Conceptual Model for Extreme Ozone Concentration Events in Dallas and East Texas Based on Reduced Dilution in Frontal Zones

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1.0 Introduction

As Texas begins to develop SIPS for attaining both 8-hour- and 1-hour-average ozone standards it is important to determine the environment in which high concentrations occur. Texas has already developed conceptual models for high concentrations for several urban areas including San Antonio, Houston, Dallas, and Port Arthur-Beaumont. This paper is a contribution to building a conceptual model of extreme concentrations for Dallas and East Texas.

This paper carries out a detailed analysis of the episode occurring during August 12-20, 1999. This episode has been identified as the controlling or design episode for 1-hour- and 8-hour-average ozone concentrations in the Dallas area. The episode occurring earlier in the month (August 1-6,1999), which had the highest concentrations of the year, is examined although in less detail. This case-specific report supplements the analyses by TCEQ (Breitenbach, 2003) and is complementary to the statistical analysis of East Texas background values by Nielsen-Gammon et al. (2004). We will heavily reference these studies to support the work described here and provide supplementary interpretations of some of their analyses.

The overarching hypothesis in this report is that the high ozone concentrations in Dallas during the 1999 episode are largely the result of a lack of dilution of mostly local and East Texas sources rather than long-range transport. The extreme concentrations may be due to relatively small-scale areas of near-zero winds ("dead zones") superimposed upon a broad area of weak winds. The dead zones appear to arise from deformed flows near stationary fronts and difluent zones associated with mesoscale high-pressure systems that reduce horizontal dilution. The fronts and small high-pressure systems may limit mixing heights. While this report emphasizes the dead zones and their lack of dilution it is recognized that other synoptic and mesoscale can contribute to extreme events.

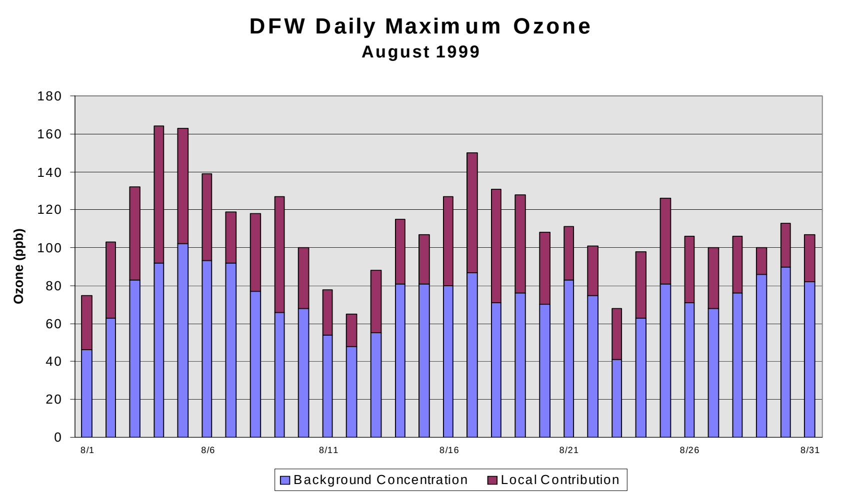

Figure 1.1 Plot of daily ozone values for DFW after Breitenbach 2004

The high ozone levels in the summer of 1999 are given in Figure 1.1 The ozone levels of August 14-20 for the Dallas area (Breitenbach, 2003) are given in Table 1. As with all design episodes, the levels are extraordinarily high, representing the extremes of the ozone statistical distribution. Thus, factors exist in the physical, chemical, or emission environments that turn average or moderately high ozone levels into extreme values.

In the Southeast (see Part I), it was found that high ozone events occurred on relatively small scales and that for most of the extreme events (design days) frontal boundaries were present. A theory based on characteristics of deformed flow near stationary fronts, which produces a near-zero wind area without divergent stretching, is postulated as the physical linkage between the frontal zones and the extreme concentrations.

Section 2.0 describes the theory and explains how extreme concentrations might be generated near frontal boundaries. Section 3.0 interprets the episode of August 12-20,1999, in light of this theory. Section 4.0 discusses structure and coherence functions as a way to understand the spatial scale of ozone. Section 5.0 briefly discusses the 1999 episode with respect to the statistical analysis of Nielsen-Gammon et al. (2004). Finally, Section 6.0 gives the summary and conclusions, and Section 7.0 makes recommendations for future work.

- August 13 - August 22, 1999 Episode

Day	Date	Max 8 hr O3	Site Name	# Sites	Remarks
F	Aug 13	67	Frisco	0	Ramp Up Day
Sa	Aug 14	103	Arlington	4	
Sun	Aug 15	97	Keller	6	
M	Aug 16	107	Keller	6	
T	Aug 17	**126**	Frisco, Denton	7	
W	Aug 18	116	Frisco	4	
Th	Aug 19	108	Midlothian	2	
Fri	Aug 20	98	Midlothian	1	
Sa	Aug 21	98	Arlington	5	
Sun	Aug 22	108	Denton	2	
Mon	Aug 23	59	Denton	0	

Table 1. From Breitenbach 2003

6.0 Summary and Conclusions

The present study has examined the meteorological conditions associated with extreme ozone events in the DFW region. The analysis and discussion centered upon the hypothesis that light winds associated with stationary fronts lead to a local buildup of ozone and precursors. The theory and basis of this hypothesis were discussed.

The meteorological analyses showed that in both events stationary fronts were a part of the descriptive synoptic field. An analysis of both observed winds and mesoscale model winds showed that the DFW area and a large part of East Texas were in an extreme light wind environment. Back trajectories were relatively short in this environment.

A spatial analysis of ozone data showed that concentrations were high where winds were light near the frontal zones and old air mass boundaries. Ozone levels were fairly low away from the frontal zones. A spatial-coherence analysis of ozone using a 60-ppb threshold confirmed that in general the spatial scale of high ozone levels is relatively small.

In terms of transport the dominant effect may have been small-scale movement of these local, high-concentration areas. While north and northeasterly winds may have been associated with high ozone, this was likely due to the fact that these N-NE winds were associated with poor dilution rather than transport of ozone from outside the region. As evidence, areas to the north-northeast in Oklahoma and Arkansas had relatively clean air. An examination of longer back trajectories indicated subsiding air from the free troposphere that may have contributed to the clean conditions to the north-northeast. Shorter trajectories into the DFW area, especially on August 16 and 17, had paths from the east-southeast almost along the frontal boundary itself. It is likely that shorter trajectories may have brought in higher levels of ozone along the front to the DFW area and thus contributed to the high background levels on August 17 identified by Breitenbach (2003).

As the episode progressed, the higher ozone levels in the frontal zone sagged south of DFW. In subsequent days, as winds vacillated between the northeast and southeast, the ozone in the frontal areas may have moved back into the DFW area as the winds shifted back to a southerly direction.

In retrospect it is perhaps not surprising that stationary fronts are associated with high ozone levels. With these fronts there is little movement of new air masses into an area. This is at the heart of what defines a lack of dilution.

As with many aspects of meteorology, the real world situation does not always perfectly match ideal hypotheses or models. While the situation in the DFW area had many of the aspects of the idealized deformation-zone hypothesis in its early phases, the situation became more complex and less ideal as the episode progressed. However, while the classic deformation field associated with the frontal boundary was harder to discern, the entire area was a stagnant zone with continental air to the north and marine air to the south. In this environment difluent zones and small-scale high pressure systems produced areas of extreme light winds over the East Texas area.

In terms of guiding control-strategy development, this study points to the episodes of August 2-6 and August 12-22 as being primarily driven by local emission sources within an extraordinary weak-wind environment. However, this does not mean that control strategies targeting only local urban mobile and point sources will be successful. In the environment of the South natural isoprene coupled with rural anthropogenic NO_x and natural NO_x from soils (and perhaps lightning near these fronts) can produce significant background levels. The same light winds that can reduce the dilution of anthropogenic emissions will operate on these rural emissions. Thus, rural background levels that under normal conditions might only reach 30-40 ppb (see NG04) might under these reduced-dilution conditions reach 50-70 ppb or higher.

7.0 Recommendations for Future Work

Additional coupled meteorological and photochemical models should be applied to these episodes. Specific attention should be paid to the role of meteorological conditions in producing areas of high ozone perhaps by simply looking at passive scalar fields emitted uniformly in the domain, as was done in the RAMS modeling for the Nashville stationary frontal case.

The principal component methodology described in NG04 potentially provides a powerful technique for relating wind-field structure to ozone concentrations. While NG04 primarily used this technique to address mean and likely ozone behavior, it could be used for the extreme events discussed here. This could be done by looking at PC coefficients (weights) for extreme ozone values.