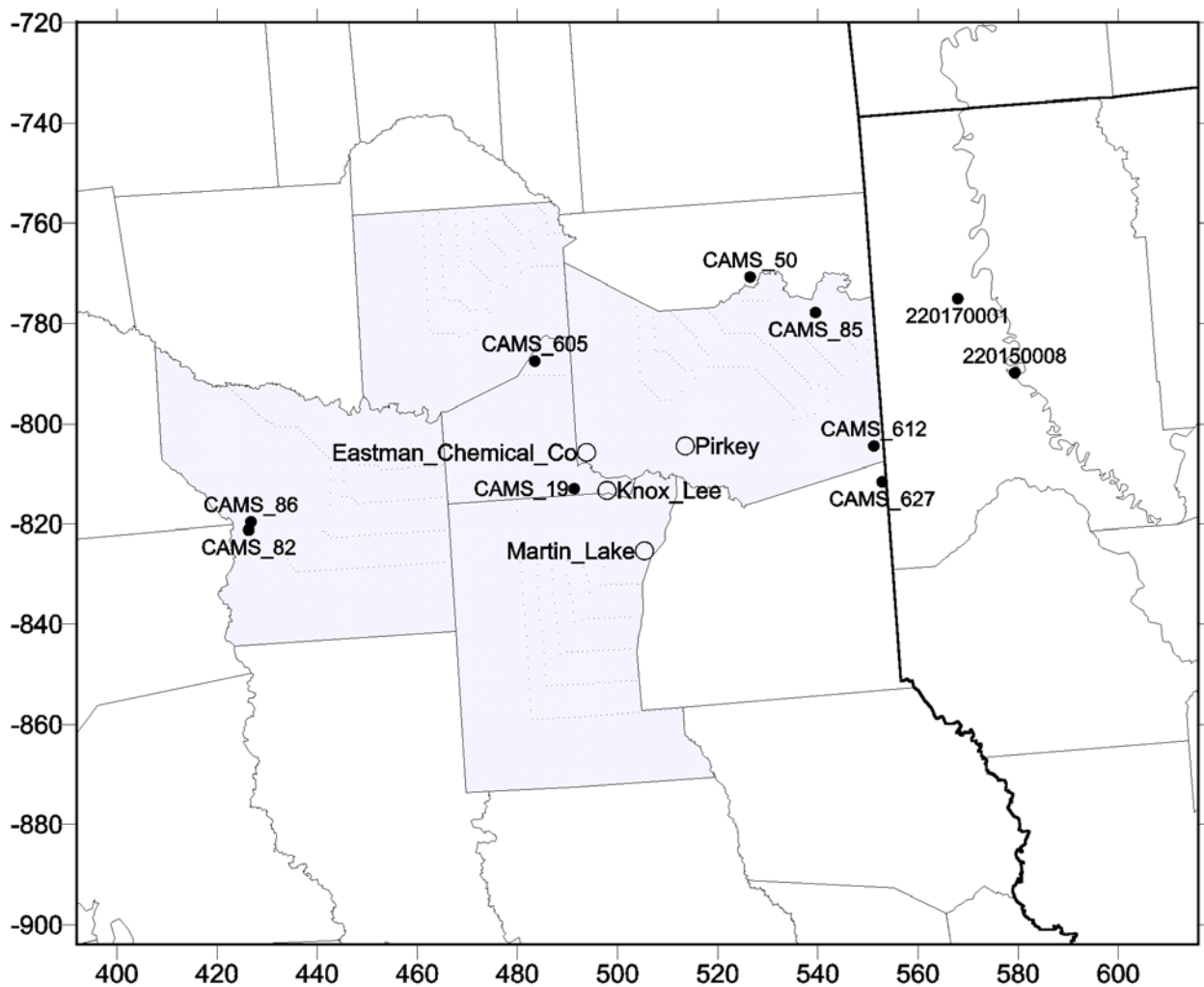


Figure 8. NE Texas air quality monitoring sites (filled circles) and major point sources (open circles). Counties in the Near Non-Attainment Area are shaded.

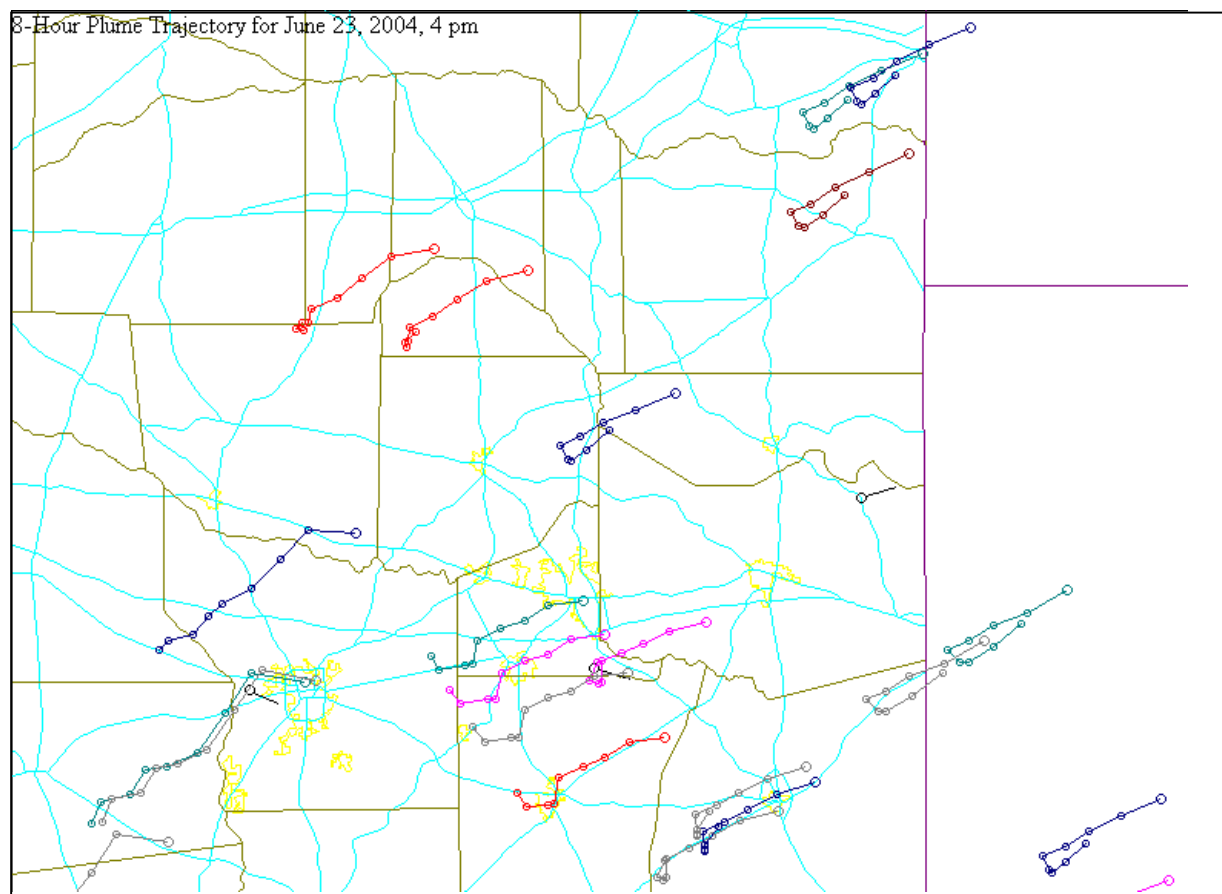


Figure 9. Positions of plumes from sources in NE Texas on 23 June 2004 at 16:00 CST; plumes were released beginning 8 hours prior to the indicated time; color coding indicates source strength.⁹

⁹ Plotting program courtesy Bryan Lambeth, TCEQ. Wind vectors shown at air monitoring sites are plotted to scale, so that the length of the vector corresponds to the distance traveled by the air during the hour of measurement. The vectors are plotted from the station circle toward the direction from which the wind was blowing and show approximately where the air that arrived at the end of the hour was located at the beginning of the hour. Wind speeds have been adjusted upward based on annual wind speed averages as compared to sites with the best overall wind exposure. This adjustment approximates the wind speed at typical daytime ozone transport altitudes from about 500 to 5,000 feet above ground level and has also been applied to the plume determinations. Plumes shown in the above plots are approximations of the plume positions at the end of the clock hour shown. The plume positions are estimated based on 10-meter wind measurements from the real-time air monitoring sites in the area. The large circles indicate the origin of each plume (i.e., the source location) and the smaller circles indicate hourly positions along the plume. The lines connecting the circles represent the centerline of the plume. Plumes are color coded based on the facility total of oxides of nitrogen (NOx) and volatile organic compounds (VOC) from the TCEQ emissions inventory:

- Bright red - 10,000 or more tons per year NOx or 5,000 or more tons per year VOC
- Bright magenta - 7,000 to 9,999 tons per year NOx or 4,000 to 4,999 tons per year VOC
- Dark red - 4,000 to 6,999 tons per year NOx or 3,000 to 3,999 tons per year VOC
- Dark blue - 2,000 to 3,999 tons per year NOx or 2,000 to 2,999 tons per year VOC
- Gray - 1,000 to 1,999 tons per year NOx or 800 to 1,999 tons per year VOC
- Dark Cyan - Urban core plume centerlines (representing very broad plumes; urban areas are outlined in yellow)

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Golden Gate Plaza • 101 Rowland Way • Novato, California 94945-5010 USA
Tel: (415) 899-0700 • Fax: (415) 899-0707

19 July 2004

Hourly ozone data for 19 July (Figure 10) show a pattern similar to 23 June but with ozone increasing at Tyler during mid-afternoon; this increase coincides with a period during which winds at Longview slowly rotated clockwise from northerly to southeasterly (see below) and suggests the high ozone over Longview was advected east to Tyler (winds tended to be more NEerly during the 23 June ozone peak which is not consistent with transport to Tyler). The regional ozone background on 19 July as suggested by data from Karnack was about 50 ppb indicating a maximum local production at Longview of 62 ppb.

Hourly O₃, NO_x, SO₂, wind speed (WS) and wind direction (WD) at Longview for the period 18 – 20 July are shown in Figure 11. The O₃ peak at 15:00 CST on 19 July was preceded by NO_x levels as high as 33 ppb (with very low SO₂ levels) during the early morning hours and is associated with a wind shift from NW to NE similar to the one which occurred on 23 June. The lack of SO₂ associated with the high NO_x levels rules out any contribution from coal fired electric generating facilities.

A Hy-Split model regional-scale back trajectory for air parcels arriving at Longview during the hour of peak ozone on 19 July is shown in Figure 12. This trajectory indicates that the air parcel arriving at Longview was over Shreveport, LA during the early morning hours having arrived from the north over Arkansas the night before and then curved east and NE towards Longview. This trajectory path is typical of Hy-Split trajectories on elevated ozone days in NE Texas.

Local-scale eight hour back trajectories for air parcels arriving at 15:00 CST on 19 July are shown in Figure 13. In this case the air parcel arriving at Longview experienced a wind shift from south to NE at around mid-day similar to that which occurred on 23 June but the afternoon wind speeds were slightly higher. As on 23 June, the wind shift impacting the local-scale trajectory is not evident in the Hy-Split trajectory (Figure 12) and one would expect significant uncertainties in trajectory position within the last few hours leading up to the ozone maximum for the reasons discussed above in connection with the 23 June event.

Examination of plume positions for 15:00 CST on 19 July 2004 (Figure 14) indicates that plumes from both Pirkey and the Eastman/Huntsman chemical complex passed near the Longview monitor at about this time (which is approximately the time of peak ozone and the afternoon peak NO_x as shown in Figure 11) and then moved further away from the monitor in subsequent hours. Although these results are consistent with a possible contribution from Eastman/Huntsman or Pirkey, one must keep in mind that uncertainties in plume positions may be substantial as discussed above.

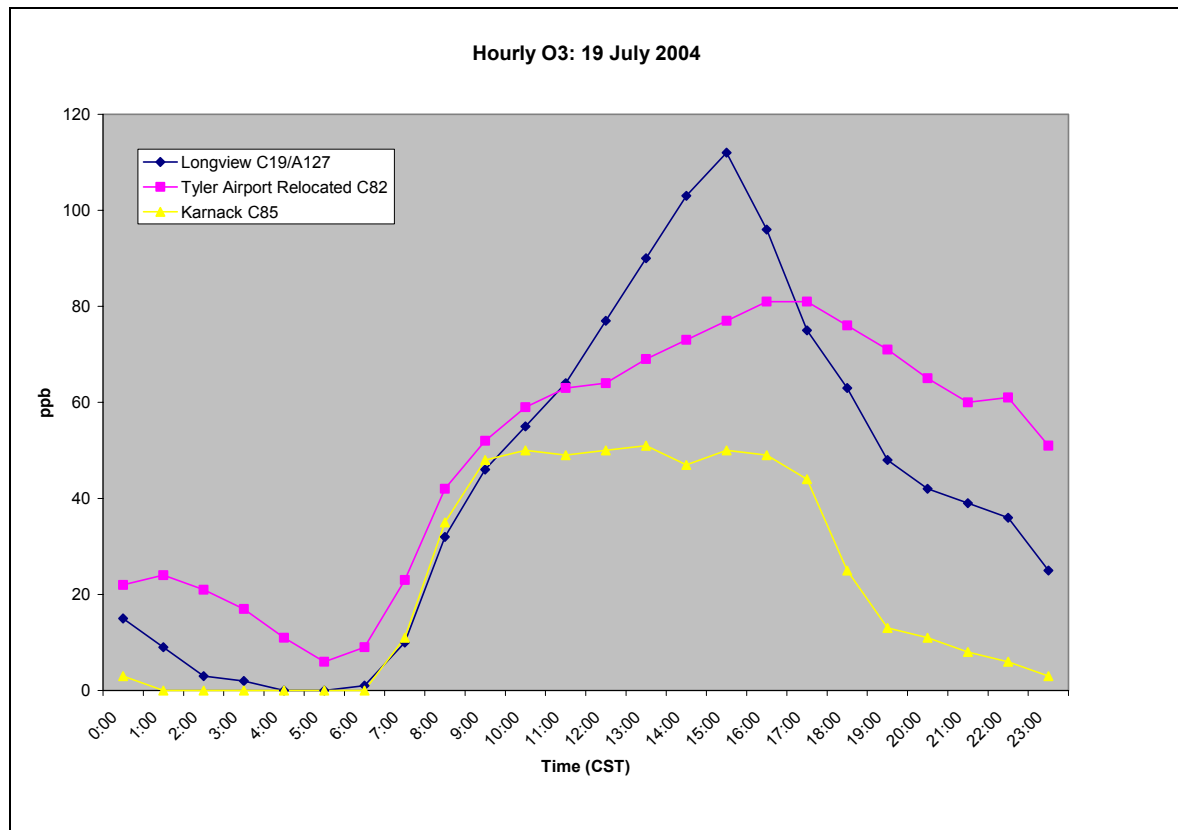


Figure 10. Hourly average ozone concentrations at monitors in NE Texas on 19 July 2004.

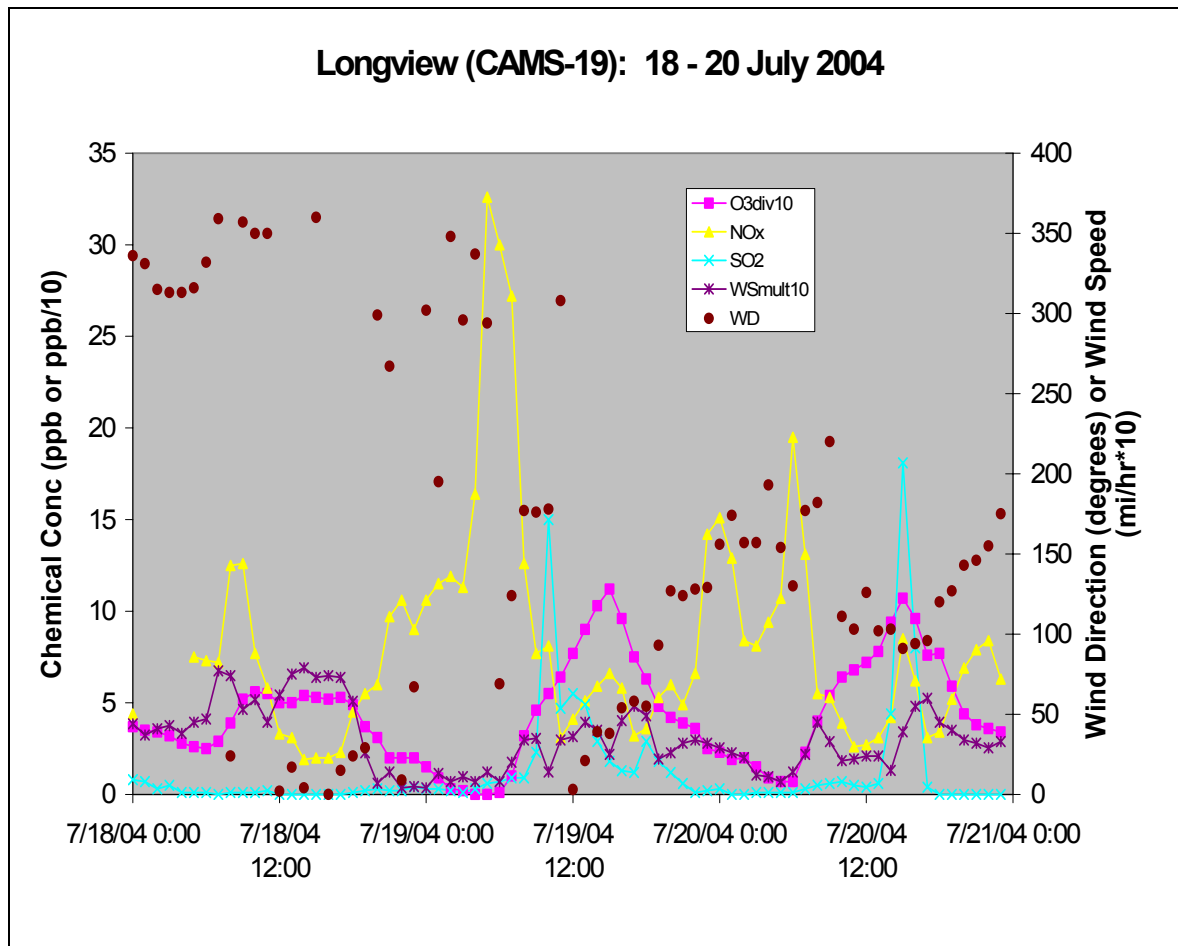


Figure 11. Hourly O₃, NO_x, SO₂, wind speed (WS) and wind direction (WD) for 18 – 20 July 2004.

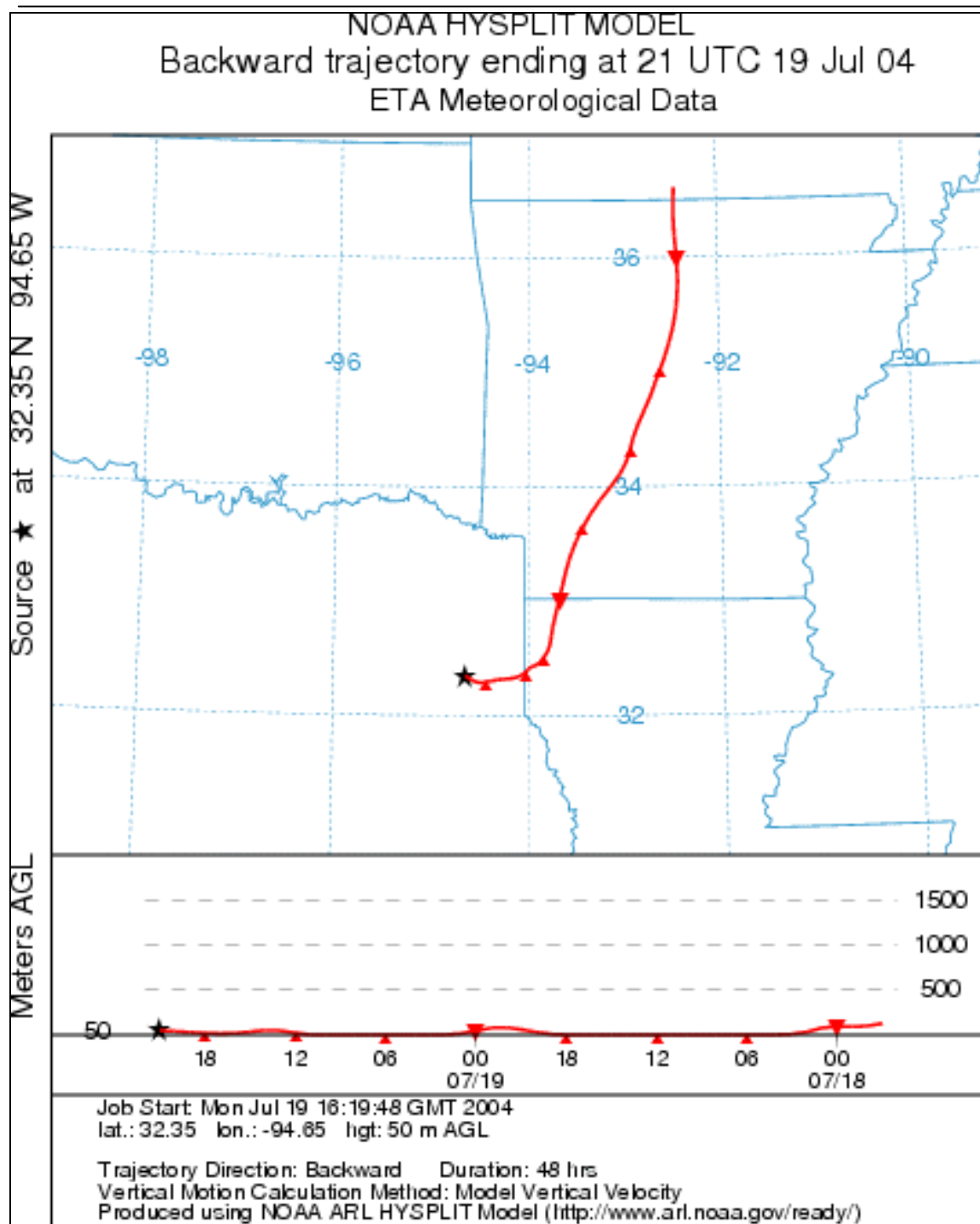


Figure 12. Hy-Split back trajectory for air parcel arriving at Longview at 13:00 CST on 19 July 2004.

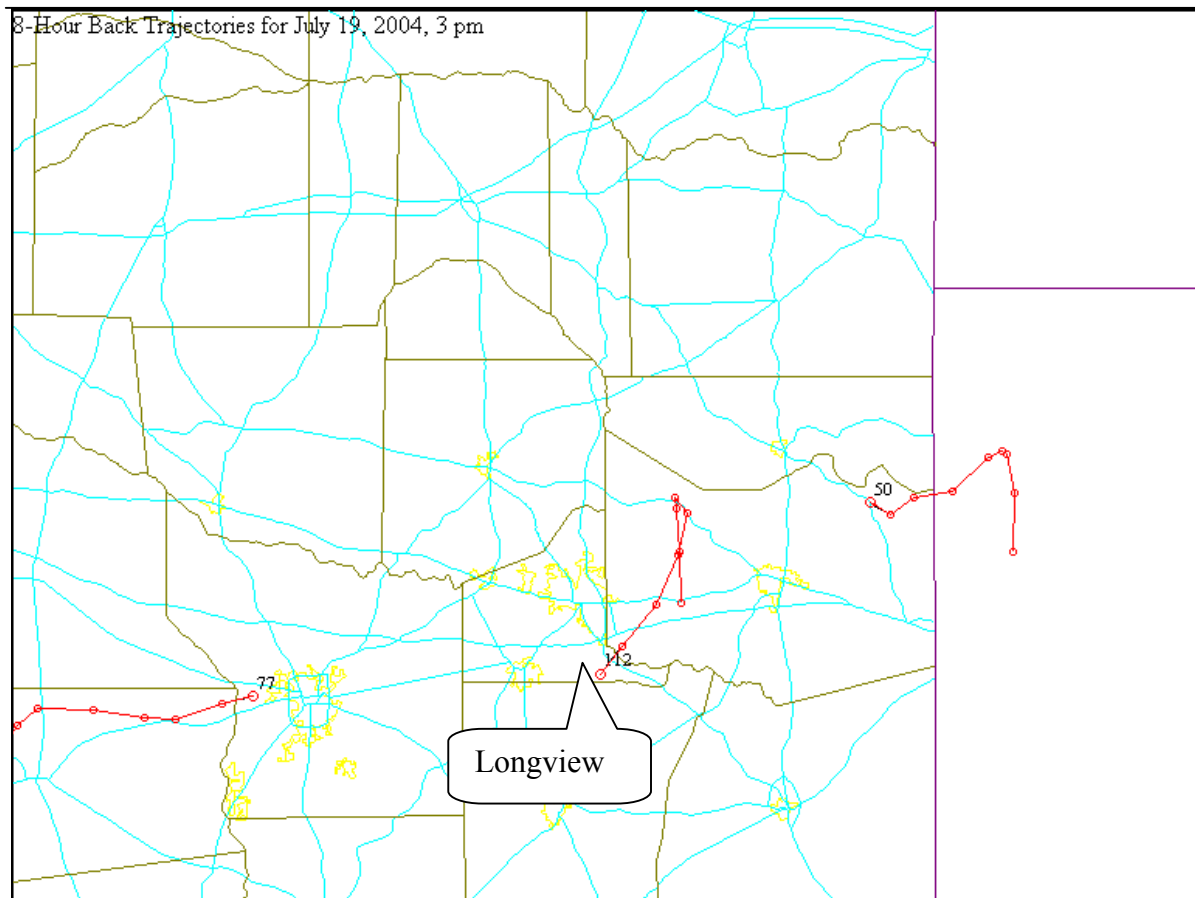


Figure 13. Back trajectories for 8-hour period ending 19 July 2004 at 15:00 CST.

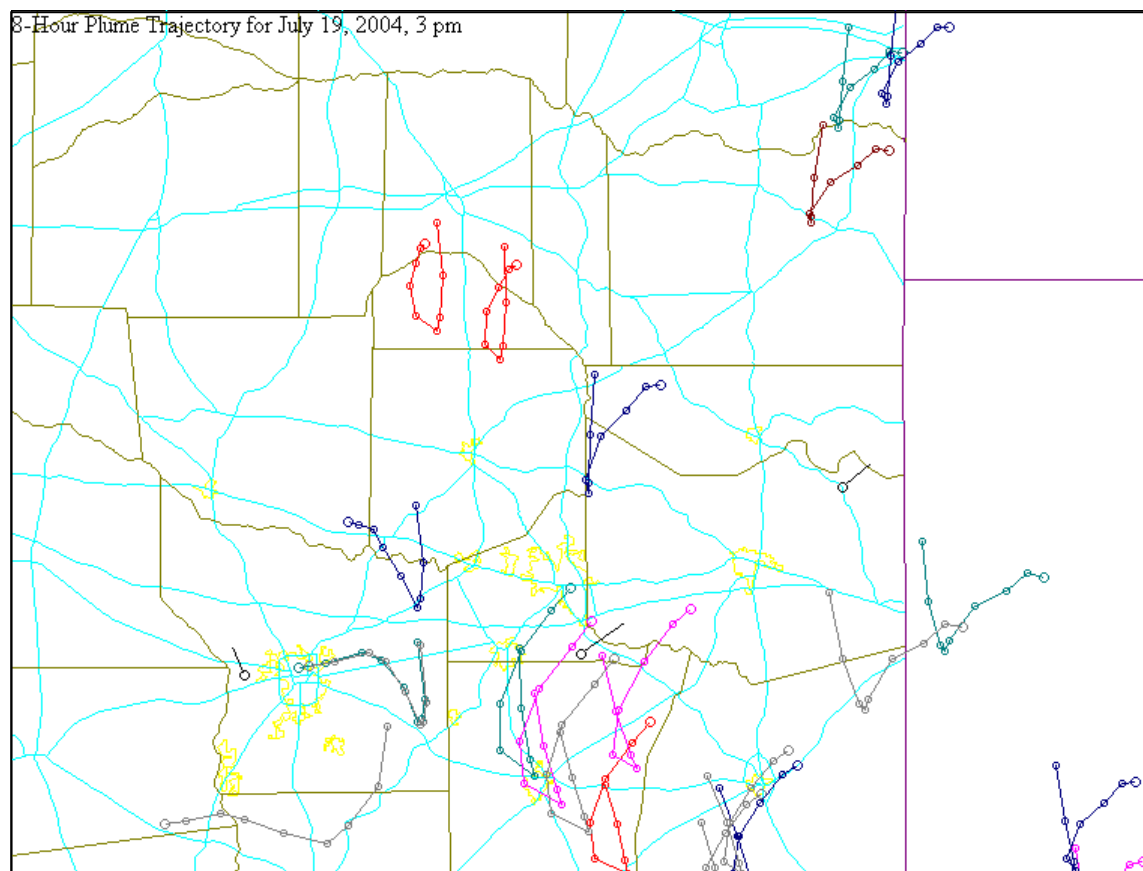


Figure 14. Positions of source plumes in NE Texas (as in Figure 9) for 15:00 CST on 19 July 2004.

20 July 2004

Hourly ozone patterns for 20 July (Figure 15) differ from those on the other days we examined, with ozone peaks at Karnack and Panola occurring one to two hours after the Longview peak; concentrations at Tyler are also higher on this day with a late peak of 80 ppb at 17:00 CST.

Time series of hourly O₃, NO_x, SO₂, wind speed (WS) and wind direction (WD) at Longview (Figure 11) show that the ozone peak at 15:00 CST on 20 July coincides with a peak in NO_x and SO₂ concentrations. Analysis of 5-minute average monitoring data for this period (not shown) indicates that the NO_x and SO₂ peaks had a time scale of about 1-hour and NO concentrations remained at zero throughout this period. The SO₂/NO_x ratio during the peak was 2:1 which is typical of a coal-fired power plant plume.¹⁰ Data from Panola and Karnack were not investigated for this analysis but further study of these data is recommended.

The plume position map for 16:00 CST on 20 July (Figure 16) shows that the Longview monitor was directly in the path of the Knox Lee plume and plumes from three sources in Panola county were over or near the monitor. The SO₂ and NO_x peaks during the afternoon of 20 July shown in Figure 11 began at 14:00 CST and ended at 17:00 CST, coincident with these potential plume impacts. However, these plume positions are subject to considerable uncertainties as discussed above in connection with the 23 June event so it is possible that other sources could have contributed to the SO₂ and NO_x peaks at Longview.

¹⁰ Vizquete, W.G. 2002. Analysis of NOAA aircraft data for plume studies in NE Texas during TexAQS2000. Univ. of Texas, Austin, October.

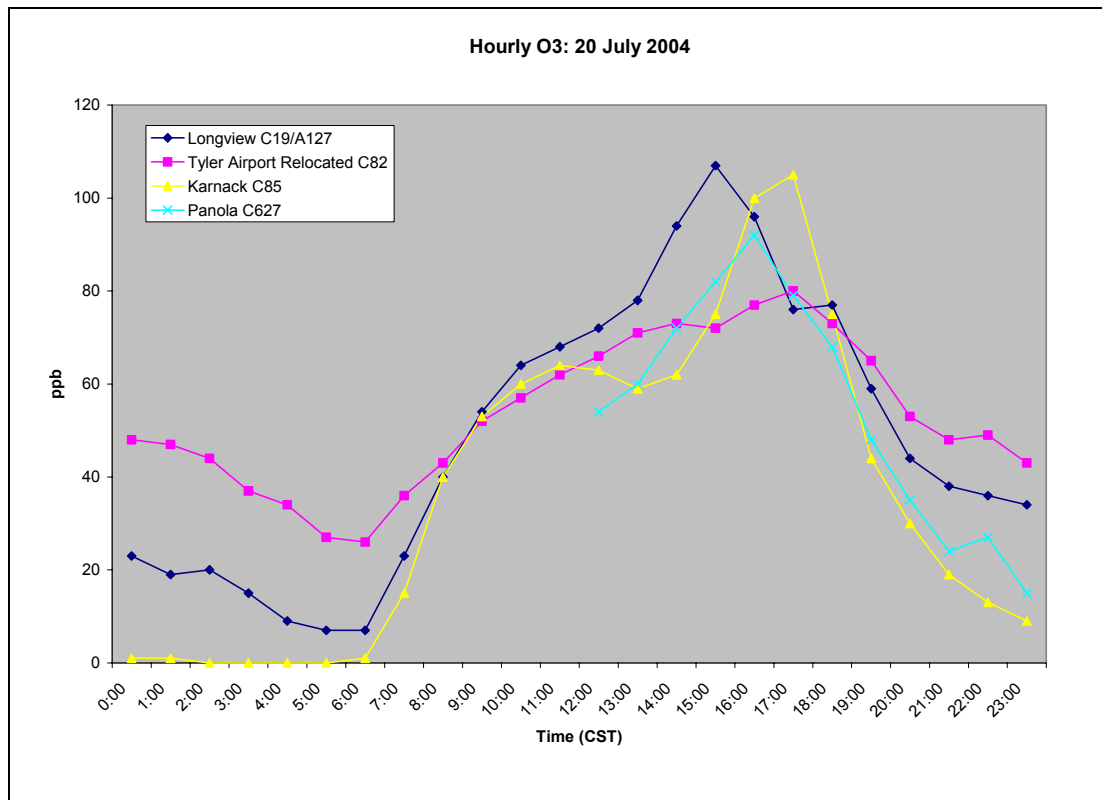


Figure 15. Hourly average ozone concentrations at monitors in NE Texas on 20 July 2004.

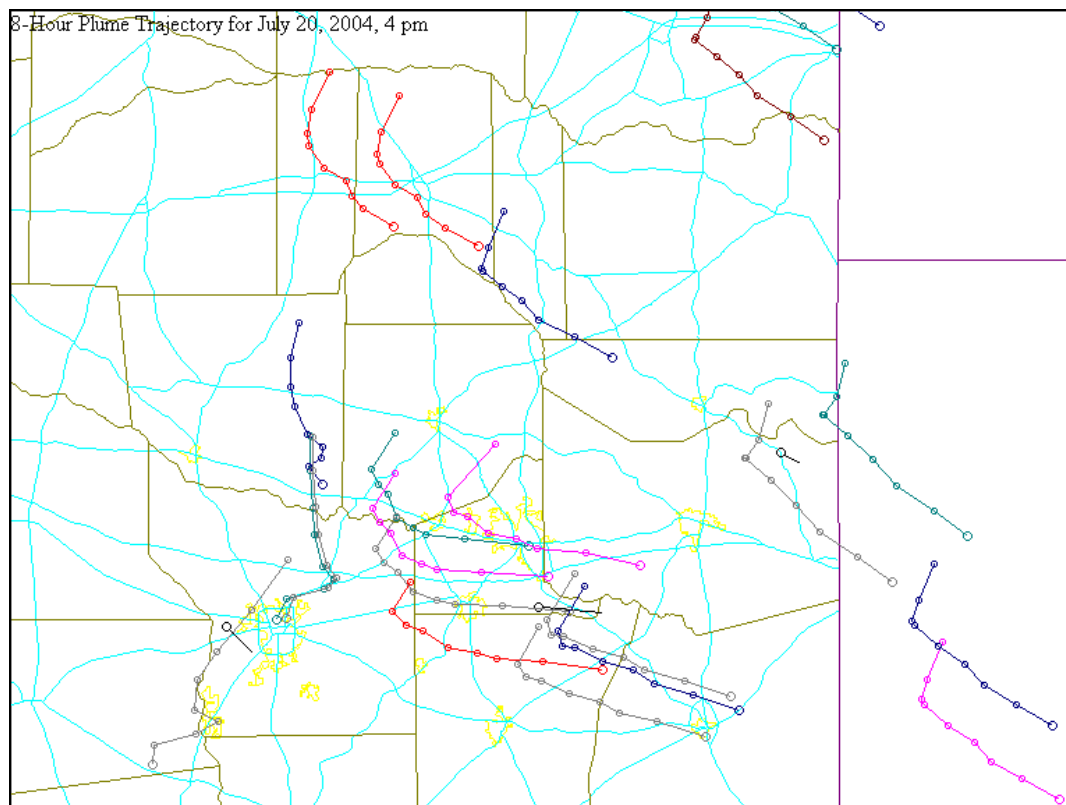


Figure 16. Positions of source plumes in NE Texas (as in Figure 9) but for 16:00 CST on 20 July 2004.

3 August 2004

Hourly ozone data for 3 August (Figure 17) show that ozone at Longview began exceeding the apparent regional level of 70 ppb at 12:00 CST and remained approximately 40 ppb above levels observed at Tyler and Karnack throughout the afternoon; there is a late peak at Panola on this day which may warrant further investigation but does not appear to have been related to events at the other monitoring sites.

Hourly O₃, NO_x, SO₂ and wind direction (WD) at Longview on 3 August 2004 (Figure 18) show a mid-day clockwise wind shift from NW to SE similar to those observed on 23 June and 19 July. In contrast to the earlier events, there is a broad afternoon ozone peak on this day with concentrations remaining above 85 ppb from 12:00 – 19:00 CST. This resulted in a high 8-hour average concentration. Afternoon SO₂ concentrations averaged approximately 5 ppb; NO₂ levels were also slightly elevated during this period at about 6 - 8 ppb.

The regional-scale Hy-Split back trajectory for air parcels arriving at Longview during the hour of peak ozone on 3 August is shown in Figure 19. This trajectory was located in western Louisiana during the early morning of 3 August having traveled southeast overnight; from there it turned east and then north to arrive at Longview at 15:00 CST.

Local-scale eight hour back trajectories for air parcels arriving at 15:00 CST on 3 August are shown in Figure 20. A re-circulation pattern is evident at Longview which would tend to trap locally generated pollutants. Back trajectories ending at the three other NE Texas monitoring sites do not exhibit the re-circulation pattern seen at Longview and mid-day peak ozone concentrations at these sites are lower than at Longview. These results are an indication of the localized nature of wind direction variations during such a stagnant, light wind event with weak meso and synoptic scale forcing. As discussed above in connection with the 23 June event, this means that the true positions of the local back trajectories are subject to considerable uncertainty.

Plume positions at 13:00 CST on 3 August (Figure 21a) show how they may be related to the sharp increase in ozone at Longview observed between 11:00 and 13:00 CST. As shown in Figure 18, winds after midnight were out of the south and then turned gradually clockwise beginning at 9:00 CST, reaching easterly by 14:00 CST and holding steady until 18:00 CST. This produced the curved plume position paths seen in Figure 21. Plumes from both downtown Longview and the Eastman/Huntsman complex are shown swinging through the location of the Longview monitor between 12:00 and 1:00 CST (Figure 21a), approximately coincident with the rapid mid-day rise in ozone. The Longview monitor was in the path of the Knox Lee plume during the afternoon period of easterly winds and remnants of the Eastman/Huntsman and Pirkey plumes which had been blown to the north and east earlier in the day passed over the monitor between 14:00 and 15:00 CST (Figure 21b). These plume passages are consistent with the broad ozone peak and slightly elevated afternoon NO_x and SO₂ levels observed at Longview on this day. Nevertheless, one must keep in mind that the plume positions are subject to considerable uncertainty as discussed above.

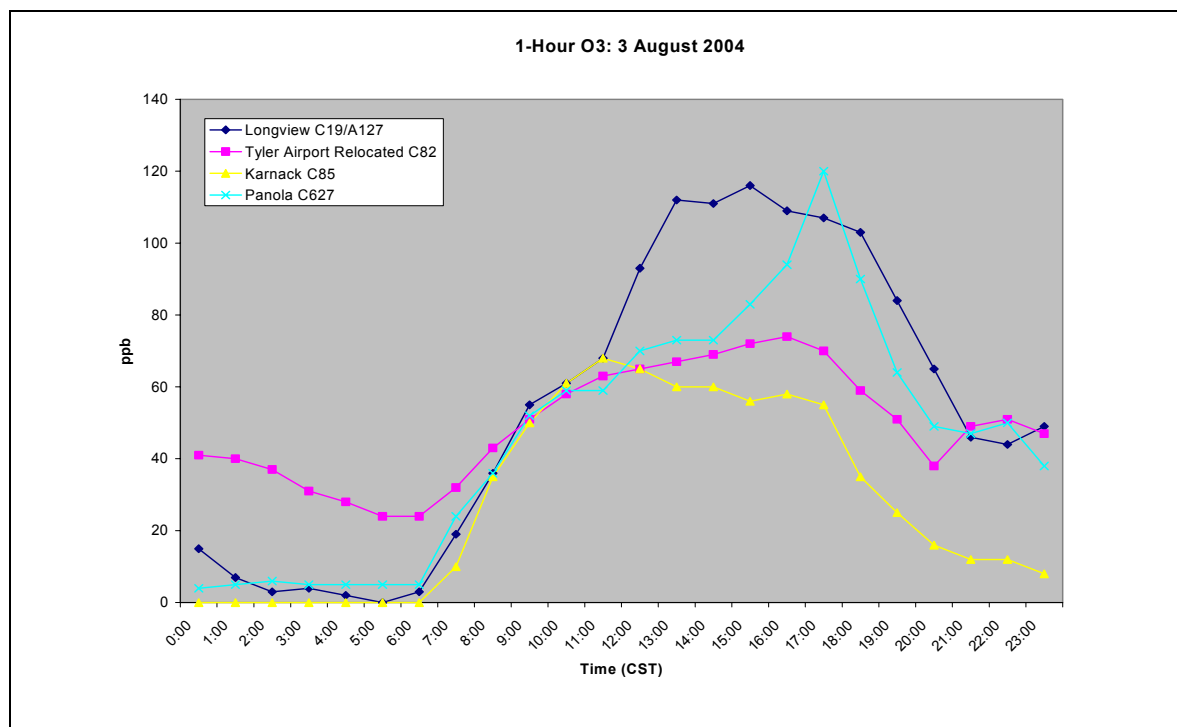


Figure 17. Hourly average ozone concentrations at monitors in NE Texas on 3 August 2004.

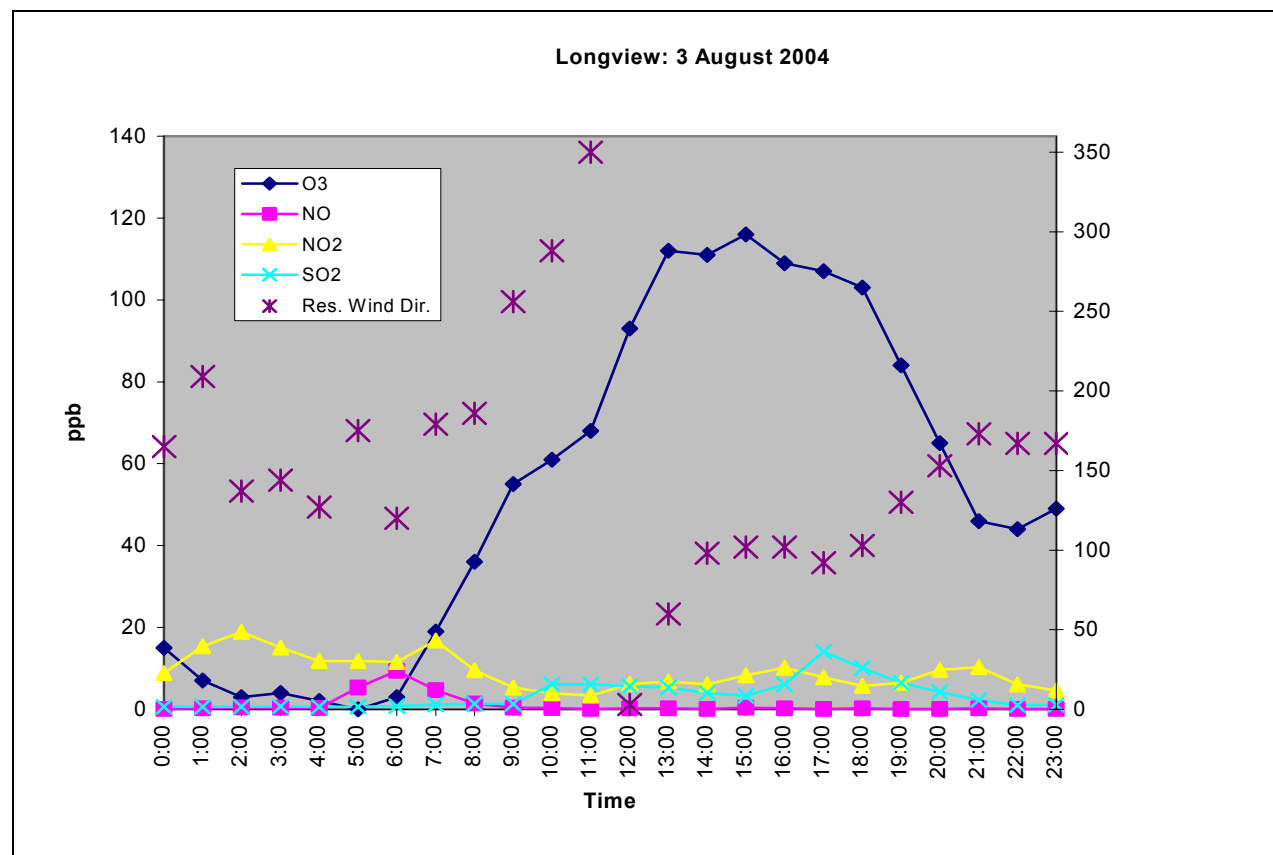


Figure 18. Hourly average pollutant concentrations and resultant wind direction at Longview (CAMS 19) on 3 August 2004.



NOAA HYSPLIT MODEL
 Backward trajectory ending at 21 UTC 03 Aug 04
 ETA Meteorological Data

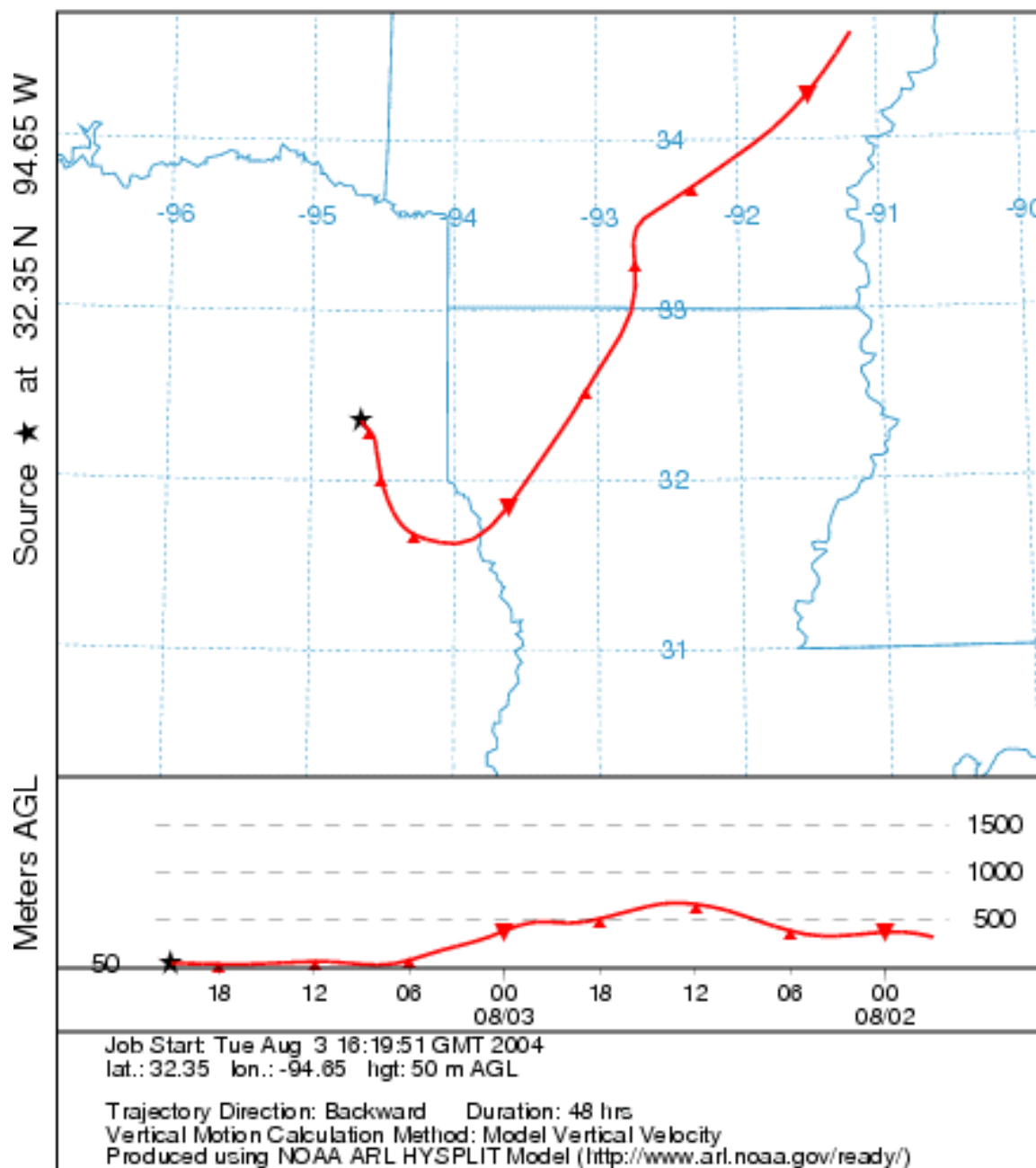


Figure 19. Hy-Split back trajectory for air parcel arriving at Longview at 15:00 CST on 3 August 2004.

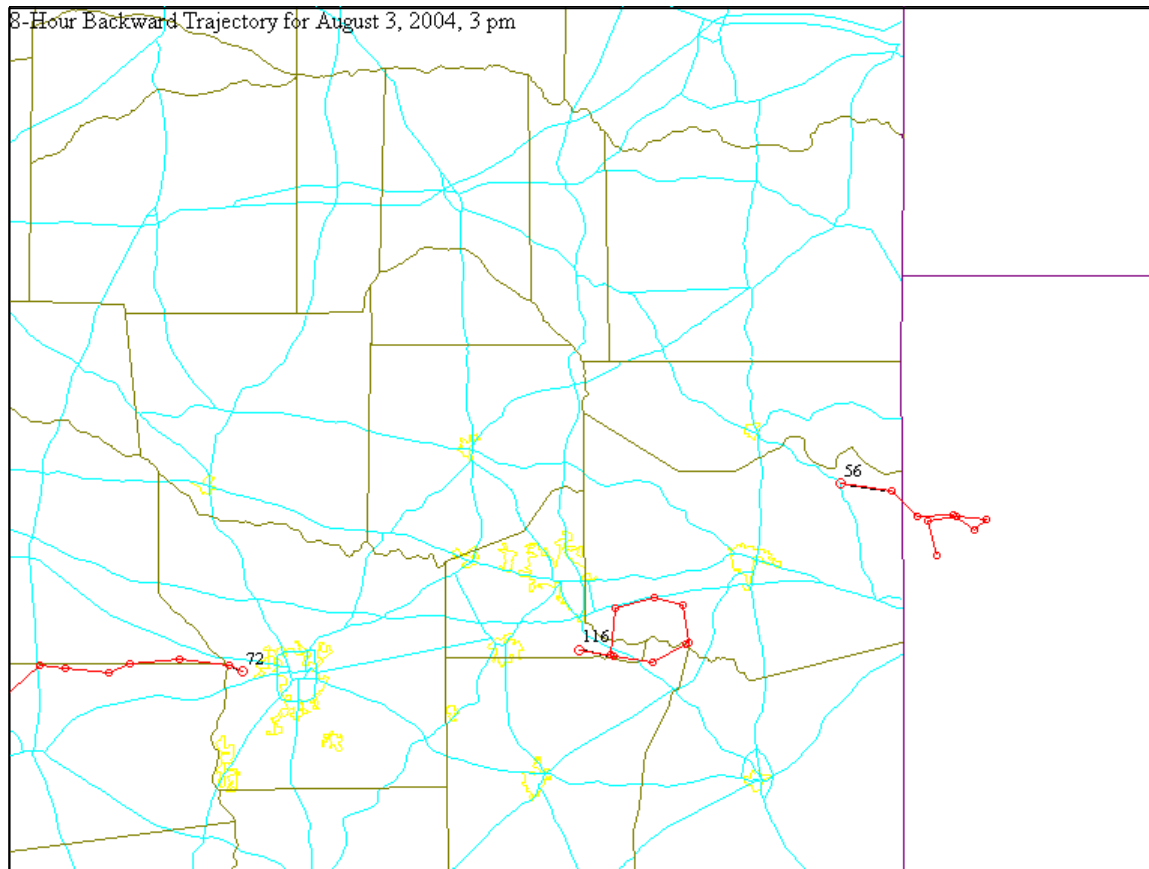


Figure 20. Back trajectories for 8-hour period ending at 15:00 CST on 3 August 2004.

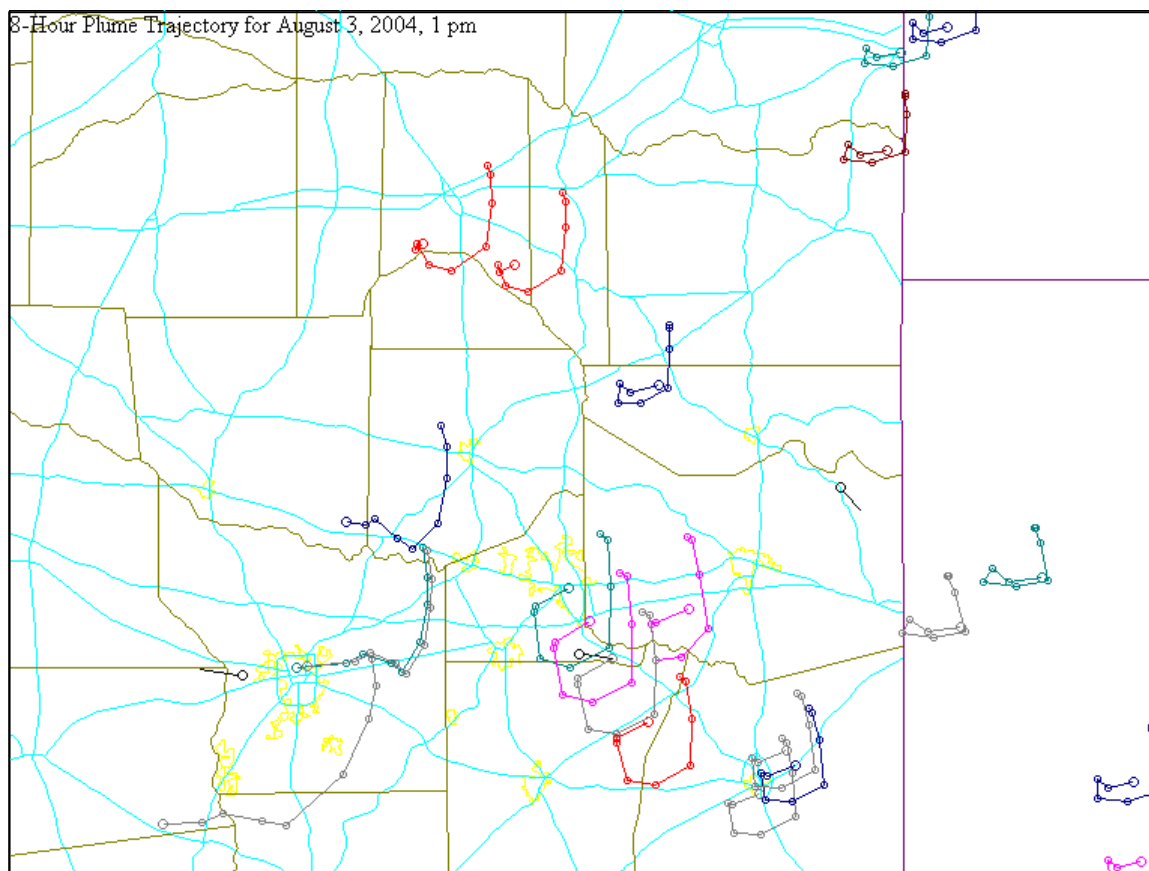


Figure 21a. Positions of source plumes in NE Texas (as in Figure 9) but for 13:00 CST on 3 August 2004.

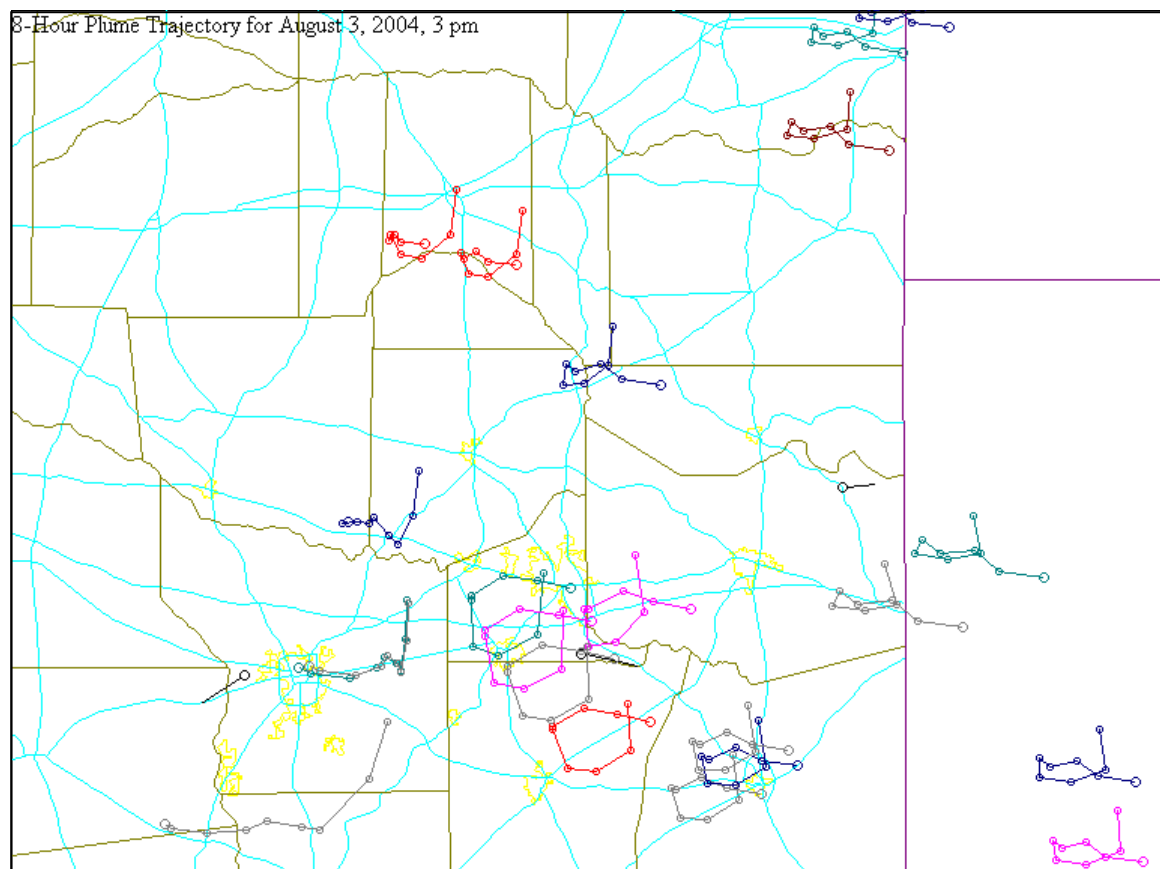


Figure 21b. Positions of source plumes in NE Texas (as in Figure 9) but for 15:00 CST on 3 August 2004.

10 August 2004

Hourly ozone data for 10 August (Figure 22) indicate that ozone at Longview began exceeding the apparently broad regional peak of approximately 80 ppb at 11:00 CST, peaking at a level of some 30 ppb above the levels at Tyler, Karnack and Panola.

Hourly O₃, NO_x, SO₂ and wind direction at Longview on 10 August (Figure 23) show a steady increase in ozone concentrations from sunrise until 12:00 CST with winds veering gradually from northwest in the morning to NE by the time of the mid-day ozone peak, similar to the pattern observed on 23 June, 19 July and 3 August. NO_x levels peak at nearly 35 ppb at 6:00, fueling the initial rise in O₃ levels, but by 10:00 NO_x levels are near zero at which time ozone had reached 70 ppb. There are no SO₂ spikes apparent in the hourly average data.

The regional-scale Hy-Split back trajectory for air parcels arriving at Longview during the hour of peak ozone on 10 August is shown in Figure 24. The trajectory passed over the Shreveport area the previous day before moving slowly to the west and then turning back on itself before finally arriving at Longview.

Local-scale eight hour back trajectories for air parcels arriving at Tyler, Longview, and Karnack at 12:00 CST on 10 August are shown in Figure 25. The Longview trajectory follows a curved pattern consistent with that seen in the Hy-Split trajectory. This partial re-circulation pattern sweeps over major sources in the immediate vicinity of the Longview monitor and suggests that the high ozone at Longview on this day likely resulted from the superposition of ozone produced from local precursor sources on the 80 ppb regional background.

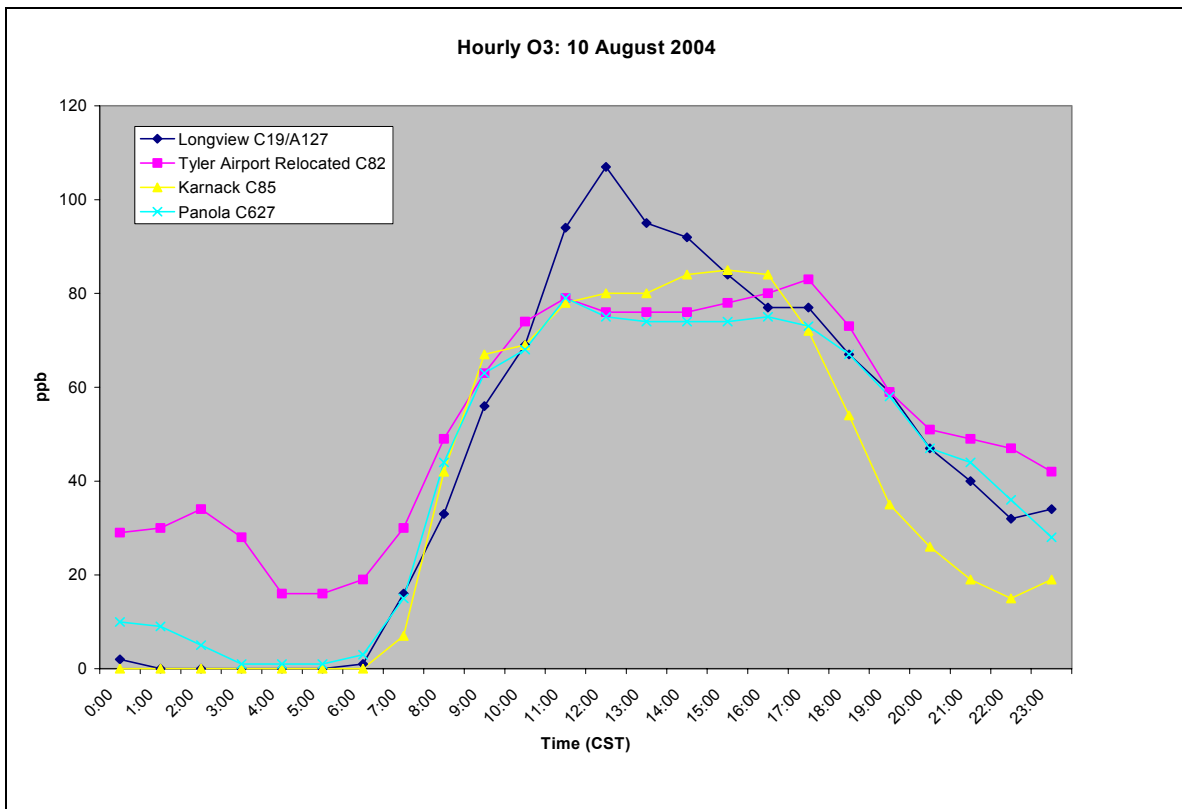


Figure 22. Hourly average ozone concentrations at monitors in NE Texas on 10 August 2004.

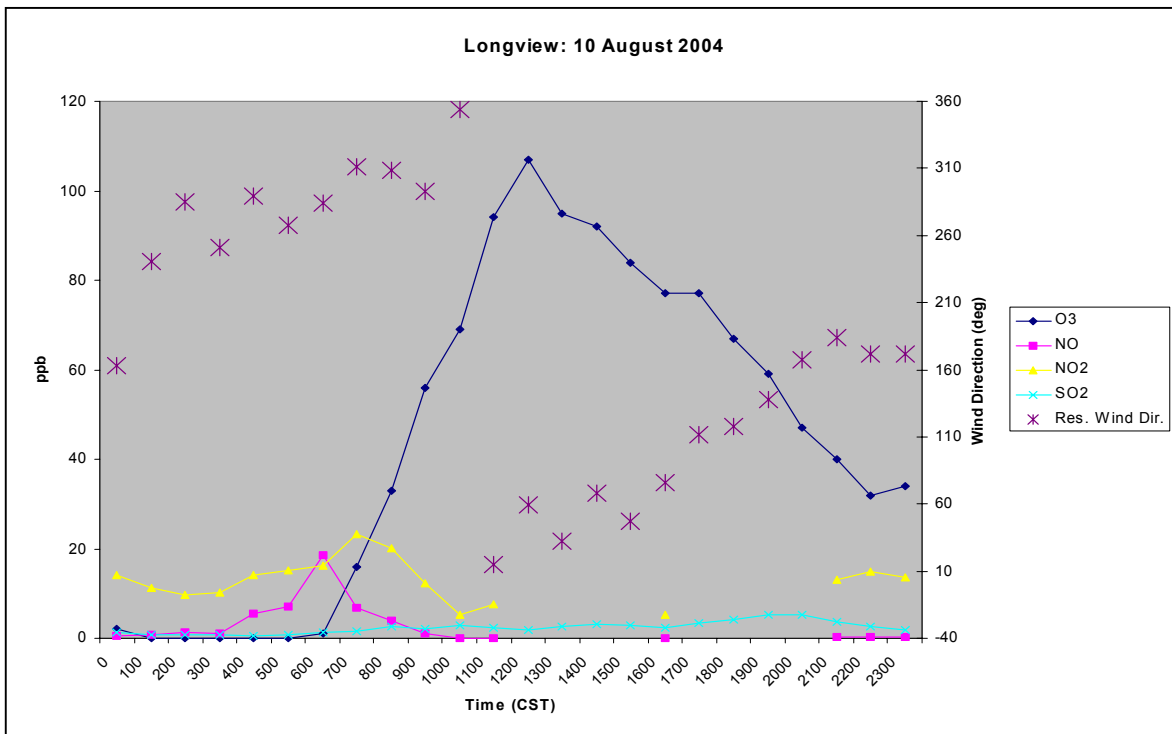


Figure 23. Hourly O₃, NO, NO₂, SO₂, and resultant wind directions at Longview (CAMS 19) on 10 August 2004.

NOAA HYSPLIT MODEL
 Backward trajectory ending at 18 UTC 10 Aug 04
 EDAS Meteorological Data

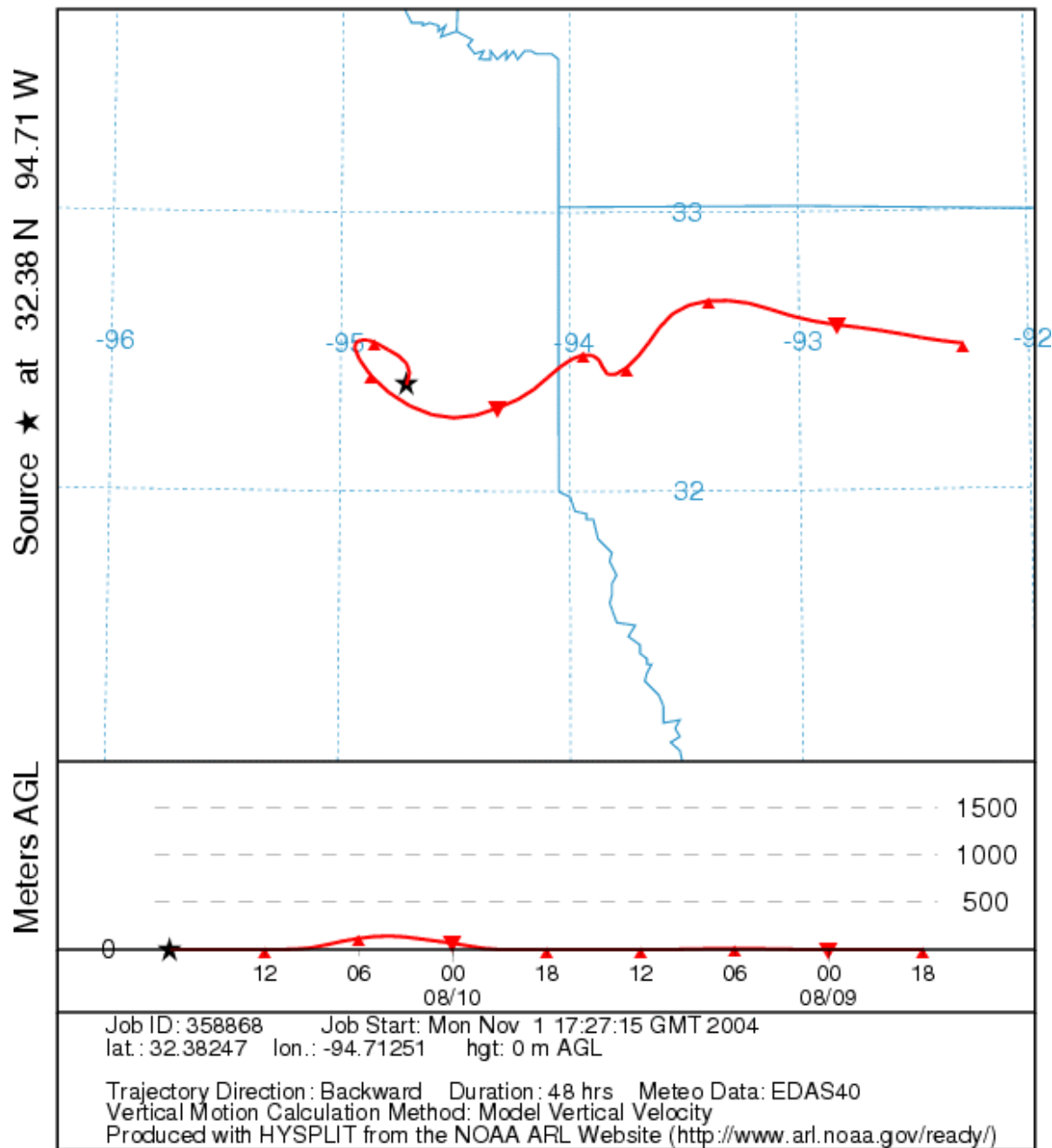


Figure 24. Hy-Split back trajectory for air parcel arriving at Longview at 12:00 CST on 10 August 2004.

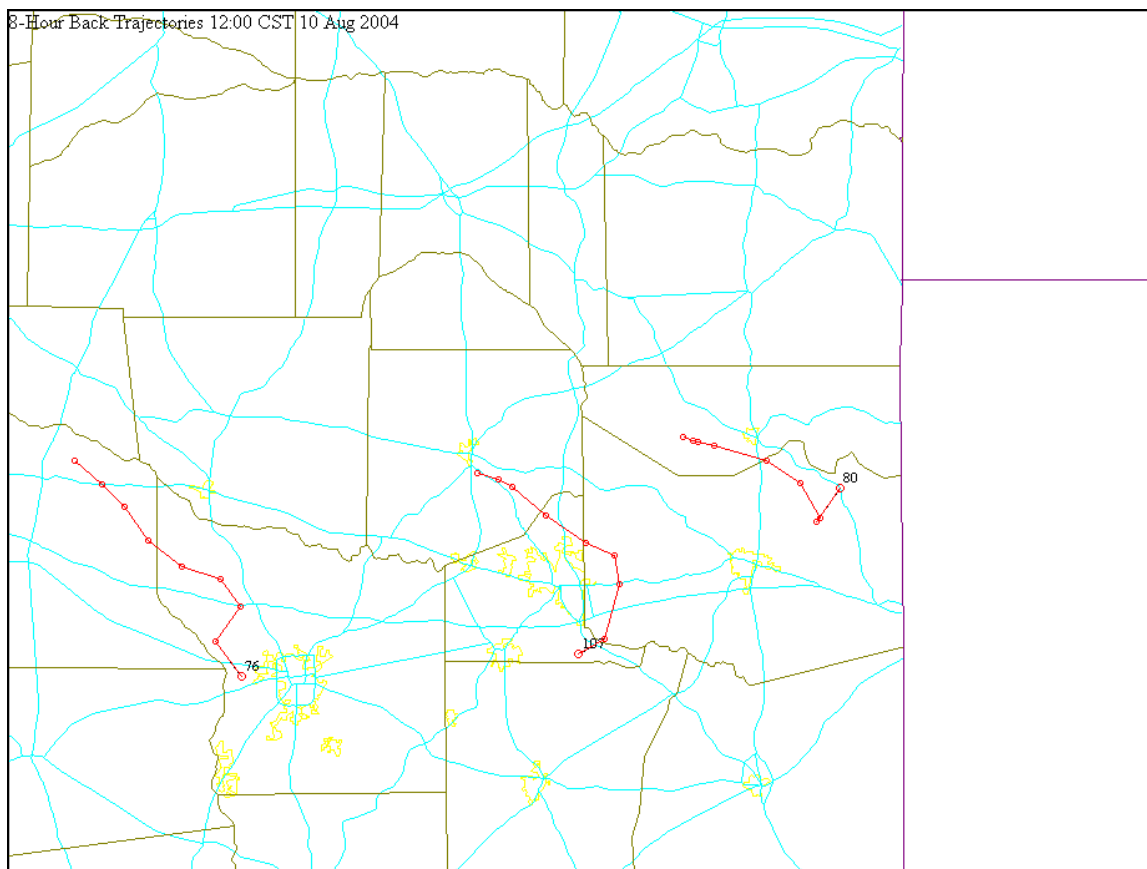


Figure 25. Back trajectories for 8-hour period ending 10 August 2004 at 12:00 CST.

17 August 2004

Hourly ozone data for 17 August (Figure 26) show a broad afternoon peak at Karnack which is roughly 20 ppb higher than the afternoon values at Longview, Tyler and Panola (except for a brief late day peak at Longview¹¹).

Hourly O₃, NO, NO₂, PM_{2.5} and wind directions at Karnack (Figure 27) show the high afternoon ozone levels were associated with elevated PM_{2.5} concentrations and S to SW winds. TCEQ staff identified plumes from two nearby forest fires on satellite pictures on this day with at least some of the smoke plumes blowing over the approximate location of the Karnack monitor (see Figure 28).¹² Precursor emissions from these fires may have contributed to the elevated ozone levels at Karnack.

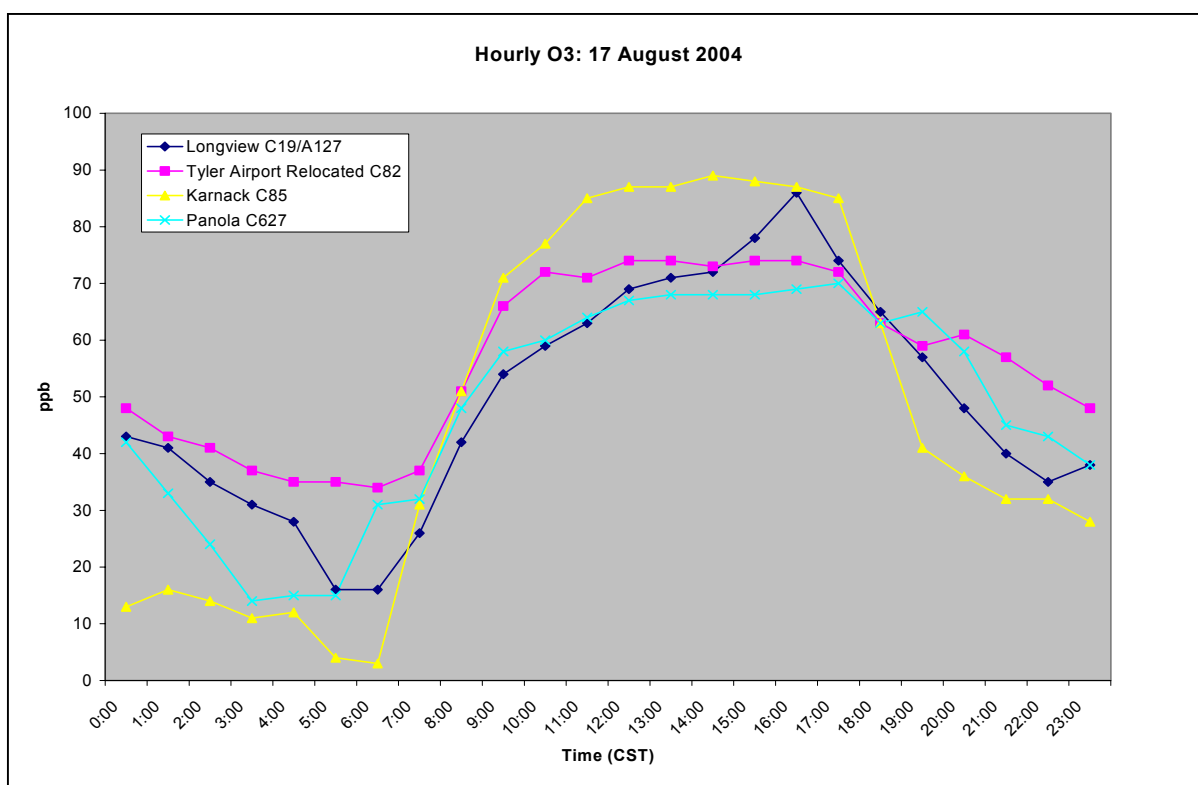


Figure 26. Hourly average ozone concentrations at monitors in NE Texas on 17 August 2004.

¹¹ Examination of hourly O₃, NO_x and SO₂ data from Longview show this late afternoon 1-hour O₃ peak of 86 ppb coincided with peaks in SO₂ and NO_x levels with a SO₂/NO_x ratio of 1.75:1 which is close to the 2:1 ratio typical of coal-fired power plant emissions.

¹² See <http://www.tnrc.state.tx.us/updated/air/monops/airpollevents/2004/event2004-08-17txne.html>.

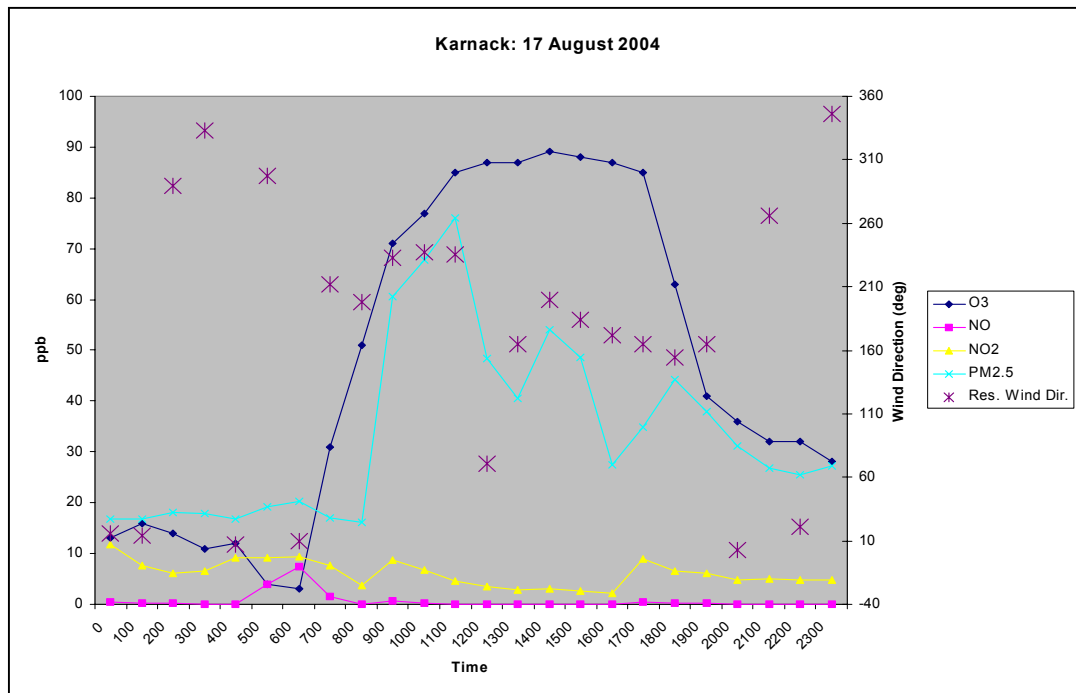


Figure 27. Hourly pollutant and wind direction data at Karnack (CAMS 85) on 17 August 2004.

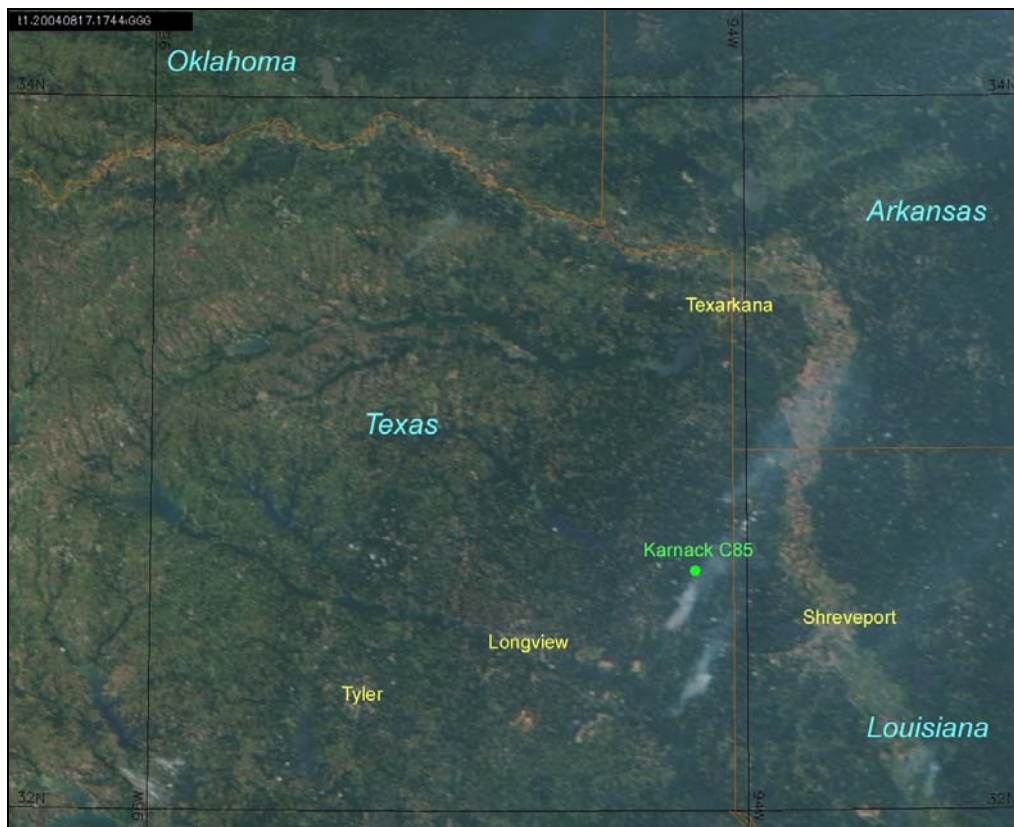


Figure 28. True color satellite image of NE Texas at 12:44 CST on 17 August 2004 showing smoke plumes from two fires at least one of which is traveling over the Karnack monitoring site. (source: <http://www.tnrc.state.tx.us/updated/air/monops/airpollevents/2004/event2004-08-17txne.html>)

10 September 2004

Hourly ozone data for 10 September (Figure 29) show a fairly similar diurnal pattern at all sites in NE Texas with the late afternoon peak level of 103 ppb at Tyler exceeding levels at Longview and Panola by just over 20 ppb and at Karnack by just over 40 ppb.

Hourly O₃, NO, NO₂ and wind direction at Tyler are shown in Figure 30. Wind directions ranged from NE to ESE all day. In contrast to many of the other high ozone events examined in this study, there was no large wind direction shift during the day. NO_x concentrations peaked at approximately 30 ppb just before sunrise.

The regional-scale Hy-Split back trajectory for air parcels arriving at Tyler during the hour of peak ozone on 10 September is shown in Figure 31. The trajectory shows steady movement of air parcels to the SW, arriving in NE Texas from Arkansas during the morning hours.

Local-scale eight hour back trajectories for air parcels arriving 15:00 CST at Tyler on 10 September are shown in Figure 32. The trajectory direction is consistent with the Hy-Split trajectory, originating over the city of Longview and passing over the city of Tyler before arriving at the monitoring site. Forward trajectories from large point and urban area sources computed by TCEQ for the 10 hour period ending 15:00 CST (Figure 33) also show the overlapping impacts of plumes from these two urban areas at the Tyler monitor. These results suggest that the alignment of local sources along the wind direction upwind of the Tyler monitor coupled with highly favorable regional meteorological conditions for ozone formation (as evidenced by the high ozone levels – up to 108 ppb 8-hour average – observed in Dallas on this day) produced the high ozone concentration at Tyler. Confidence in the trajectory results for this day is much greater than for days with more light and variable winds such as 23 June because the local-scale back trajectories are consistent with the Hy-Split trajectory and, together with the plume plots in Figure 33, show a consistent, steady flow from the NE over a large portion of NE Texas.

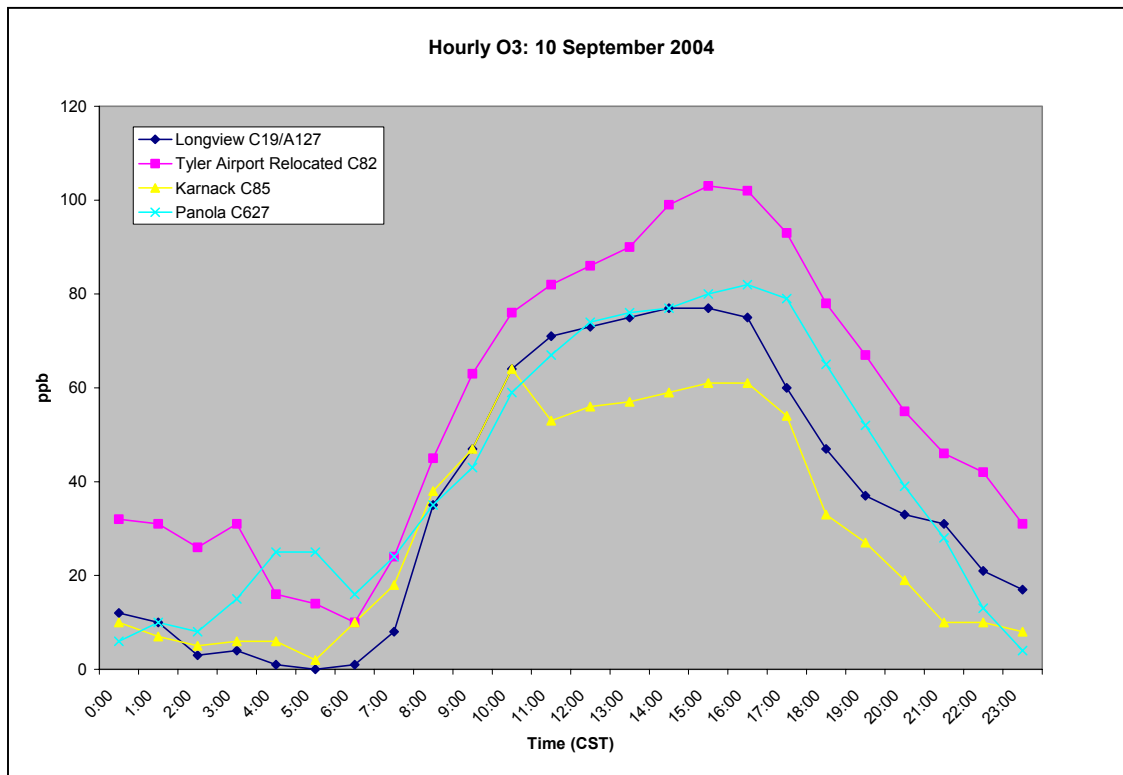


Figure 29. Hourly average ozone concentrations at monitors in NE Texas on 10 September 2004.

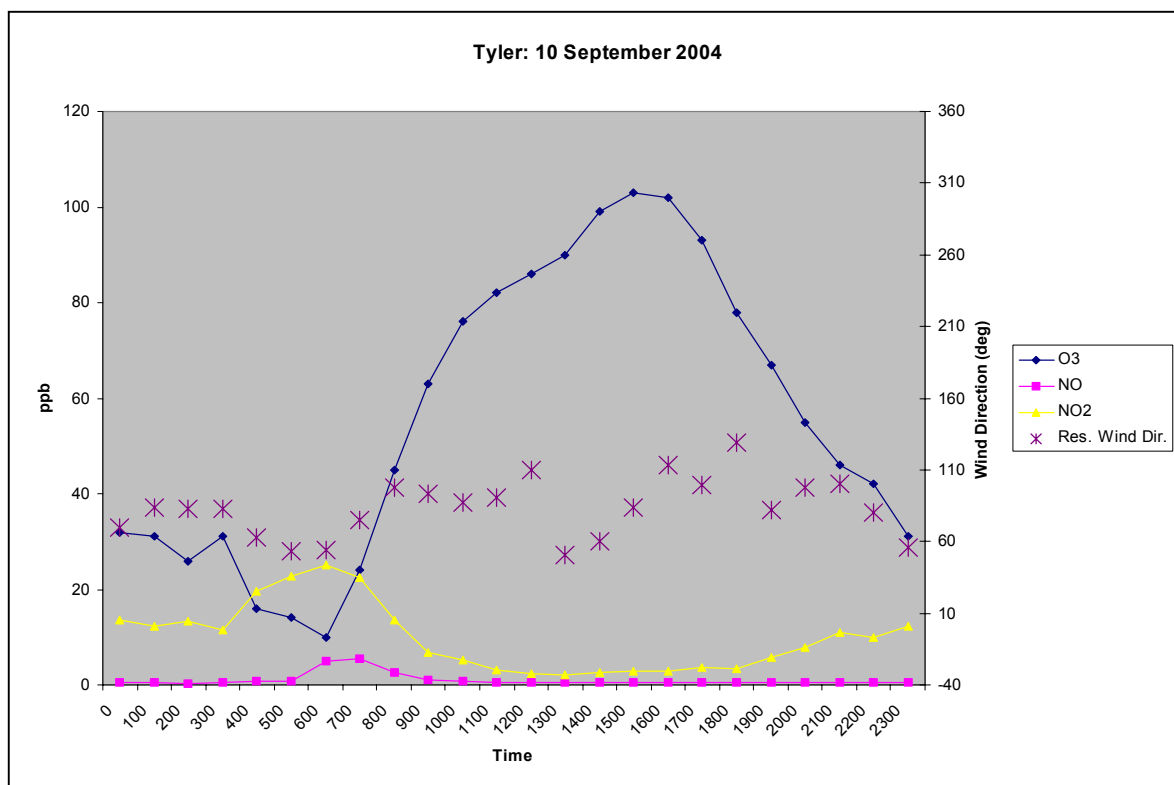


Figure 30. Hourly average O₃, NO, NO₂ and resultant wind direction at Tyler (CAMS 82) on 10 September 2004.

NOAA HYSPLIT MODEL
 Backward trajectory ending at 21 UTC 10 Sep 04
 EDAS Meteorological Data

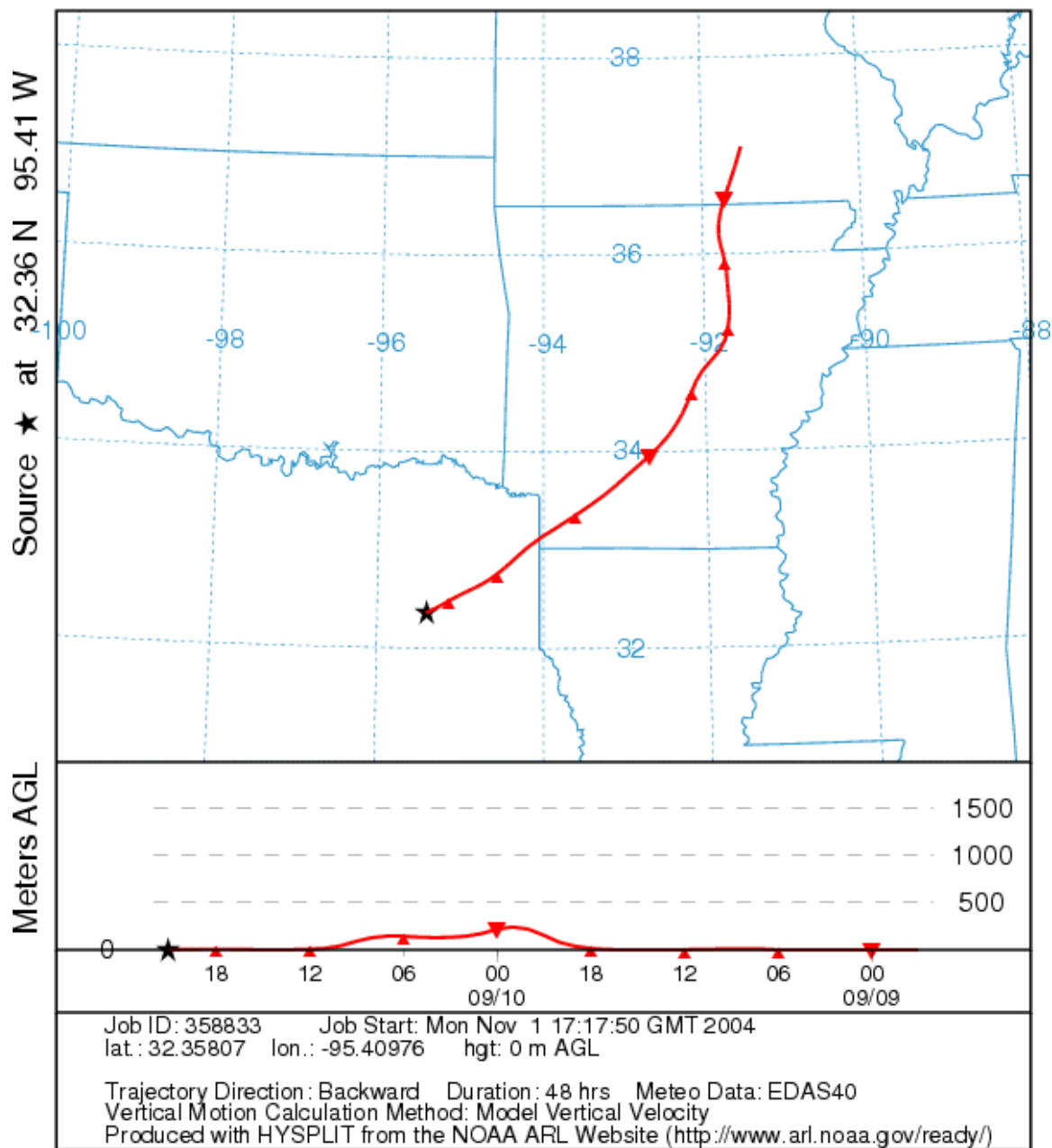


Figure 31. Hy-Split back trajectory for air parcel arriving at Longview at 15:00 CST on 10 September 2004.

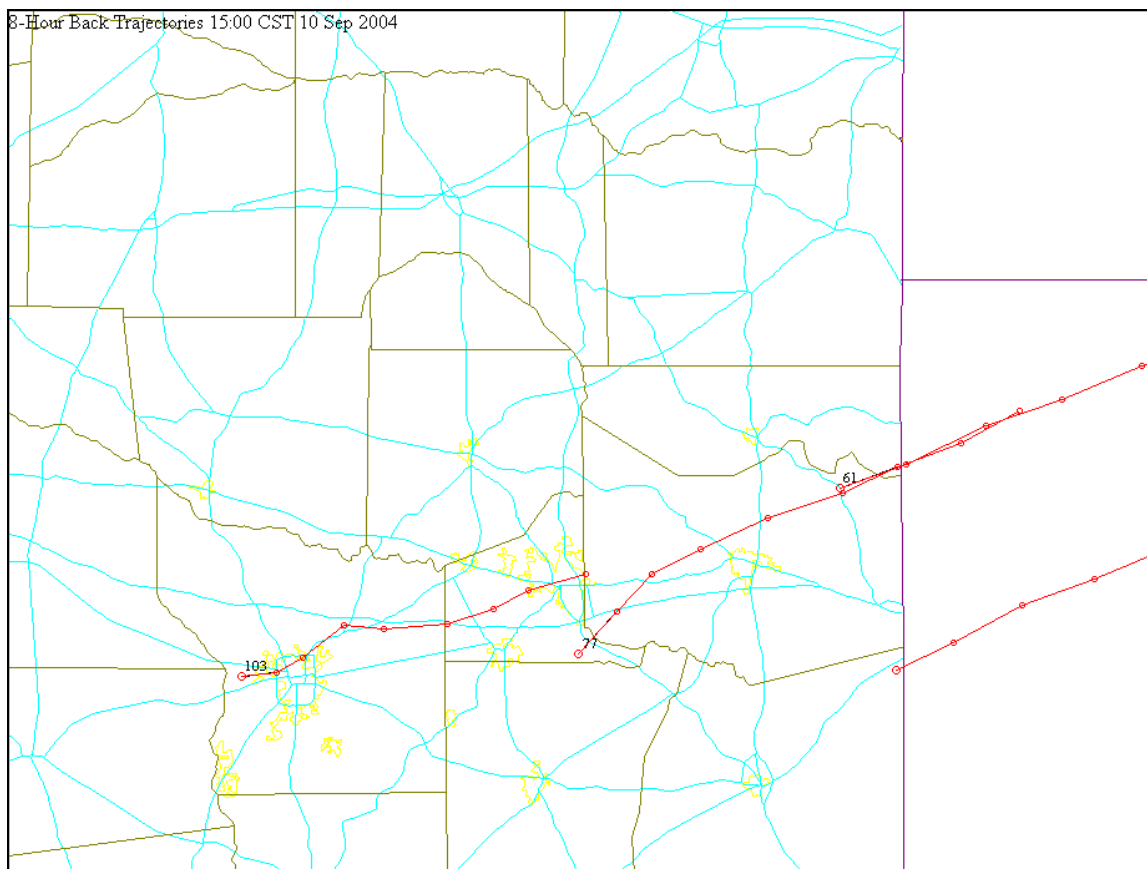


Figure 32. Back trajectories for 8-hour period ending 10 September 2004 at 15:00 CST.

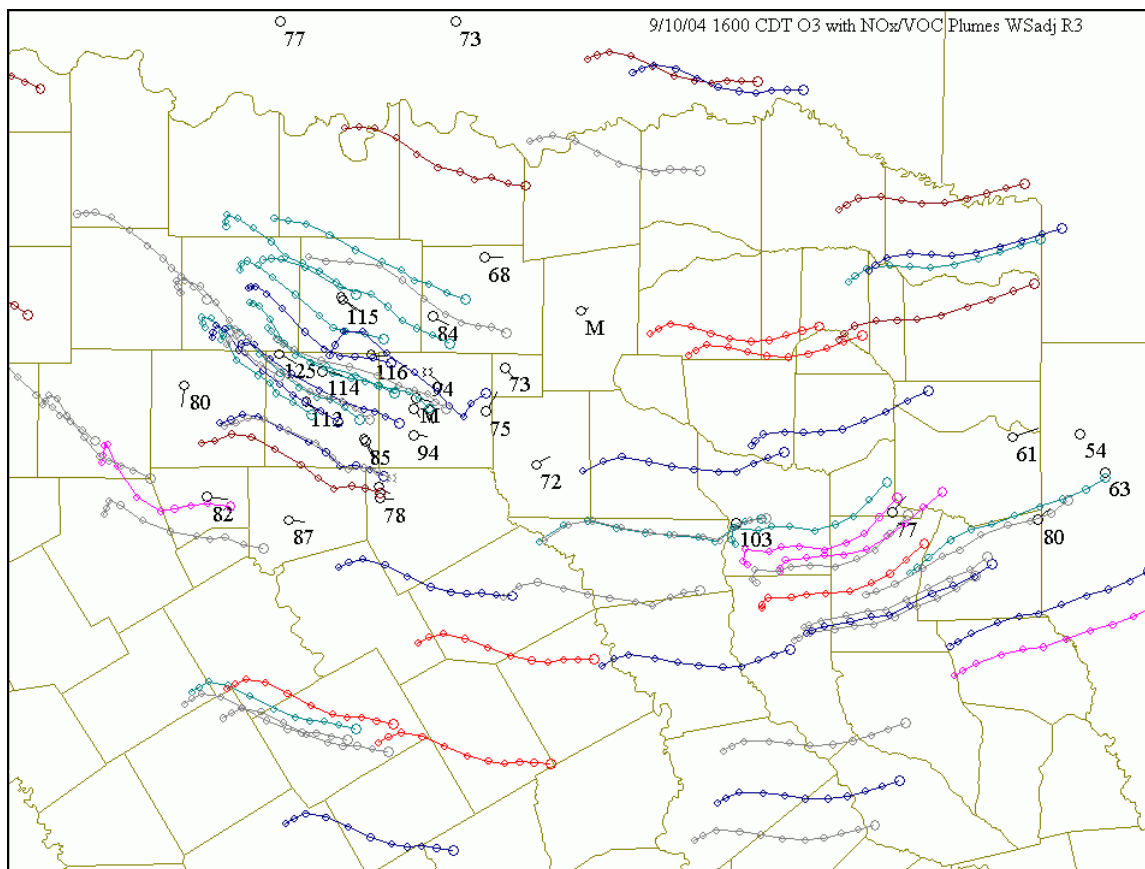


Figure 33. Positions of plumes in greater NE Texas on 10 September 2004 at 15:00 CST; plumes were released beginning 5:00 CST. Color coding indicates source type and strength (see Figure 9); plumes in dark Cyan represent urban core area sources. Numbers just below and to the right of each air monitoring station show ozone concentration at 15:00 CST in ppb.

29 September 2004

Hourly ozone data for 29 September (Figure 34) show similar concentration profiles at Karnack and Longview but with a roughly 20 ppb spike added mid-day at Longview. The diurnal ozone trace at Tyler for this day is very similar to that on 10 September.

Hourly O₃, NO, NO₂ and wind direction at Longview on 29 September are shown in Figure 35. Wind directions were quite variable, trending from W overnight, becoming variable near sunrise, SE during the morning and turning NE during the afternoon. The rise in O₃ between 12:00 and 14:00 is associated with a shift in wind direction from the SE to the N along with a slight increase in NO₂.

The regional-scale Hy-Split back trajectory for air parcels arriving at Longview during the hour of peak ozone on 29 September (Figure 36) shows the parcel arriving in Longview from the E and NE, as is typical of high ozone events in this area.

Local-scale eight hour back trajectories for air parcels arriving at 14:00 CST on 29 September are shown in Figure 37. These trajectories indicate stagnation and re-circulation of the flow in the hours just prior to the ozone peak. This local-scale feature is not resolved by the Hy-Split trajectory for reasons discussed above in connection with the 23 June event and we cannot be sure of the exact local trajectory positions in the hours just prior to arrival at Longview but these results are consistent with local stagnation and re-circulation just prior to the afternoon ozone peak. It is likely that this pattern resulted in a buildup of pollutants from sources within the vicinity of Longview. Examining of hourly plume position plots similar to those in Figure 9, 14 and 40 for this day (not shown) supports the hypothesis that plumes from local sources, possibly including downtown Longview, passed over the monitor between 13:00 and 14:00 CST. The time series of O₃ and NO₂ in Figure 35 show that air arriving at the Longview monitor from the north contained 20 ppb more O₃ and some additional NO₂ as compared to what was observed in the SE flow just prior to the mid-day wind shift.

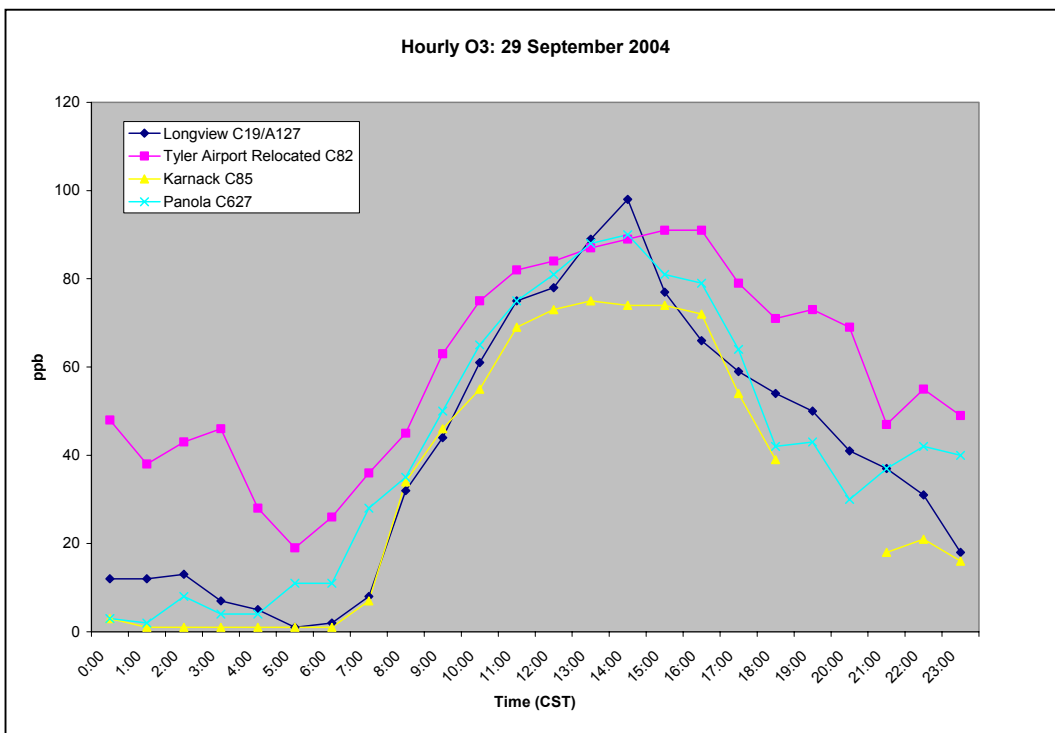


Figure 34. Hourly average ozone concentrations at monitors in NE Texas on 29 September 2004.

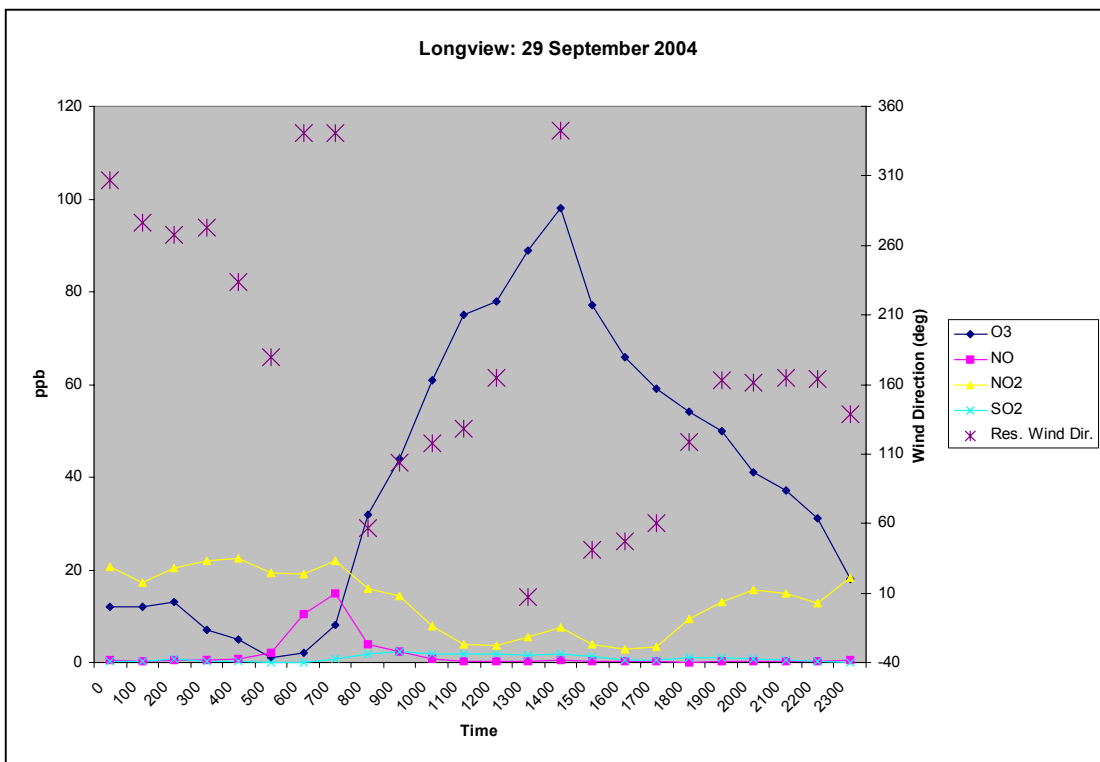


Figure 35. Hourly O₃, NO, NO₂ and resultant wind directions at Longview on 29 September 2004.

NOAA HYSPLIT MODEL
 Backward trajectory ending at 21 UTC 29 Sep 04
 EDAS Meteorological Data

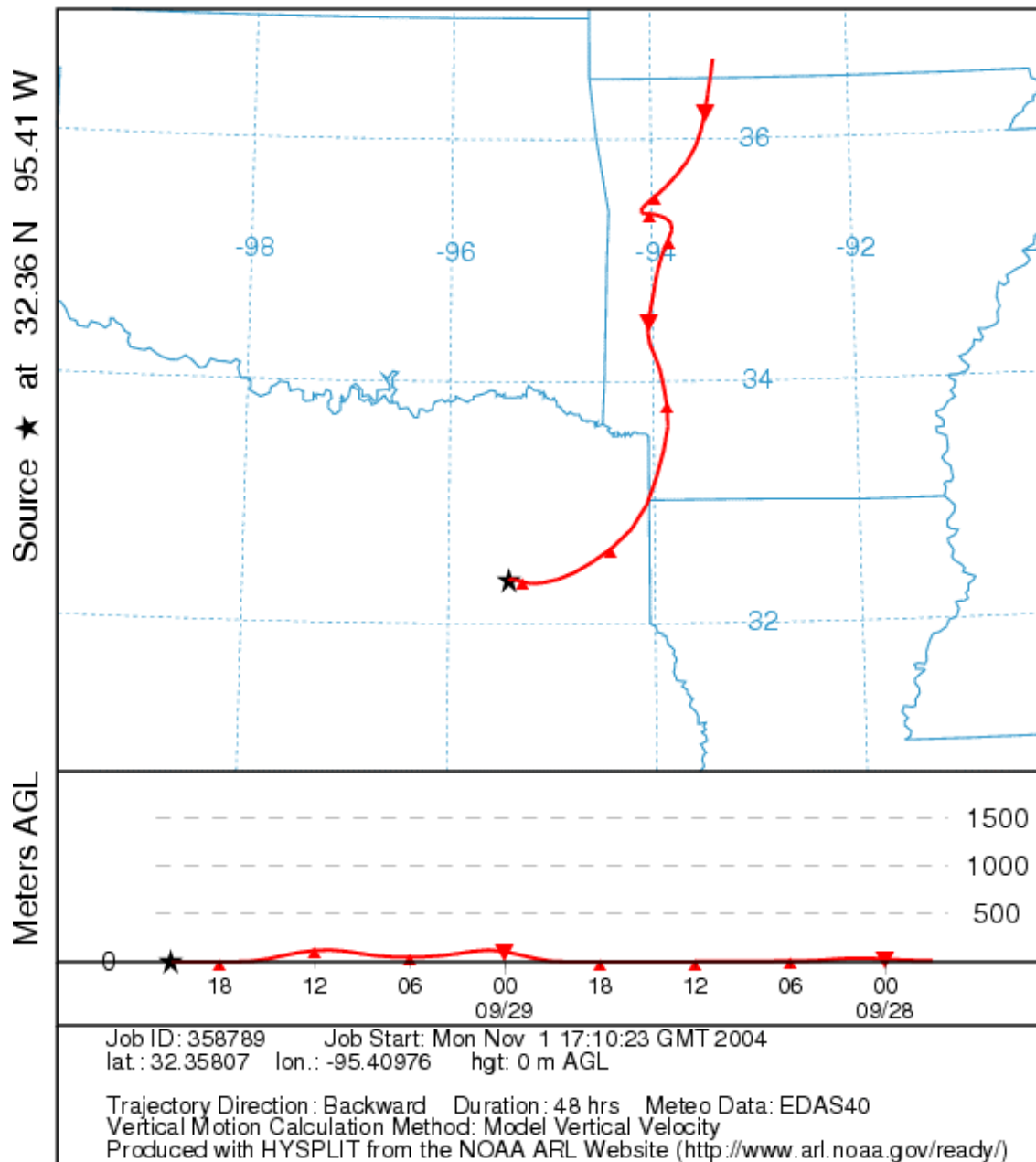


Figure 36. Hy-Split back trajectory for air parcel arriving at Longview at 15:00 CST on 29 September 2004.

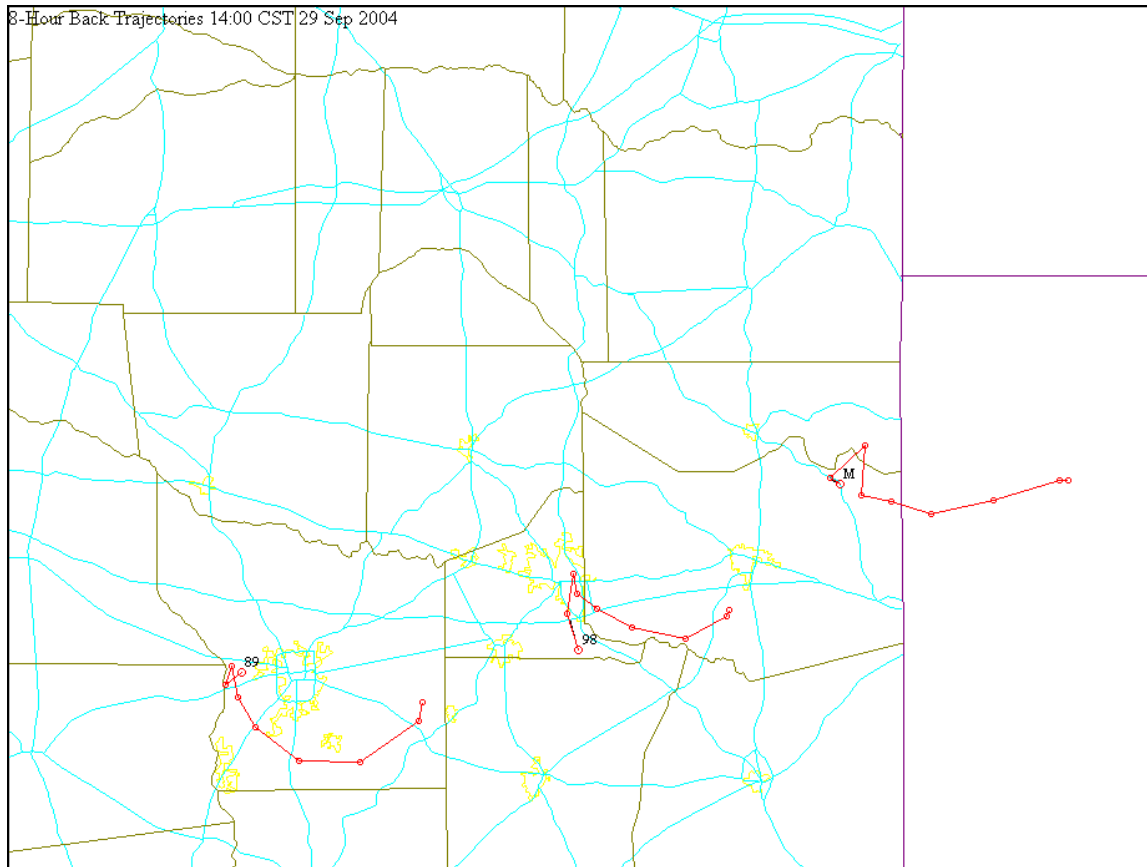


Figure 37. Back trajectories for 8-hour period ending 29 September 2004 at 14:00 CST.

1 October 2004

Hourly ozone data for 1 October 2004 (Figure 38) show a similar broad afternoon ozone peak at all sites in NE Texas with the highest peak at Karnack (90 ppb) occurring one hour after the peak of 87 ppb at Tyler. The diurnal patterns at Tyler and Longview are very similar but morning ozone at Tyler was 25 – 40 ppb greater than at Longview. With a morning ozone increase at Tyler nearly as large as that at Longview, this margin was only slightly eroded during the day. In contrast, both Longview and Karnack had similar ozone levels at sunrise but the ozone increase at Karnack outpaced that at Longview by 20 ppb.

Hourly O₃, NO, NO₂, PM_{2.5} and wind direction at Karnack on 1 October are shown in Figure 39. A wind shift from NE to SSW occurred at sunrise (6:00 CST) with the wind turning slowly SSE during the afternoon before becoming light and variable after sunset (18:00 CST). This is in contrast to Tyler where winds were SSE before and just after sunrise and turned SW after 9:00 CST. Elevated PM_{2.5} levels were observed at Karnack in conjunction with the southerly winds.

The regional-scale Hy-Split surface back trajectories for air parcels arriving at Tyler and Karnack at the approximate time of maximum ozone concentration are shown in Figure 40. The northerly paths followed by the surface air parcels just before arriving at the monitoring sites suggests that the air mass at higher levels may have come from further south, in particular from the emission rich Houston – Galveston – Beaumont/Port Arthur area. This suspicion is born out by comparing the surface trajectory for Karnack with trajectories for air parcels arriving at 500 m and 1000 m above the surface (Figure 41). As a result of the higher wind speeds at these levels, the trajectories extend further south to the Gulf coast area of SE Texas, passing between Houston and Beaumont/Port Arthur. This result provides some support for the hypothesis that transport of ozone and ozone precursors from the Gulf coast nonattainment areas may have been a contributing factor to the elevated ozone levels seen in NE Texas on this day.

Local-scale eight hour back trajectories for air parcels arriving at monitoring site in NE Texas at 13:00 CST on 1 October 2004 (Figure 42). These trajectories show a steady SW flow during the hours preceding the ozone peak, consistent with the Hy-Split results discussed above.

Examination of active fire determinations from MODIS satellite data for 29 September – 1 October (Figure 43) show a fire just to the south of Karnack during this period which, given the southerly wind pattern, could have resulted in some additional ozone at this site. This hypothesis is consistent with observations of elevated PM_{2.5} at Karnack (Figure 39).

As described above, conditions during this event are different from the other high ozone days observed in 2004: ozone peaks at all sites in NE Texas are broad and with relatively little difference in peak values from site to site which is consistent with the influence of a distant, large-scale group of sources. Trajectory results indicate possible transport of ozone and precursors from the Houston – Beaumont/Port Arthur area on this day.

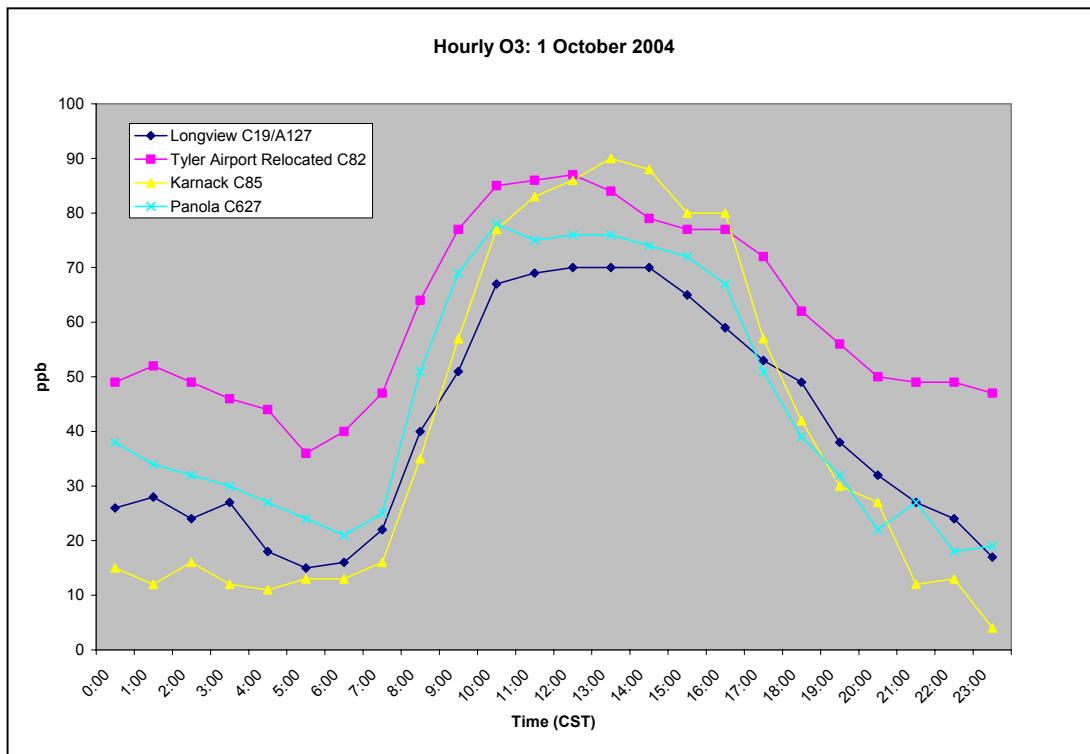


Figure 38. Hourly average ozone concentrations at monitors in NE Texas on 1 October 2004.

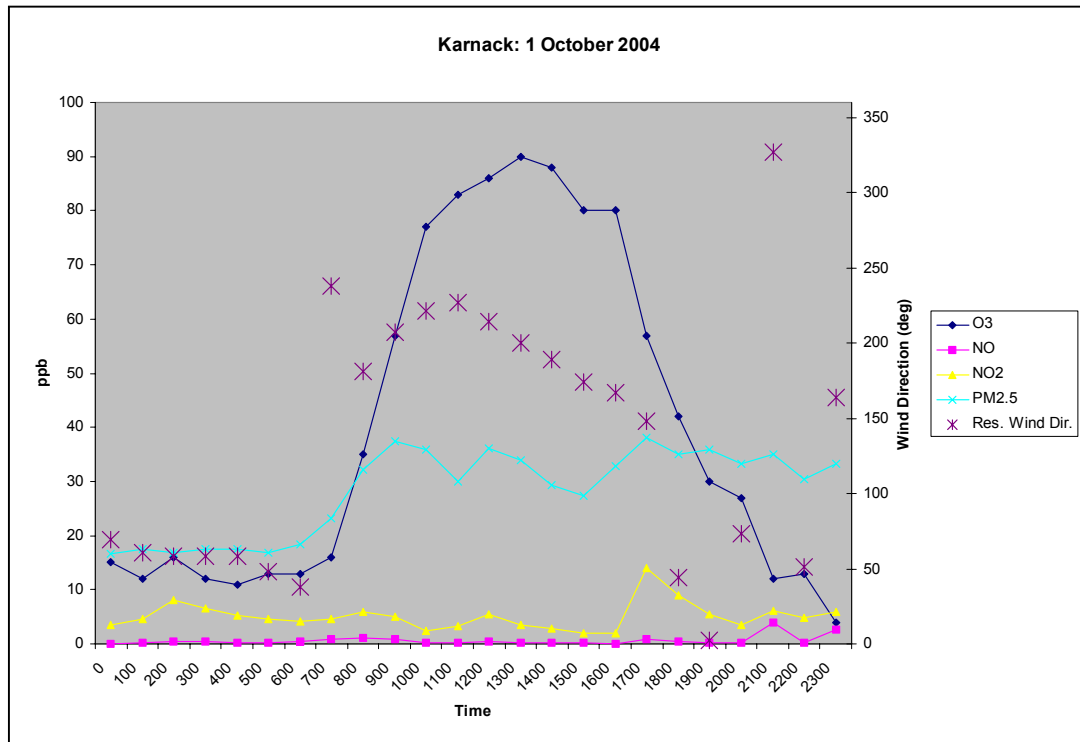


Figure 39. Hourly O₃, NO, NO₂, PM_{2.5} and resultant wind direction at Karnack on 1 October 2004.

NOAA HYSPLIT MODEL
 Backward trajectory ending at 18 UTC 01 Oct 04
 EDAS Meteorological Data

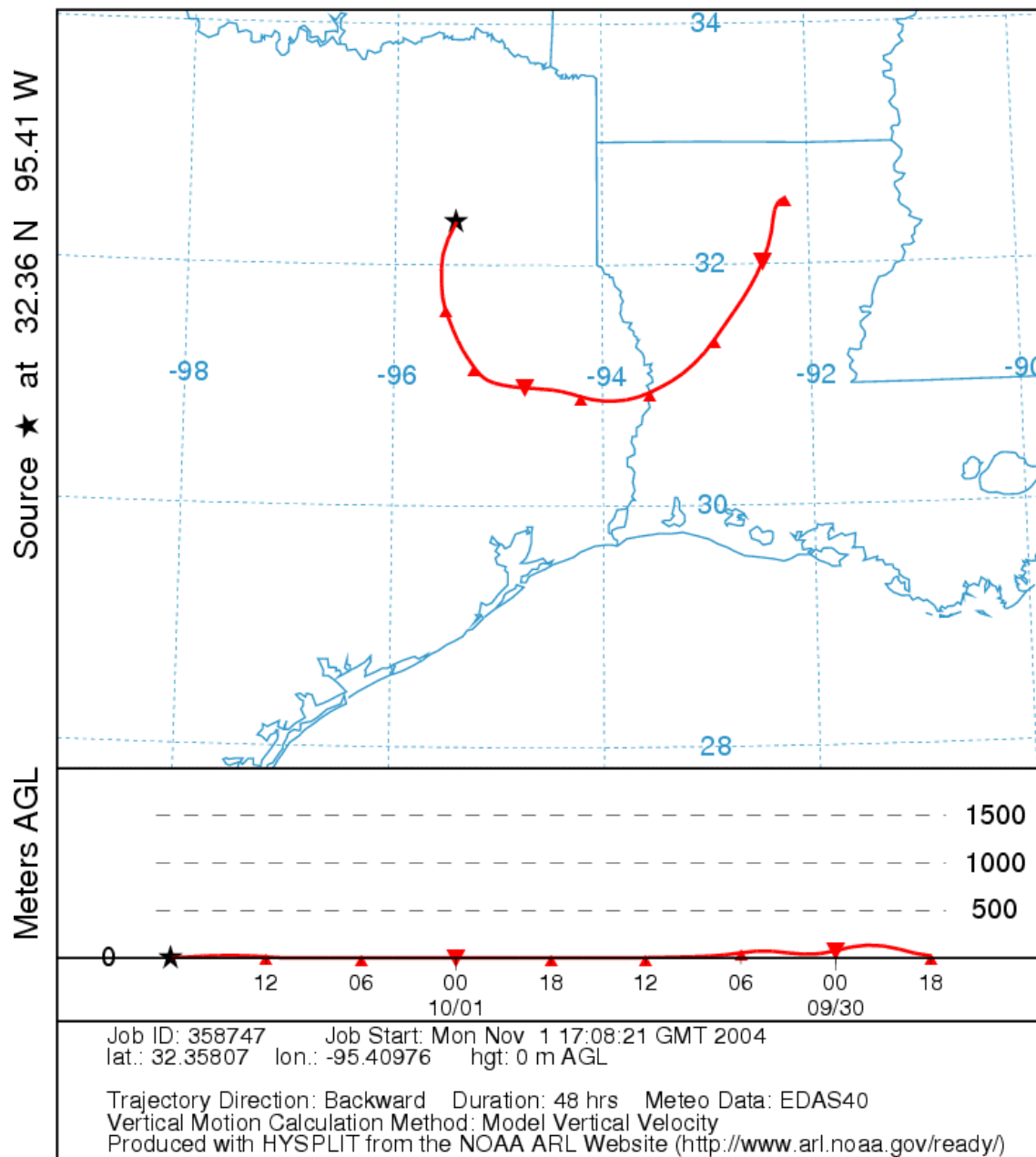


Figure 40a. Hy-Split back trajectory for air parcel arriving at Tyler at 12:00 CST on 1 October 2004.

NOAA HYSPLIT MODEL
 Backward trajectory ending at 18 UTC 01 Oct 04
 EDAS Meteorological Data

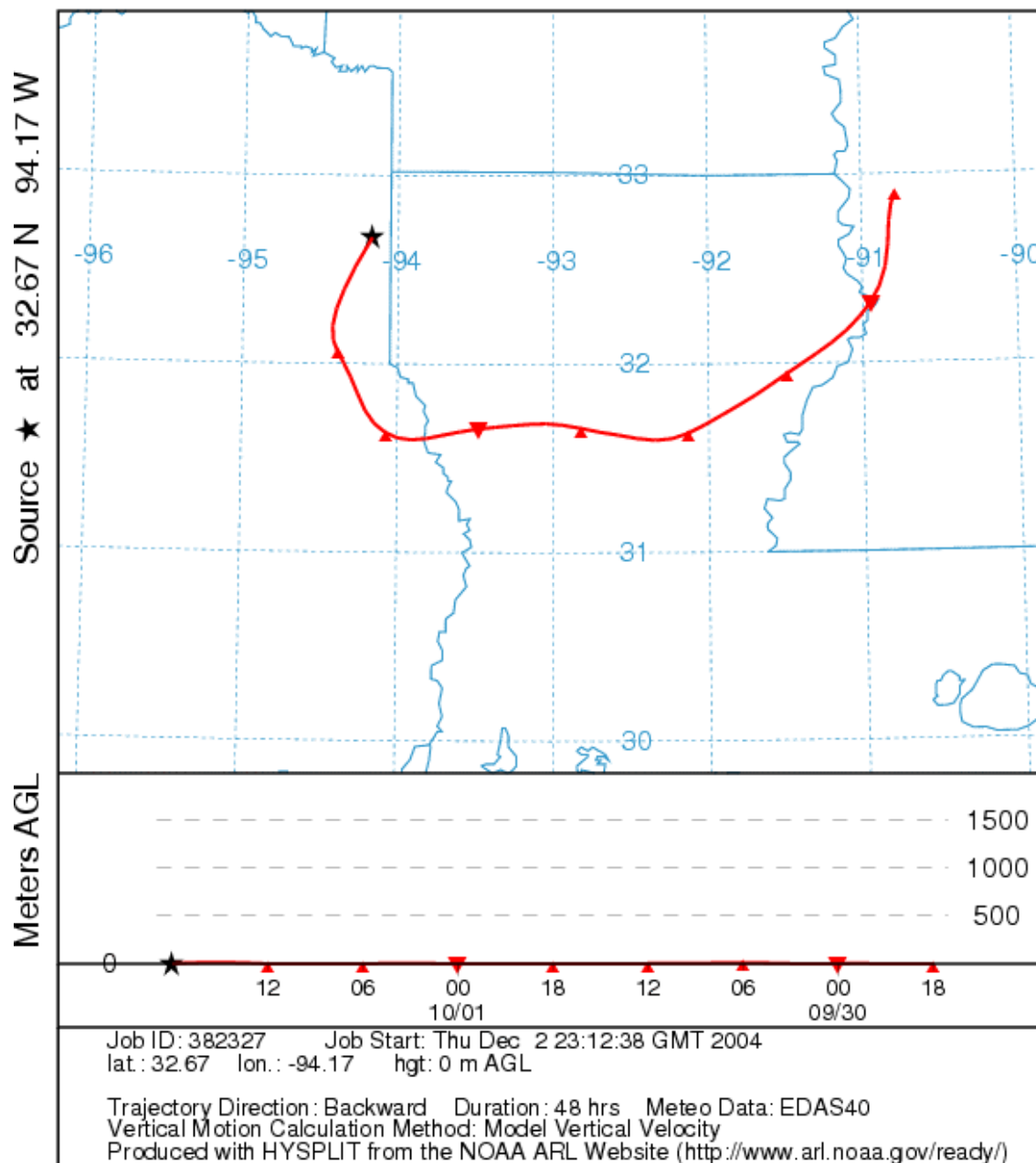


Figure 40b. Hy-Split back trajectory for air parcel arriving at Karnack at 12:00 CST on 1 October 2004.

NOAA HYSPLIT MODEL
 Backward trajectories ending at 18 UTC 01 Oct 04
 EDAS Meteorological Data

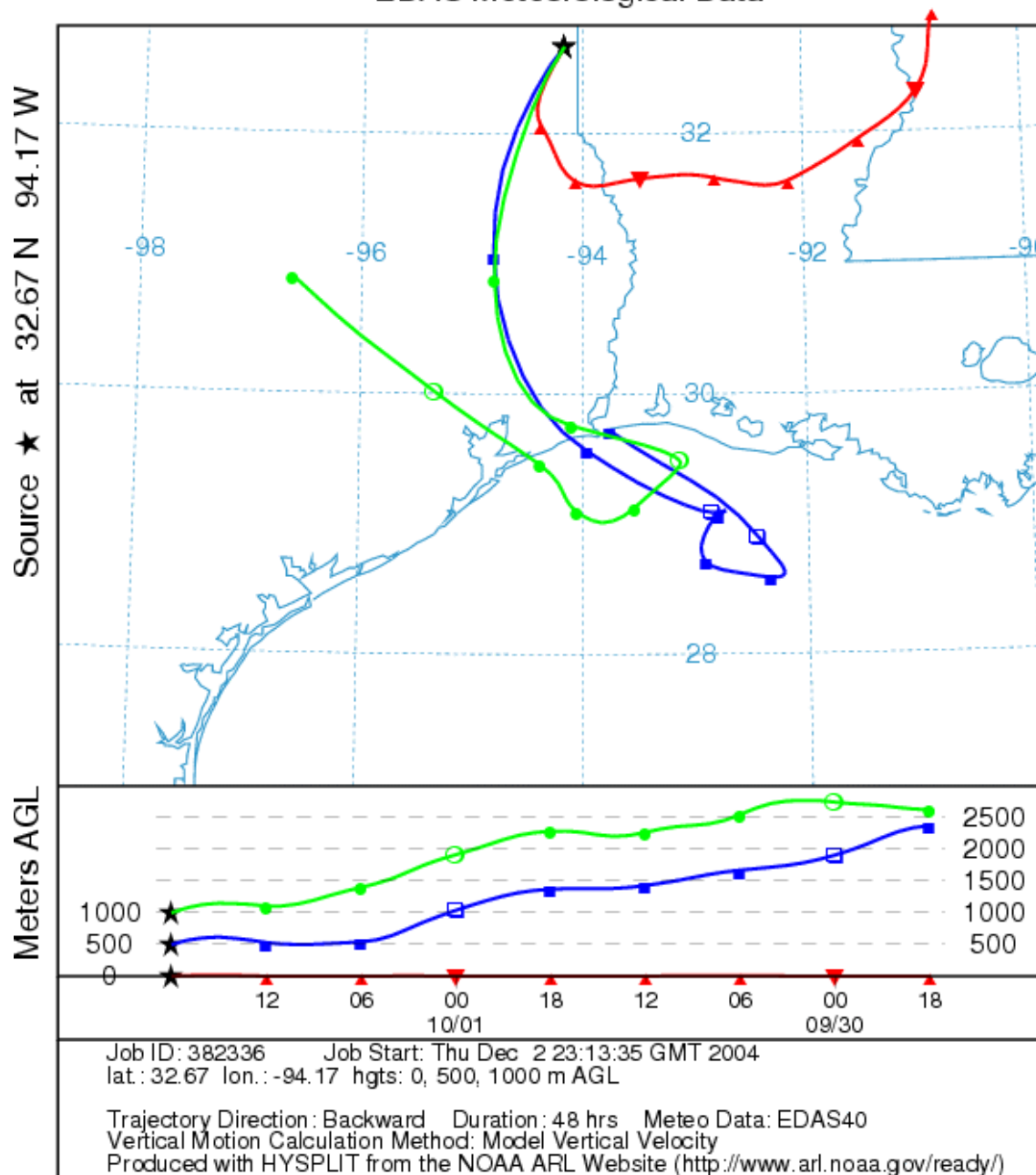


Figure 41. Hy-Split back trajectories for air parcels arriving at the surface (red), 500 m (blue) and 1000 m (green) levels at Tyler at 12:00 CST on 1 October 2004.

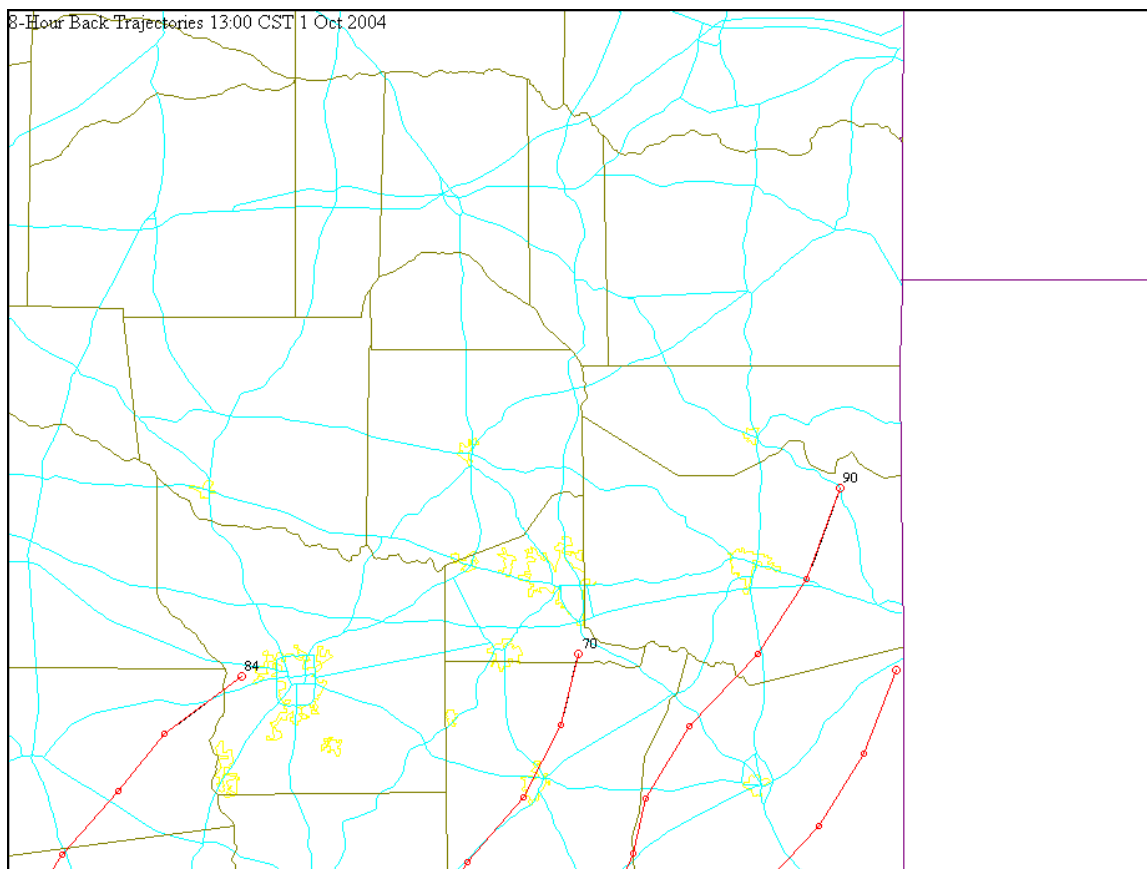


Figure 42. Back trajectories for 8-hour period ending 1 October 2004 at 14:00 CST.

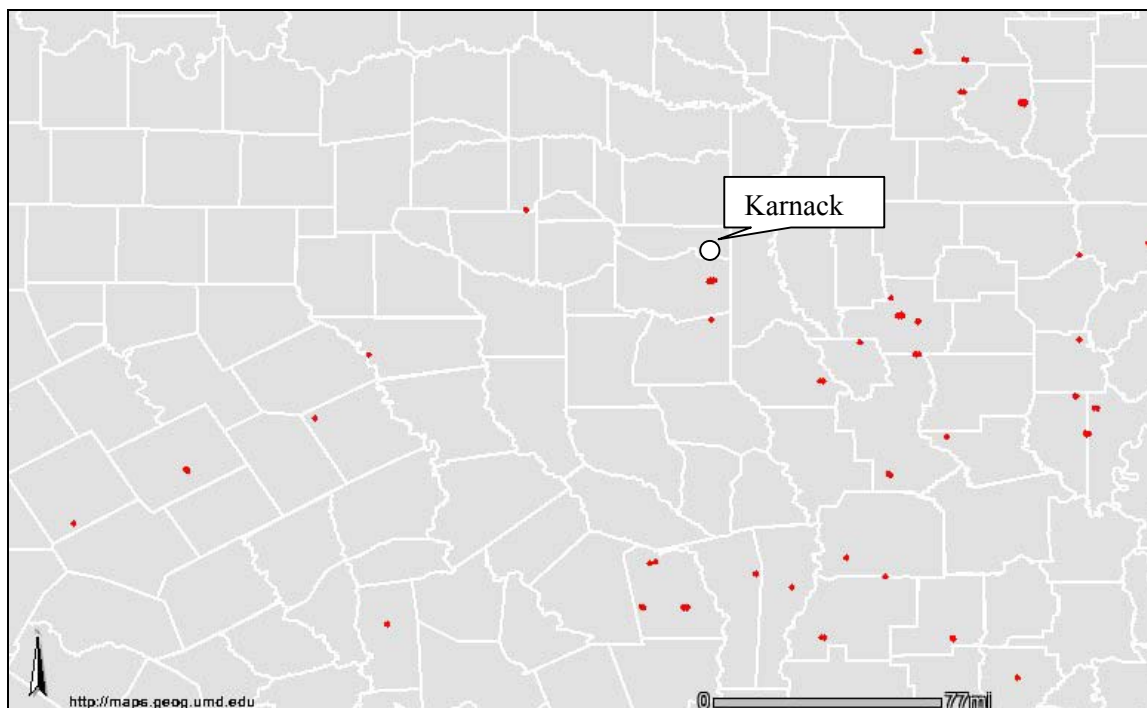


Figure 43. Locations of active fires in NE Texas and vicinity from MODIS: 30 September – 1 October 2004.

SUMMARY

Principal features of the 2004 high ozone events in NE Texas described above are summarized in Table 3. For each day, a rough estimate is given of the regional background ozone level and the additional amount of ozone produced from local sources. These estimates are based strictly on comparisons of the highest and lowest daily maximum hourly ozone concentrations across the (up to four) monitoring sites in NE Texas operating on the given day. We are thus making the implicit assumption that the lowest daily maximum value represents the regional background and the difference between this value and the highest value reflects the amount of local ozone production. Both the background and local production estimates are rounded to the nearest 10 ppb. Regional background ozone levels on the five days on which the 8-hour standard was exceeded ranged from 50 – 80 ppb, representing a substantial fraction (from just under one-half to as much as three-fourths) of the daily peak ozone. Thus in 2004, as in prior years, elevated regional background ozone continues to be an important contributor to ozone exceedance events in NE Texas.

As shown in Table 3, four of the nine days examined (23 June, 19 July, 3 August, 10 August) are characterized by a shift in wind direction during the middle of the day from N-NW to NE-SE. This resulted in a re-circulation pattern that kept ozone precursor emissions within the local area, allowing concentrations to build and more ozone to be formed. Due to the location of the Longview air quality monitor near several major point and area sources, the resulting ozone impact was higher at this site than at the other monitors. Positions of plumes from major point sources in the area estimated via spatial interpolation of hourly surface winds, although subject to considerable uncertainties under these types of conditions, show plume passages over the Longview monitor were roughly coincident with times of elevated ozone and NO_x concentrations on all four days examined. Elevated SO₂ was also observed in some cases, consistent with coal-fired power plant plume impacts. The re-circulation pattern was most pronounced on 3 August, resulting in a broad diurnal ozone peak and thus a comparatively high 8-hour average concentration.

September 29 represents a slight variation on the re-circulation pattern described above as morning winds on this date at Longview were from the SE and the presence of a local peak added on top of an elevated regional background is less clear than on the other four re-circulation days. Nevertheless, the local scale trajectory results for this date are consistent with the hypothesis that local sources, including sources in the Longview urban area, contributed to the mid-day 20 ppb jump in ozone at Longview on this date.

Table 3. Principal features of high ozone events in NE Texas during 2004.

Date	Winds (morning) shifting to (afternoon) ¹³	Location of Peak O ₃	Flow Pattern (from back trajectories)	Est. Regional Background Ozone (ppb) ¹⁴	Est. Local Ozone Production (ppb) ¹⁵
23 June	N-NW shifting to NE-SE	Longview	Re-circulation	40	80
19 July	N-NW shifting to NE-SE	Longview	Re-circulation	50	60
20 July	SW shifting to NE	Longview	From SE	80	30
3 Aug	N-NW shifting to NE-SE	Longview ¹⁶	Re-circulation	70	50
10 Aug	N-NW shifting to NE-SE	Longview	Re-circulation	80	30
17 Aug	S – SW all day	Karnack	From S-SW	70	20
10 Sep	NE-E all day	Tyler	From NE- E	60	40
29 Sep	SE shifting to NE	Longview	Re-circulation	80	20
1 Oct	SW shifting to SE	Longview-Karnack	From S-SW	70	20

A variety of conditions were found to be associated with the other four high ozone days listed in Table 3 (20 July, 17 August, 10 September and 1 October):

- 20 July was characterized by a faster and longer lasting flow regime from the ESE during the afternoon than on the re-circulation days and high 1-hour ozone peaks were observed at Karnack and Panola in addition to the peak at Longview. These observations are consistent with ozone and precursor transport from Louisiana. The simultaneous SO₂, NO_x and O₃ peaks on the afternoon of 20 July at Longview (with an SO₂/NO_x ratio of 2:1 and a short-lived 30 ppb bump-up in ozone) are consistent with the impact of a coal-fired power plant plume. Further investigation is needed to understand the sources of high ozone at Karnack and Panola on 20 July.
- Conditions on 17 August are consistent with emissions from nearby fires impacting the Karnack monitor which recorded the highest ozone on this day. A late afternoon O₃ peak at Longview is associated with a peak in SO₂ and NO_x at a SO₂/NO_x ratio of nearly 2:1, consistent with impact of a coal-fired power plant plume.
- Steady E to NE winds on 10 September appear to have resulted in the superposition of plumes from the cities of Longview and Tyler over the Tyler monitoring site under conditions highly favorable to ozone formation, resulting in an exceedance of the 8-hour standard at Tyler on this day.
- Moderately high ozone readings on 1 October were associated with a steady S- SW flow. Back trajectory calculations show results consistent with potential transport of ozone and ozone precursors from Louisiana or southeastern Texas, including the Houston – Beaumont/Pt. Arthur areas. Some of the ozone at Karnack may also have been associated with a fire detected just to the south of the monitoring site.

¹³ From wind data at monitor with highest daily maximum 1-hour O₃ concentration.

¹⁴ Based on lowest of the daily maximum 1-hour values at monitors in NE Texas on this day (rounded to nearest 10 ppb).

¹⁵ Based on difference between highest and lowest daily maximum 1-hour values at monitors in NE Texas on this day (rounded to nearest 10 ppb).

¹⁶ Late short-term peak at Panola (see Table 1).

Given the potentially important role played by large local sources on many of the high ozone days discussed above, we examined continuous emissions monitoring (CEM) data from the three major electric utilities in the Tyler-Longview-Marshall area on the high ozone days listed in Table 2 (all except 17 August). These data were provided by the plant operators. Daily NO_x emissions from these sources on the high ozone days are compared with the average daily emissions for the entire study period (23 June – 1 October) in Figure 44. Day-specific emissions at Pirkey and Knox Lee are very close to the average; emissions at Pirkey on 3 August were below average. Emissions at Knox Lee varied from day-to-day with the highest values (roughly double the average) on 3 August and 10 August. The plant did not operate on 10 September and for most of 1 October. In addition, a review of records of episodic releases of VOCs on the high ozone days examined for this study provided by Texas Eastman revealed no major releases on these days. No data was provided by plant operators on potential releases from the co-located Huntsman facility. These results show that the high ozone events examined in this study were not associated with any unusual source activity but they confirm that local sources identified above as potentially contributing to the observed high ozone levels during the stagnation/re-circulation events were operating during these events.

CONCLUSIONS

Our review of high ozone events in NE Texas shows that ozone levels during the 2004 season were in line with those that have been observed in the area since 2001 and that the meteorological conditions associated with these events are similar to those identified in earlier studies.^{17,18,19} The current 8-hour ozone design value for the area remains just below the level of the National Ambient Air Quality Standard and between one and three exceedances of the standard have been recorded at Longview each year since 2001. There therefore remains the possibility that a series of adverse weather events could result in a violation of the standard sometime in the near future.

Results of our analysis confirm that the single most common set of circumstances resulting in high ozone in NE Texas is a stagnation/re-circulation pattern under which precursor emissions from sources in the vicinity of the Longview monitor build up during the day forming ozone that, when added to a high regional background ozone level, results in a mid-day hourly ozone peak at Longview as high as 120 ppb and an 8-hour average that can exceed 100 ppb. From the 2004 data, it appears that a minimum regional background of 50 ppb is required to produce an exceedance of the 85 ppb 8-hour standard under these conditions. The highest ozone is usually observed at Longview during these types of events due to the arrangement of local sources in an arc extending from the N to the SE of the monitoring site.

Besides the stagnation/re-circulation pattern described above, high ozone concentrations were observed under a variety of other conditions during 2004. While the local sources most likely to

¹⁷ Stoeckenius, T. and G. Yarwood, 2004. *Conceptual Model of Ozone Formation in the Tyler/Longview/Marshall Near Nonattainment Area*. ENVIRON Int. Corp., January.

¹⁸ Yarwood, G., G. Mansell and C. Emery, 2000. Conceptual model for 8-hour ozone in East Texas and episode selection for new photochemical modeling. Memorandum to NETAC Technical Committee, ENVIRON International Corp., 12 September.

¹⁹ Stoeckenius, T., G. Yarwood, S. Coulter-Burke, E. 2002. *Analysis of Factors Influencing Ozone Trends in the Tyler/Longview/Marshall Near Nonattainment Area*. Prepared for East Texas Council of Governments, October.



have contributed significantly to these events varied from day to day (impacts from coal-fired sources, local fires, superposition of the Longview and Tyler urban plumes), these events all have in common the presence of a very high regional ozone background ranging from 60 to 80 ppb. Thus, emissions on a large regional scale continue to play an important role in producing conditions that can lead to 8-hour ozone exceedances in NE Texas.

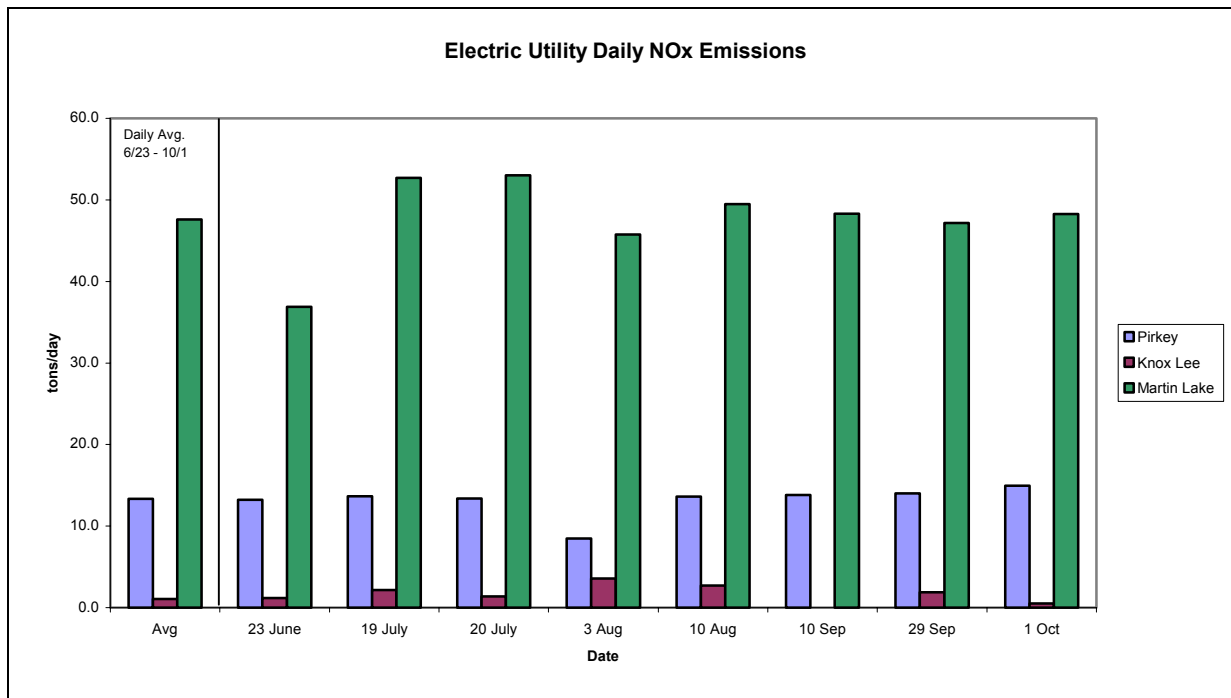


Figure 44. Daily NO_x emissions from electric utilities in the Tyler-Longview -Marshall area on high ozone days in 2004 compared to average over all days from 23 June to 1 October.