

Policy Implications Report

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Stationary Front Experiment

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Note – the following conclusions only represent those of the authors and not of HARC or TCEQ.

1.0 Introduction

In an analysis of synoptic structures associated with high one hour and eight hour ozone in the Dallas Ft. Worth (DFW) area it was also found that stationary fronts were associated with the three highest ozone events in the summer of 1999 (see figure 1). One of these cases (August 11-17, 1999) was also selected as the design period for the eight hour SIP for the DFW area. Additionally, under the Southern Oxidant Study (SOS) stationary fronts were found to be associated with extreme concentration events and design days for SIPs in several southeastern cities (see figure 2). These frontal zones by their very nature are complex in both their winds and thermal settings.

As a result of this study and the previous findings under SOS a pilot program was developed and proposed to use aircraft during the TEXAQSI to sample in the vicinity of a stationary front if one presented itself. The Baylor Aztec aircraft with ozone, NO_y, backscatter along with winds, temperature and pressure was selected to fly the stationary front experiment. On August 21 a stationary front was forecasted to sag near to the DFW area. A flight was planned and carried out to sample across the front and the vertical structure. A similar flight was carried out the following day (August 22) when the front sagged south of DFW. During the flights ozone and NO_y distributions were collected along with other chemical and meteorological data. In general the data showed that highest ozone occurred in the vicinity of the front.

After the flight HARC issued a contract to the University of Alabama in Huntsville and Southeast Atmospheric Modeling to analyze the flight data. A final technical report was provided on the analysis of the flight data and model simulations (McNider et al 2009). The following provides the summary and conclusions from that report.

2.0 Summary of Technical Report

The findings of the study were discussed in the context of the hypotheses given in the introduction. These are reproduced below.

(1) Light winds in and near the actual front lead to a zone of poor dilution leading to a build up of precursors and ultimately ozone.

The actual flight data of wind speeds provided some support but not dramatic support. There was a slight decrease in wind speeds as the aircraft proceeded north toward the front on the August 21 flight and increase as it headed back south (see figure 7). The same was true on the August 22 flight (figure 11). But there were peaks of wind near the front which may be due to convection. The model analyses of surface and flight level winds clearly showed the expected “dead zone” near the front (see figure 13 and 15). The high concentrations in the

observations also were near the front. The role of light winds as a contributor to high concentrations is supported.

- (2) *Higher surface temperatures due to light winds enhance thermal decomposition of NO₂ leading to longer chain lengths in ozone production. Additionally, higher temperatures enhance surface biogenic and evaporative hydrocarbon emissions.* Because temperatures were changing over the flight time it is difficult to separate the increase in temperature from the spatial variation in temperature. However, the model simulations (see figures 12 and 14) clearly show an increase in temperature thus temperatures could play a role in the high ozone near the front.

- (3) *Subsidence on the north side of the front inhibits boundary growth and reduces dilution of boundary layer air from mixing from above.*

The aircraft clearly show that the concentrations increase sharply north of the front on both flight days (see figures 5 and 8). The model ozone (figures 23 and 28) cross-sections also support the view that higher ozone is occurring where the model is indicating subsidence. The circulation is complex in the model with two descending cells near the front especially on August 21. Thus, the limited vertical mixing may play a role.

- (4) *The very nature of a stationary front means that movement of the front back and fourth can lead to short and even circular trajectories leading to a build up of ozone.*

The 1999 DFW SIP case had a stationary front which sagged south then pushed back north then sagged south again on subsequent days. The August 21 and 22 study cannot address this factor since the front sagged southward on both days. There may have been some minor oscillation of the front overnight but this was not observable.

- (5) *Due to the complex trajectories in a frontal zone and ultimate connection of the frontal surface to a tropopause fold the air above the front may be enriched with ozone of stratospheric origin.*

The trajectory calculations (figure 29) do show complex behavior with strongly divergent trajectories depending on the spatial end point. However, the trajectories to the north of the front (where connection to the upper troposphere is more likely) did not show long or descending trajectories into the front. Additionally, there was no indication from the aircraft vertical profiles near the front (see the time series figures (figure 7 and 11) or profiles (figures 6 and 9)). The model also does not show higher ozone aloft in the simulations although this would be suspect because of limitations in specifying tropopause folds in the model. In general the analysis does not support ozone aloft as a contributor of high ozone.

- (6) *Some stationary fronts have deformed flows rather than convergent flows and thus have little lifting and associated cloudiness leading to a productive photochemical environment.*

The frontal zone for the August 21 and 22 did not have extensive long-lived clouds. Scattered fair weather cumulus developed both mornings south and north of the front. With earlier and more clouds along the front (see GOES images figure 31). While the cumuli fields were prevalent the smaller area of ascending

motion than descending motion in the cloud topped boundary layer meant that the skies were predominantly clear. This led to substantial photochemical production potential based on aircraft NO_2 fields (figures 33 and 34). There were late afternoon deep convection events on both days along the front. But, clouds dissipated over night. The model simulations showed that the model without satellite assimilation of clouds substantially reduced the photochemical potential compared to observations (figure 32). Thus, it appears that this front has substantial photochemical potential especially in the early part of the day.

In summary it appears that the high ozone in the vicinity of a stationary front may be the cumulative result of a combination of physical factors. Thus, it may be in modeling stationary front that attention needs to be given to the robustness of the model of all these factors. The model failed substantially in getting the cloud distribution right along the front.

3.0 Policy Implications of Stationary Fronts as Settings for Extreme Concentration Events

The analysis of extreme concentration events under the Southern Oxidant Study and for DFW, found the somewhat surprising result that many of the events that were used in SIP development were in fact stationary front events. This was contrary to the popular view that high concentration events would primarily occur under the classic - center or east of center of a high pressure system. This classic synoptic situation provided the clear skies, light wind and subsidence to produce a high pollution potential. The question then is - are their characteristics of the stationary fronts that may invalidate the SIP or reduce its effectiveness?

3.1 Critical Characteristics of Stationary of Stationary Fronts

The following uses the results of the aircraft analyses and model results to address this question.

Scale: One difference between a stationary front case and a traditional high pressure situation is the scale of the phenomena. A high pressure case may have fairly homogeneous conditions over several hundred kilometers. In fact quasi-geostrophic theory indicates that gradients are weak under high pressure systems and large in low pressure systems. However, in frontal situations wind directions, wind speed and temperature gradients can be quite large in part because by definition they are boundaries. One factor which increases the scale of stationary fronts compared to cold or warm fronts is that because they evolve as a balance of forces geostrophic adjustment theory suggests that gradients will relax over Rossby Radius of Deformation. However, the scale of gradients in the aircraft case studies and in an analysis of the summer 1999 cases show that gradients are larger than might be expected in high pressure settings. These gradients

mean that small differences in a model can lead to large differences in air quality source attribution.

Location: The concern in using a stationary front setting is that slight differences in where the front is located can cause large differences in wind directions and wind speeds. In the 2006 case, it was difficult to tell precisely where the front really was since temperature difference and humidity differences were small. In fact, in trying to understand where the front was in selecting flight days we often could not tell where the front was located within 50 km or so. Also, the rawinsonde network which has a spacing of several hundred kilometers and is largely the basis for the temperature and wind fields used in models cannot locate such frontal structures precisely.

Clouds: Unlike the center of a high pressure system, frontal zones because of a convergent component often support clouds and moist convection. However, long-lived structures such as stationary fronts have often evolved into deformed flows (i.e. flows are front parallel) as opposed to convergent flows so that lifting may be small. However, under many situations even small lifting can produce clouds. In the 2006 studies it appears that under the weak forcing clouds are not persistent. Mornings were clear and afternoon convection occurred relatively late. Thus, considerable photochemical production potential was available. It is also apparent that the stationary fronts that have presented themselves as causing high ozone events are not like very dynamic stationary fronts where frontal over-running produces substantial and persistent clouds.

Model Performance: In examining the performance of the MM5 model which was used in conjunction with the aircraft data, we were in general pleased with its performance. It appeared to capture the location relatively well and the winds were fair agreement with the aircraft data. However, we were looking at fairly large scale measures of its performance. Because of the weak gradients we could not determine precisely the location of the front from aircraft data. The most glaring breakdown in the model was in the location and prediction of clouds. The model tended to over-estimate the amount and clouds and their intensity. Morning clouds were more pervasive in the model than in reality. This is perhaps not surprising in that cloud performance in models especially in weakly forced situations has been poor. The satellite assimilation of clouds greatly improved average specification of photolysis compared to aircraft observations although differences and issues remain.

3.2 Dealing with Stationary Fronts in a SIP Development Environment

The sensitivities of the stationary front environment listed above may undermine the accuracy and robustness of SIP modeling. Slight changes in the location of the front may cause large differences in paired in space and time statistics between models and observations. Such discrepancies may undermine confidence in the simulations by industry, the public and regulators. Thus, stationary fronts may not be the best environment to carry out SIPs. If other design days are available under the center of high pressure systems that have levels as high as the stationary front case, then these cases may be preferred.

On the other hand, based on the past work in the Southeast and the 1999 study in Texas (McNider et al 2005), it is clear that the synoptic settings of stationary fronts with their combination of attributes that together can cause high concentrations, cannot be ignored. Thus, to really test whether areas will indeed meet standards, the stationary fronts may be the most challenging setting to test control strategies.

We were encouraged that despite potential problems in determining the exact location of the front that the MM5 model and CMAQ did a reasonable job in capturing the physical structure and air quality environment of the front. If this is the case then a reduction in emphasis could be given to paired in space and time statistics and more emphasis given to subjective measures of the model in capturing the structure of the fronts. Clouds are still a challenging issue but use of satellite derived cloud parameters can reduce these model errors.

4.0 Summary and Conclusions

Stationary fronts provide a challenging environment to test SIP control strategies. Nevertheless, they may be the limiting conditions in producing high concentrations. SIPs can be developed within the environment of stationary fronts but traditional measures of model performance may need to be down-played. Rather, subjective measures of the ability of the model to replicate the structure of the environment as was done in the technical report should be developed.

Confidence in models and control strategies is the most important fact for industry, the public and regulators. It is hoped that this study will increase the confidence of control strategies developed in stationary front environments.

References:

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High ozone events during 1999 were associated with stationary front

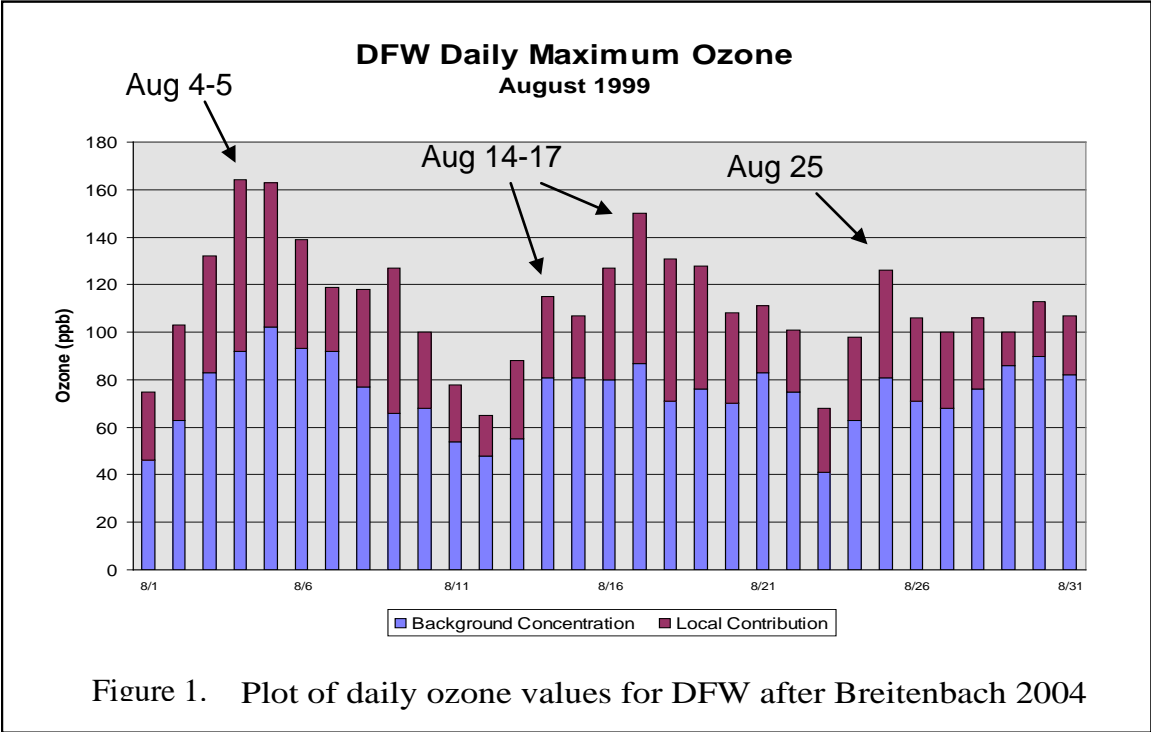


Figure 1. Plot of daily ozone values for DFW after Breitenbach 2004

Period/Location	Concentration (ppb) ¹ Maximum 1- hr. avg.
July 12, 1983 Nashville	148
July 25 – August 3, 1987 Atlanta/Montgomery	201
May 31, 1988 Atlanta	158
June 20 – July 1, 1990 Atlanta	187
August 2-3, 1990 Atlanta	141
August 17, 1990 South Atlanta	145
August 9-11, 1992 Atlanta	132
July 20-22, 1993 Charlotte	153

Figure 2. High concentrations associated with stationary fronts found under the Southern Oxidant Study (SOS).