Sonoma Technology, Inc.

1360 Redwood Way, Suite C
Petaluma, CA 94954-1169
707/665-9900
FAX 707/665-9800
www.sonomatech.com

DATA PROCESSING AND ANALYSIS OF ALOFT AIR QUALITY DATA COLLECTED IN THE UPPER MIDWEST

EXECUTIVE SUMMARY
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By:
Clinton P. MacDonald
Erin Shields
Paul T. Roberts
Sonoma Technology, Inc.
1360 Redwood Way, Suite C
Petaluma, CA 94954-1169

Prepared for:
Lake Michigan Air Directors Consortium
2250 East Devon Avenue
Des Plaines, IL 60018

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TABLE OF CONTENTS

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LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

1. INTRODUCTION

From 1987 through 2003, Wisconsin Department of Natural Resources (WDNR) and Robert Jacko made 619 aircraft flights on 192 days collecting aloft air quality and meteorological data in the Upper Midwest. Aloft air quality data enable a better understanding of the processes that influence air quality because they provide information in the third dimension and spatial information between and above surface monitoring sites. Sonoma Technology, Inc. (STI) performed four tasks related to these data:

1. prepared a single, consistent, quality-controlled, well-organized database of aircraft data;
2. produced summary statistics and graphical displays of the aircraft data that will be helpful in answering key questions;
3. performed analyses to answer questions about ozone, $PM_{2.5}$, and their precursors using aircraft and other supporting air quality and meteorological data; and
4. recommended future analysis and monitoring.

Because funding was limited, STI focused on Tasks 1 and 2: organizing and quality-controlling the data and creating useful data plots for data analysis. Limited data analysis completed for this project included statistical analysis of about 120 flight days and a case study analysis of an episode on August 13-20, 2003; however, the analysis results are intended to be a starting point and a catalyst for further analyses.

The remainder of this executive summary documents task activities and summarizes the products of and findings from this project, including information on data validation and the MS Access database of aircraft data, graphical displays available in electronic format, a summary of current findings from the limited data analysis, comparison to relevant findings from the 1991 Lake Michigan Ozone Study (LMOS), and recommendations for future aircraft monitoring and data analyses. Appendix A is a presentation delivered, via conference call, to the Lake Michigan Air Directors Consortium (LADCO) on May 13, 2004, and contains additional information about the products and findings, including details of the data analysis results.

2. DATA SUMMARY

This section describes the data processed as part of this project, including data quality control.

2.1 DATA PRODUCTS

Continuous air quality and meteorological data and integrated air quality data collected by WDNR and Robert Jacko from 1987 through 2003 are contained in an MS Access database. This database is provided to LADCO on a compact disc (CD) in conjunction with this executive summary. In the time standard table, the WDNR data are in Central Standard or Daylight Time (CST or CDT) depending on the time of year, and the Jacko data are in CST regardless of time of year. The continuous air quality data include ozone, nitrogen oxide (NO), nitrogen dioxide (NO_2), oxides of nitrogen (NO_x), and oxides of nitrogen plus their reaction products (NO_y), which are all reported every 10 seconds; light scattering data reported every 60 seconds; and meteorological data reported every second. The integrated data tables contain volatile organic compounds (VOCs), carbonyl, and particulate matter ($PM_{2.5}$) data which are integrated over each flight.

The $PM_{2.5}$ data presented several problems. Total $PM_{2.5}$ mass was not measured, and insufficient species were measured for mass and ion balances. Backup filters to correct for nitrate losses were not available; thus, nitrite values are underreported. Prior to 2002, problems with the instrument flow rates made it difficult to determine an exact PM size cut point. Therefore, the PM cut point prior to 2002, may not be exactly at $PM_{2.5}$. Finally, the blanks were sometimes contaminated. Therefore, the $PM_{2.5}$ data should be used cautiously in analysis.

2.2 QUALITY CONTROL

Quality assuring the WDNR and Jacko aircraft data was a significant effort in this project. General quality assurance (QA) was performed for all years on all continuous data, and a more detailed analysis was performed for the integrated samples from 2002 and 2003 and for the 2002 and 2003 wind data. The earlier integrated data, and all continuous data, were validated by WDNR; thus, only a general QA was required.

The database was delivered to STI with separate tables and/or databases for each year of continuous data, in addition to MS Excel spreadsheets for each year containing the integrated sample data. STI standardized parameters for consistency, including units conversions. We also performed a check of unusually large or small values; any significant anomalies were labeled suspect, and obviously invalid data (e.g., –999) values were invalidated. We appended all years into one table in the database, and imported the integrated samples into MS Access for consistency.

The major changes to the database of WDNR continuous data include

- Invalidating any unflagged negative values for latitude, longitude, and altitude (for example, –999, –777, –112).
- Invalidating zero values for latitude and longitude.
- Invalidating light scattering less than 0.21 Mm^{-1}.
- Suspecting ozone less than –0.5 ppb.
- Suspecting any significantly high values if neighboring values were typical.
- Invalidating wind data where heading changed at a rate greater than 5 degrees per 10 seconds.
- Invalidating wind vectors when the aircraft changed direction.

The major changes to the database for the Jacko continuous data include

- Invalidating data flagged with comments “not valid”, “invalid”, “missing data”, and “stabilizing”.
- Invalidating ozone data from July 1, 2001, through July 7, 2002, because the ozone data randomly fluctuated by 100% during this period.
- Invalidating instrument startup periods for 1999 flights with highly erratic data.

3. SUMMARY OF PLOTS

This section discusses the aircraft data plots produced for this project. Spatial and time series plots of data collected on each flight are useful for case study analysis. Statistical plots that summarize the data for each flight type help determine the average air quality conditions and provide context for the case study results. Summary plots synthesize each case study day's meteorology and air quality and help support the findings determined from the individual flight plots. Finally, integrated data plots depict integrated PM species data from flights by date collected and are useful for determining the monthly differences between the chemical components of $PM_{2.5}$.

3.1 INDIVIDUAL FLIGHT PLOTS

Spatial and time series plots of the 2000 through 2003 WDNR and Jacko aircraft data were created and are stored as GIF images on a CD delivered to LADCO in conjunction with this executive summary. **Figure 3-1** shows example spatial and time series plots of ozone and wind data. These types of plots were also created for NO_y and light scattering data. The spatial plot in Figure 3-1(a) shows the flight path as a multicolored line. The line color indicates ozone concentrations (ppb) as depicted in the legend. Next to the flight paths are the times of day associated with the aircraft's position. The flight date, flight begin and end times, and time standard of the data are shown above left of the figure. When available, wind data are shown as vectors that point toward the direction the wind is blowing. The wind vector scale is shown in the bottom left (e.g., 10 m/s) in Figure 3-1(a). Below the spatial plot is a time series plot of the same data with the addition of altitude data. The altitude is shown as a light gray line and is reported in feet above mean sea level (msl). The approximate elevation of Lake Michigan is shown as a blue line. In addition to the spatial/time series plot combination, the CD contains time series plots that show a combination of ozone, NO_y, and light scattering data.

3.2 STATISTICAL SUMMARY PLOTS

In addition to individual flight plots, average concentrations by area, by altitude, by episode or nonepisode, and by time of day were calculated and displayed. **Figure 3-2** is an example of a plot showing statistical summary data. Additional plots are contained in Appendix A. The flight areas for the summaries include SUP (Lake Superior), Sup Enroute (Lake Superior en route), STL (Saint Louis), STL Enroute (Saint Louis en route), JACKO (La Crosse, Wisconsin, to Lafayette, Indiana), LMI – N (Lake Michigan North), and LMI – S (Lake Michigan South). An episode is defined when regional maximum 8-hr average ozone concentrations exceed 80 ppb in Chicago, St. Louis, Milwaukee, or Grand Rapids. There are three altitude bins: less than 1000 ft msl, 1000 to 1500 ft msl, and greater than 1500 ft msl. The times of day are in CDT, and data within approximately one hour of each time of day were used in each respective average.

3.3 SUMMARY PLOTS

For August 13-20, 2003, summary plots of meteorological and air quality conditions were created to address technical questions listed in Section 4 and are shown in Appendix A. **Figure 3-3** is an example of a summary plot for August 18, 2003. In Figure 3-3, the blue line shows the 500-m back trajectory arriving over Lake Michigan during the afternoon. The trajectory data used to make these plots were generated using National Oceanic and Atmospheric Administration's (NOAA) HYSPLIT model and Eta Data Assimilation System (EDAS) data. Each dot on the blue line indicates the trajectory position in six-hour increments. The same-day surface flow is indicated by the black arrow and was estimated from EDAS data. The first (blue) number in the blue parentheses is the estimated aloft ozone concentration, and the second number represents the NO_y concentration, being transported into the region. These estimates were determined from morning aircraft data. The first (black) number in the black parentheses is the estimated surface ozone concentration, and the second number represents the NO_y concentration, being transported into the region. These estimates were determined from morning aircraft data and the previous day's upwind surface ozone data. Other numbers on the plot represent afternoon peak ozone concentrations measured by the aircraft averaged over a period of about 2 minutes. Over Lake Michigan, the numerator shows the aloft concentration (greater than 1000 ft msl), and the denominator shows the near surface concentrations (less than 1000 ft msl). From this summary plot, we conclude that on August 18, 2003, aloft and surface ozone concentrations transported from northern Indiana and Michigan were about 30 to 40 ppb and peak concentrations were about 80 ppb. Therefore, the local contribution to the peak ozone concentration was about 40 ppb on this day.

3.4 INTEGRATED DATA PLOTS

The WDNR 2002 integrated $PM_{2.5}$ speciated data are plotted by date for flights in the early morning, midmorning, midafternoon, and late morning. These four plots are shown in Appendix A. The speciated data in the plots include sulfate, nitrate, organic carbon, elemental carbon, chloride, ammonium, and ammonia.

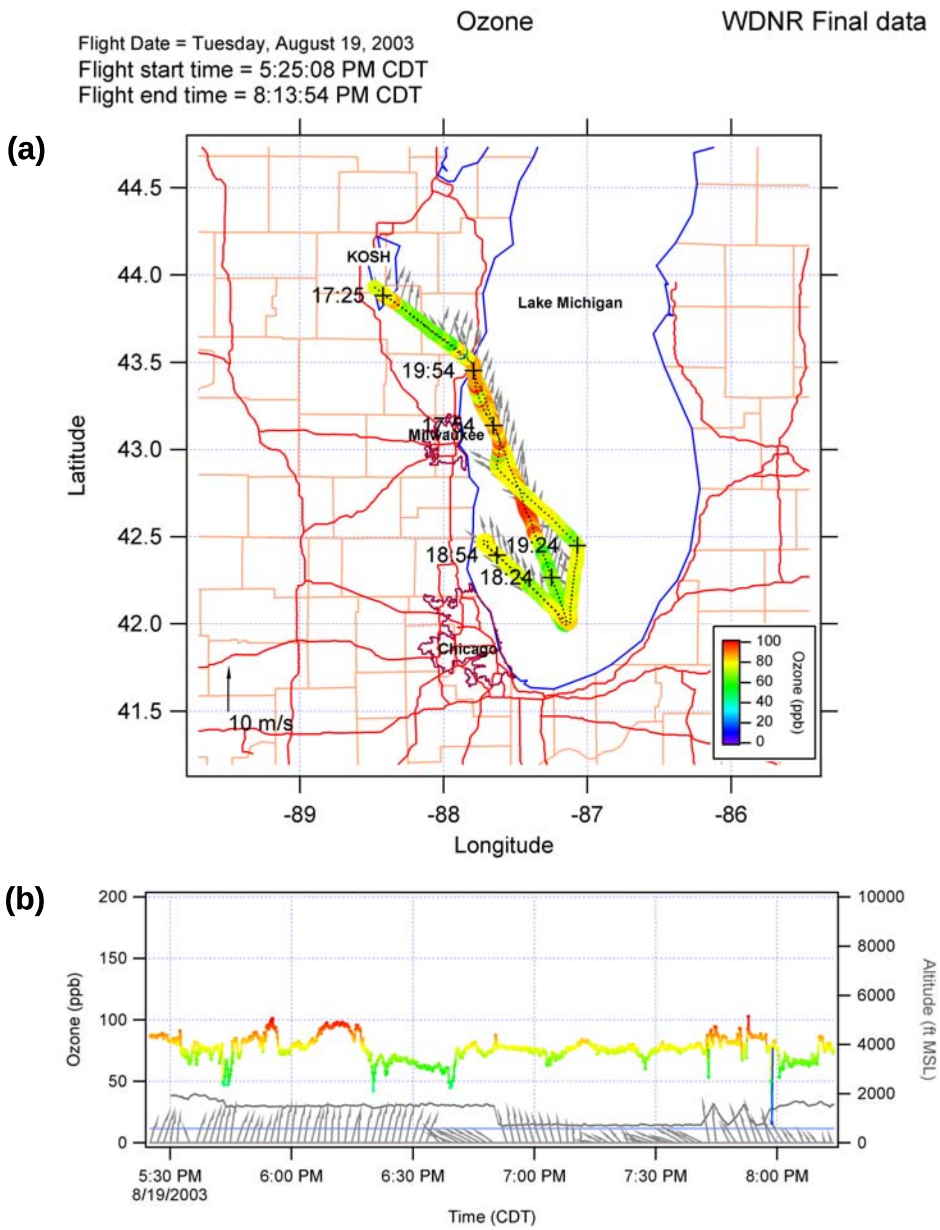
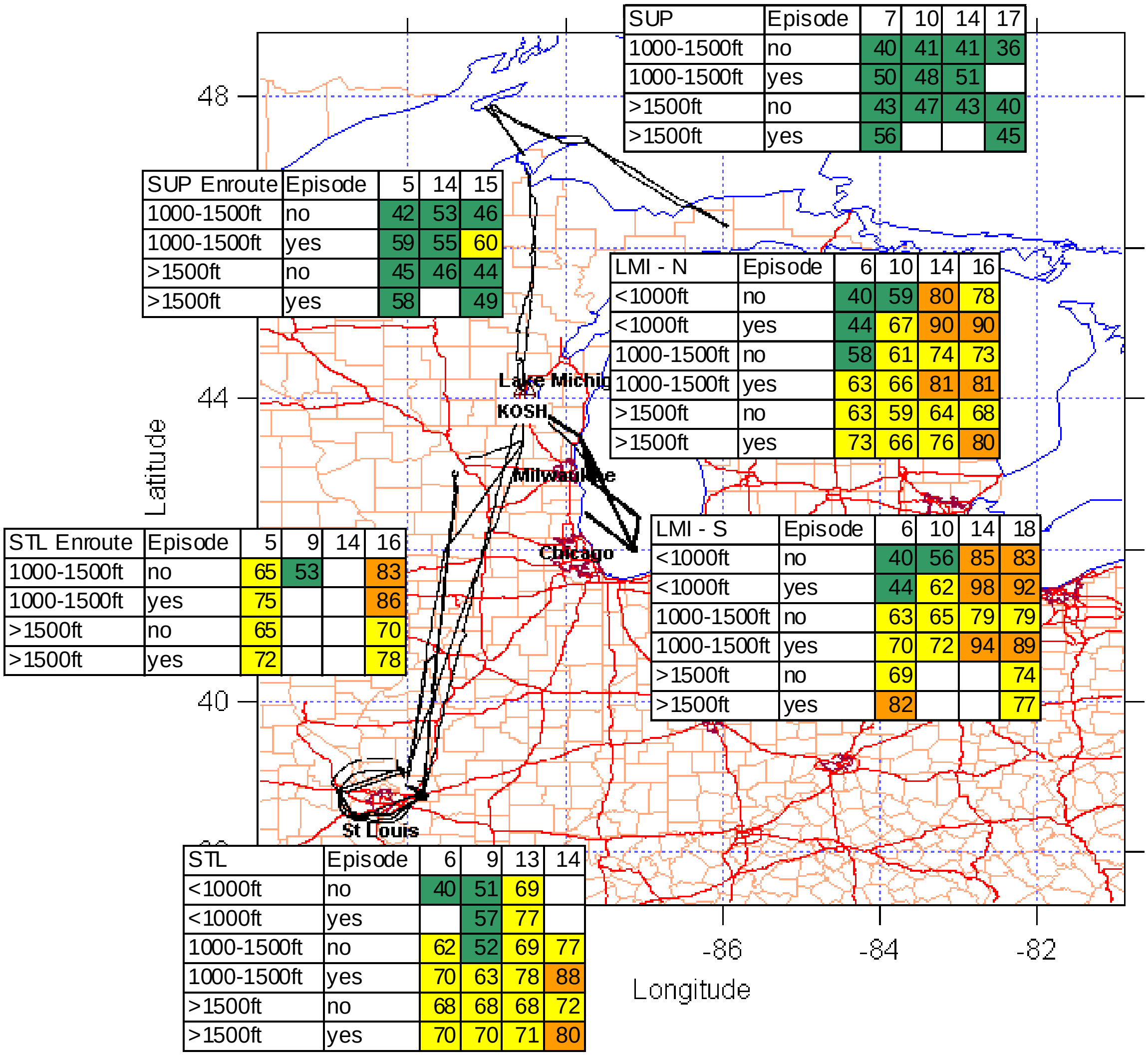


Figure 3-1. Example of (a) spatial and (b) temporal plots of aircraft ozone, wind, and altitude data.



SUP	Episode	7	10	14	17
1000-1500ft	no	40	41	41	36
1000-1500ft	yes	50	48	51	
>1500ft	no	43	47	43	40
>1500ft	yes	56			45

SUP Enroute	Episode	5	14	15
1000-1500ft	no	42	53	46
1000-1500ft	yes	59	55	60
>1500ft	no	45	46	44
>1500ft	yes	58		49

LMI - N	Episode	6	10	14	16
<1000ft	no	40	59	80	78
<1000ft	yes	44	67	90	90
1000-1500ft	no	58	61	74	73
1000-1500ft	yes	63	66	81	81
>1500ft	no	63	59	64	68
>1500ft	yes	73	66	76	80

STL Enroute	Episode	5	9	14	16
1000-1500ft	no	65	53		83
1000-1500ft	yes	75			86
>1500ft	no	65			70
>1500ft	yes	72			78

LMI - S	Episode	6	10	14	18
<1000ft	no	40	56	85	83
<1000ft	yes	44	62	98	92
1000-1500ft	no	63	65	79	79
1000-1500ft	yes	70	72	94	89
>1500ft	no	69			74
>1500ft	yes	82			77

STL	Episode	6	9	13	14
<1000ft	no	40	51	69	
<1000ft	yes		57	77	
1000-1500ft	no	62	52	69	77
1000-1500ft	yes	70	63	78	88
>1500ft	no	68	68	68	72
>1500ft	yes	70	70	71	80

Figure 3-2. Example of statistical summary plot.

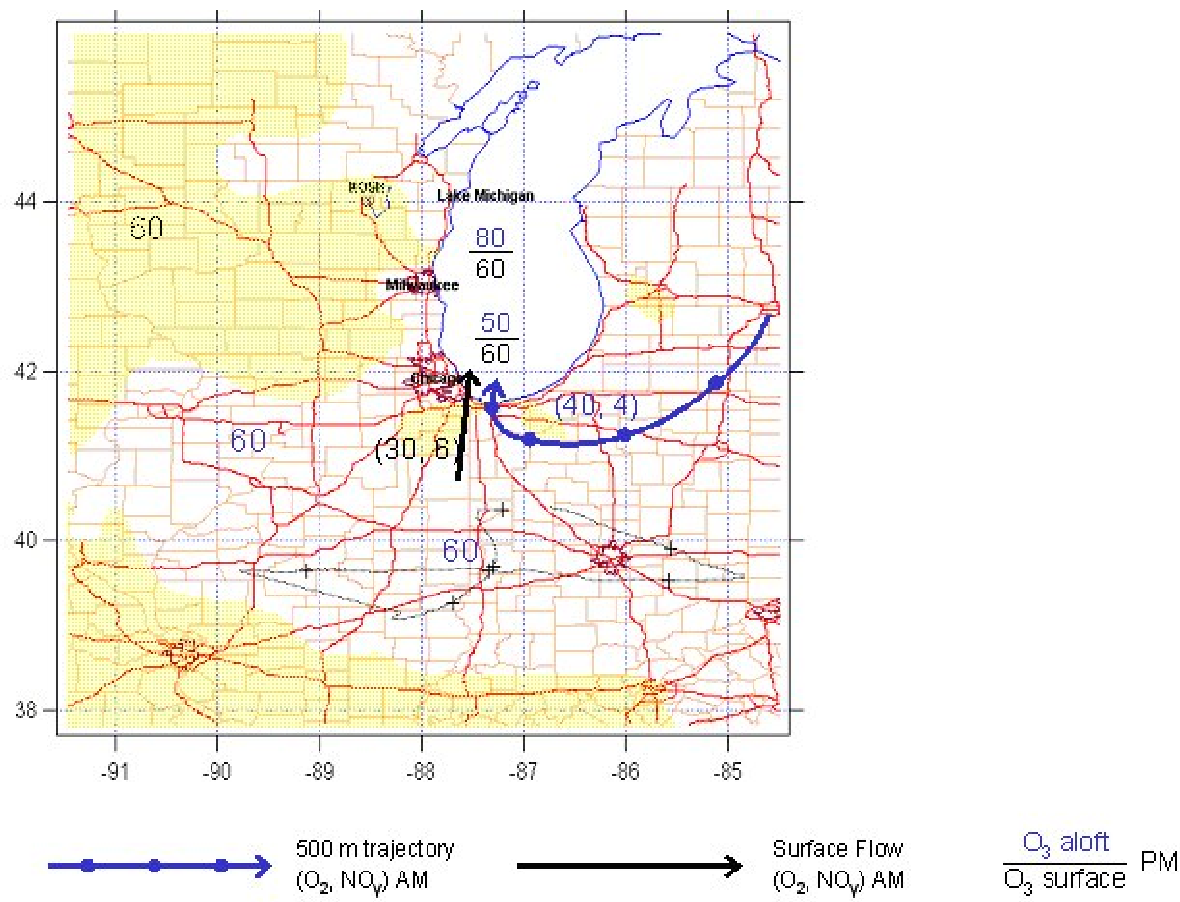


Figure 3-3. Example summary plot for August 18, 2003. Moderate surface concentrations are shaded in yellow.

4. SUMMARY OF FINDINGS

Several questions about air quality in the Upper Midwest were addressed through case study analysis of the August 13-20, 2003, period and statistical analysis of all appropriate 1987-to-2003 aircraft flights. The aircraft data used in the analysis were collected over Lake Michigan, Saint Louis, between Lake Michigan and Saint Louis, and at the southern end of Lake Superior. In addition to the flight data, other supporting data, including synoptic weather charts, transport trajectories created with NOAA's HYSPLIT model, and the U.S. Environmental Protection Agency's regional ozone maps, were analyzed. Several questions are addressed, and their associated findings are reported here. In the findings, "aloft" refers to altitudes from 1000 to 1500 ft msl or about 500 to 1000 ft agl; "near the surface" refers to altitudes about 200 to 500 ft agl; and "episode day" is when the 8-hr regional maximum ozone concentration exceeded 80 ppb for Chicago, Saint Louis, Milwaukee, or Grand Rapids. Plots to support these findings and more detailed analyses can be found in Appendix A.

Note that on August 14, 2003, much of the East Coast and Canada experienced a power blackout. According to Marufu et al. (2003), the blackout shut down many power plants, causing a 90% reduction in sulfur dioxide and a 50% reduction in smog in some areas in the East on August 15. It is not clear from this analysis whether the shutdown of power plants had any influence on air quality in the Midwest.

1. *In terms of air quality, how representative are the flight days?*

   Figure 4-1 shows a time series plot of days when the WDNR and Jacko aircraft flew and the daily 8-hr maximum ozone concentration was reached in Chicago, Saint Louis, Milwaukee, or Grand Rapids from 2001 through 2003. Figure 4-1 shows that the aircraft flew on days with a wide range of ozone concentrations including days with both low and high ozone concentrations. However, the aircraft flew on more days with high ozone than with low ozone concentrations. Therefore, the aircraft data, on average, do not equally represent all day types and represent poor air quality days better.

2. *During the summertime, how do air quality boundary conditions vary as a function of time of day, location, and altitude?*

- During the August 13-20, 2003, case study, morning aloft boundary ozone concentrations ranged from about 35 to 75 ppb and were about 35 to 40 ppb when the air mass originated in Canada and 60 to 75 ppb when the air mass originated in the Midwest.
- On average during the 1987 through 2003 period, morning aloft concentrations were about 65 to 75 ppb, except over Lake Superior where morning aloft concentrations were about 40 ppb. These averages are similar to the concentrations observed in the August case study.
- On average during the 1987 through 2003 period and the August case study, morning ozone concentrations were higher aloft (typically about 60 to 75 ppb) compared to near the surface (typically about 40 to 50 ppb). However, during two case study days, ozone concentrations were 20 to 30 ppb near the surface, probably due to titration by fresh NO_x emissions.

- On average during the 1987 through 2003 period, morning aloft ozone concentrations on episode days were about 5 to 10 ppb higher than on non-episode days.
- During the August case study, incoming NO_y concentrations ranged from about 2 to 10 ppb, but were occasionally higher.
- On average during the 1987 through 2003 period, morning NO_y concentrations were about 5 to 10 ppb aloft and about 8 to 15 ppb near the surface, except near Lake Superior where NO_y concentrations were about 1 to 3 ppb, regardless of altitude. These concentrations did not vary much between episode and non-episode days.

3. *What is the relationship among local flow patterns, boundary layer structure, and the horizontal and vertical distribution of pollutants?*

   During the August case study,

- There were three main flow patterns—easterly, westerly, and southerly. The southerly flow resulted in the highest ozone concentrations; however, high concentrations occurred under all three flow patterns.
- Over Lake Michigan, the lowest 500 ft was usually decoupled from aloft layers in the morning and afternoon as indicated by higher NO_y concentrations at the surface than aloft, especially in the morning.
- Morning ozone concentrations near the surface were often low, and NO_y concentrations were high, indicating that ozone was titrated, except when winds were strong from the south as was the case on August 19 and 20, 2003.
- Ozone concentrations in the afternoon were sometimes higher aloft than at the surface.
- The highest ozone concentrations occurred late in the afternoon and early in the evening as opposed to midafternoon.

   For the 1987 through 2003 period

- Over Lake Michigan, on average, near-surface ozone concentrations were about 80 to 90 ppb and were about 5 to 9 ppb higher than the aloft concentrations, suggesting that these layers were often decoupled. (Averages are based on data from 119 flight days.) Furthermore, ozone concentrations occurred over the Lake and along the shoreline of Wisconsin and Michigan higher than those over the inland regions. Typically, the highest ozone concentrations occurred below about 200 m agl of the Lake and onshore within several km of the shoreline (either at the surface or at altitudes below about 200 m agl).
- Ozone concentrations were similar over the southern and northern ends of Lake Michigan, suggesting a large air mass of similar chemical composition.
- Ozone concentrations over Lake Michigan were often titrated near the surface in the morning hours, except under strong southerly wind conditions. Afternoon titration was not apparent in the aircraft data; however, the flight path was usually, at closest, roughly 40 km from Chicago and 20 km from Milwaukee. In comparison, air quality monitoring and modeling results from the 1991 Lake Michigan Ozone Study (LMOS) suggest an ozone

"valley" is present and extends downwind of Chicago (see Roberts, et al, 1994). Although limited in spatial and temporal coverage, the 1991 field data indicate that the ozone "valley" may extend 70 to 90 km downwind of Chicago in the morning and about 50 km in the afternoon. (This is farther downwind than observed in some other major urban areas, due to the influence of meteorological conditions over the Lake.)

- Over Lake Michigan, the highest ozone concentrations occurred late in the day at about 1800 CDT.
- Over Lake Superior, ozone concentrations were near natural background levels at all altitudes at all times of day, ranging from about 35 to 45 ppb. (Averages are based on data from 21 flight days.)
- Over Saint Louis, near-surface ozone concentrations were about 70 ppb and were similar to the aloft concentration, suggesting a well-mixed layer to about 1500 ft msl. (Averages are based on data from only 10 flight days.)

4. *What is the contribution of pollution transported from upwind areas and local pollution to local peak ozone concentrations? Has this changed over time?*

   For the August case study,

- Background contributions ranged from about 35 to 75 ppb and were usually about 60 to 70 ppb. A 35 ppb concentration occurred on one day and originated in Canada. These concentrations are lower than those observed during the 1991 LMOS when boundary conditions for ozone were 70 to 100 ppb during episodes. However, because background concentrations were determined from limited case study, it is not possible to conclude that background concentrations were generally lower in 2003 compared to 1991.
- Most surrounding states contributed to background ozone on at least one day during the episode.
- Same-day local contribution ranged from 20 to 60 ppb:
  - about 20 ppb on 1 of 7 days;
  - 30-40 ppb on 4 days
  - about 60 on 2 days

5. *Does local carryover of pollutants in aloft layers significantly contribute to peak ozone concentrations?*

   During the August case study,

- On two days, when winds were strong from the south, local carryover of pollutants did not significantly contribute to peak local ozone concentrations.
- On the other five days, when winds were light to moderate and recirculated from east back to west over the course of a few days, regional background concentrations mixed with local carryover to produced the observed morning aloft background concentrations. It is difficult to differentiate between local and regional carryover. It may be possible in

future analysis to use $PM_{2.5}$ and VOC data to determine air mass age, which may help differentiate local and regional carryover and contribution to local ozone.

6. *What is the seasonal and spatial distribution of $PM_{2.5}$?*

- Measured $PM_{2.5}$ concentrations ranged from 20 to 60 µg/m^3 in the summer and from about 10 to 20 µg/m^3 in the winter. (Note, these values represent the sum of the measured species concentrations, which, as noted above, does not accurately reflect the total $PM_{2.5}$ mass.) Note that winter flights were confined to Lake Superior, which probably explains the low concentrations in the winter.
- $PM_{2.5}$ concentrations were similar in the morning hours and afternoon.
- In the summertime, the aloft $PM_{2.5}$ concentrations were on the order of 20 to 40 µg/m^3 over much of the region (i.e., over Lake Michigan, the Lafayette-LaCrosse boundary flight, and the southern flight route to Dolly Sods) and was dominated mostly by sulfate and organic carbon. Lower aloft $PM_{2.5}$ concentrations (on the order of 20 to 30 µg/m^3) were measured on the northern flight route to Lake Superior, with much less sulfate.
- In the wintertime, the aloft $PM_{2.5}$ concentrations were dominated by organic carbon, although the magnitude of the organic carbon levels were lower than those in the summertime, indicating the influence of secondary organic aerosols in the summertime. Wintertime $PM_{2.5}$ concentrations also included significant amounts of nitrate on several days. Note again that winter flights were confined to Lake Superior.
- Elemental carbon was a small contributor (<2 percent) to $PM_{2.5}$ in all seasons.
- $PM_{2.5}$ and light scatter data have a decent relationship of about 1 to 6 (i.e., $PM_{2.5}$ (µg/m^3) = 1/6 * Bext (Mm)$^{-1}$), suggesting that continuous light scatter data can be cautiously used to estimate continuous $PM_{2.5}$ data and, consequently, provide important information for interpreting integrated $PM_{2.5}$ data.

7. *What were the characteristics of $PM_{2.5}$ during the August case study?*

- Note, not enough species were collected to account for the total $PM_{2.5}$ mass.
- Regional background concentrations between La Crosse and Lafayette were about 20 to 35 µg/m^3 and were dominated by organic carbon and sulfate.
- Concentrations over Lake Michigan ranged from about 20 to 45 µg/m^3 and were also dominated by organic carbon and sulfate. The organic carbon concentrations over the Lake appear to be consistently higher than the regional concentrations, indicating the effect of local emissions. The sulfate concentrations over the Lake are similar to the regional concentrations.
- The relative contribution of individual species did not vary much throughout the day.

8. *What types of aloft sampling should be conducted in the future to support ozone and $PM_{2.5}$ research?*

This question is addressed in Section 5.

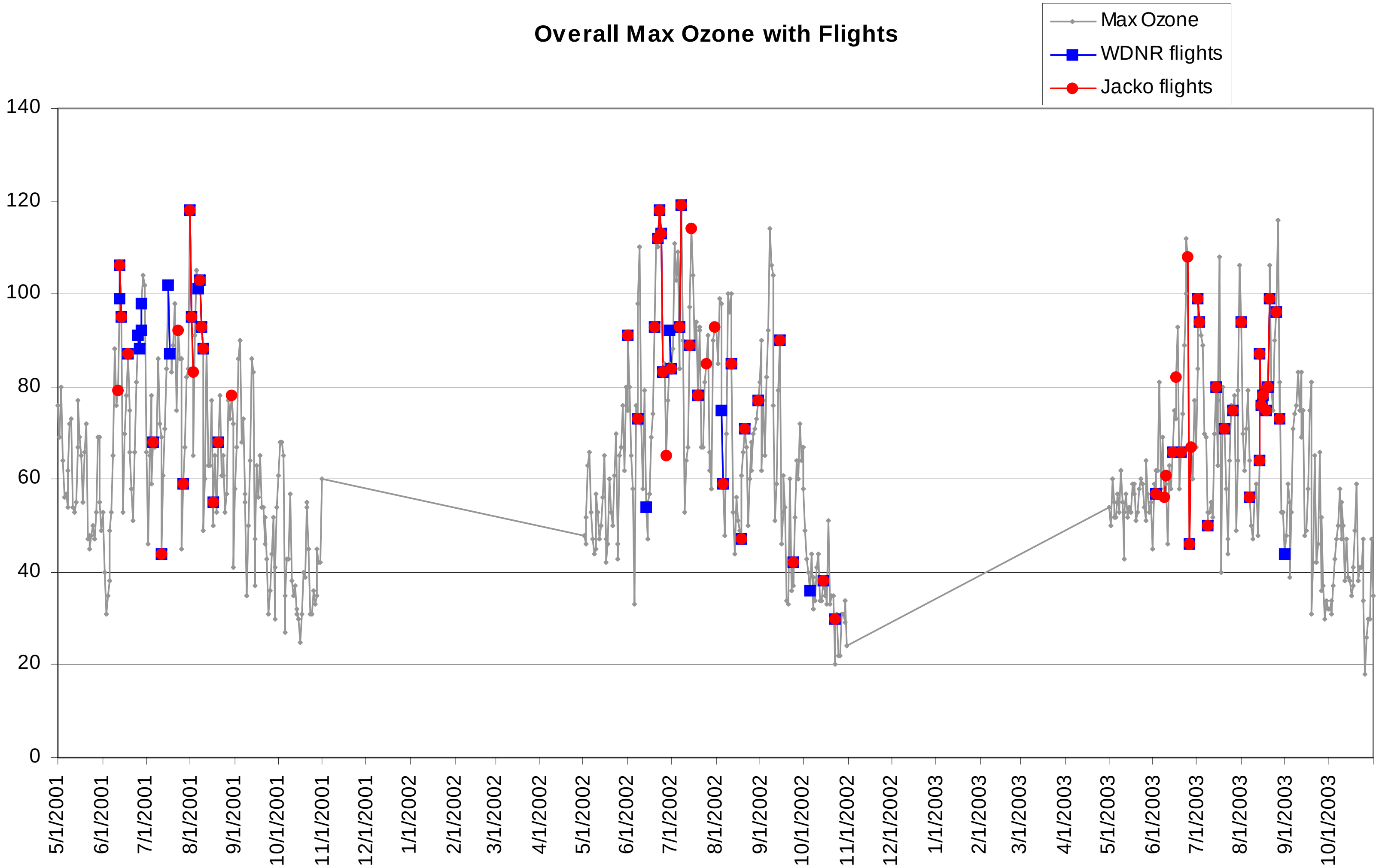


Figure 4-1. Time series plot of days when the WDNR (blue points) or Jacko (red points) aircraft flew and an 8-hr maximum ozone concentration was reached in Chicago, Saint Louis, Milwaukee, or Grand Rapids.

5. RECOMMENDATIONS

From 1987 through 2003, the WDNR and Robert Jacko flew aircraft to collect aloft air quality data in the Lake Michigan area, primarily in the summertime. STI focused on organizing and quality-controlling the data and creating useful data plots for data analysis. Limited data analysis was also completed for this project; however, the analysis was intended to be a starting point and a catalyst for further analyses. In particular, case study analysis was performed on only 8 flight days. Therefore, the conclusions discussed in this document and in the presentation (Appendix A) are not universal or definitive. With this caveat, these recommendations focus on additional data analysis using the wealth of aircraft data and, additionally, on future aircraft monitoring. The goal of the data analysis and monitoring efforts outlined in these recommendations is to enhance the conceptual understanding of regional haze, particulate matter, and ozone pollution in the Lake Michigan region. The conceptual model can support forecasting, modeling and model verification efforts, and, ultimately, state implementation plan (SIP) development.

5.1 DATA ANALYSIS

Based on the initial review of the data, we recommend the 1987 through 2003 WDNR and Jacko data be used to address the following questions using a much broader spectrum of flight data than already analyzed. Analysis of data from 20 to 30 more flight days will greatly expand the confidence and applicability of the conclusions, but some questions might be addressed using up to 100 flight days.

1. *How do air quality boundary conditions vary as a function of time of day, location, and altitude?*

   Work completed: This question has been addressed statistically for all appropriate flights and all years; however, case study analysis was performed for only 8 flight days.

   Additional analysis: Perform case study analysis of plots of aircraft, trajectory, and wind data for at least 20 to 30 additional flight days.

2. *Has the amount of material transported into the region changed over time? How do we expect boundary conditions to change in the future?*

   Work completed: These questions have not been addressed.

   Recommended analysis: Plot upwind boundary conditions as a function of year and determine if there is a trend. Then, correlate changes in boundary conditions over the past decade to changes in emissions. If there is a meaningful relationship, the relationship and estimates of future emissions can be used to predict future boundary conditions.

3. *What is the relationship among local flow patterns, boundary layer structure, and the horizontal and vertical distribution of pollutants including $PM_{2.5}$?*

   Work completed: This question has been addressed using case study analysis for only 8 flight days.

Additional analysis: Analyze spatial plots of aircraft data, surface and aloft wind data, trajectories, and weather charts for at least 20 to 30 additional flight days to enhance a conceptual understanding of the processes that influence the distribution of pollutants. Note that in the completed work, a fair relationship between integrated $PM_{2.5}$ and nephelometer data was developed. This relationship can be used cautiously to evaluate the continuous nephelometer data as a surrogate for $PM_{2.5}$, thus allowing an approximate spatial and temporal distribution of $PM_{2.5}$.

4. *What is the contribution of pollution transported from upwind areas and local pollution to local peak ozone concentrations? Has this changed over time?*

   Work completed: This question has been addressed using case study analysis for only 8 flight days.

   Additional analysis: For at least 20 to 30 additional flight days, use morning and afternoon upwind aircraft air quality data, morning air quality data aloft, afternoon downwind aircraft and surface air quality data, and 48-hr trajectories calculated at multiple levels to determine regional transported ozone that is added to locally generated ozone to create peak local ozone. Review the data by year to determine if it has changed over time.

5. *What are the source areas of the transported pollution and how does the composition (ozone, NO_x, VOCs, $PM_{2.5}$) of the incoming air vary with source region?*

   Work completed: This question has been addressed using case study analysis for only 8 flight days.

   Additional analysis: For at least 20 to 30 additional flight days, use trajectories, synoptic weather charts, and AIRNow ozone maps to determine likely source areas and source area concentrations and composition.

6. *Does local carryover of pollutants in aloft layers significantly contribute to peak ozone concentrations?*

   Work completed: This question has been addressed using case study analysis for only 8 flight days.

   Additional analysis: For at least 20 to 30 additional flight days, analyze morning vertical air quality data measured near metropolitan areas. Using these data, calculate the potential contribution to midday, mixed-layer ozone of aloft ozone mixed to the surface. Perform simple box-model calculations to identify the effect on average and peak surface ozone concentrations of mixing aloft ozone with fresh surface emissions.

7. *What is the same-day region of influence of urban plumes?*

   Work completed: This question has not been addressed.

   Recommended analysis: Review afternoon spatial plots of ozone data for at least 20 to 30 additional flight days and record the typical length and width of the urban plumes. Describe the similarities and differences and locations of the plumes relative to contributing factors such as synoptic and local meteorology, transport direction, regional and local contribution, etc.

5.2 MONITORING

The goal of monitoring air quality using aircraft is to collect data that can be used to address specific questions that cannot be easily addressed with standard surface data. The advantages of aircraft data over surface data are that aircraft measurements provide data in the vertical and in areas where surface monitors do not exist. The data collected by the WDNR and Jacko aircraft have proven to be useful in answering many air quality questions. However, some modifications to the existing flight paths might further enhance the quality of the data to address additional questions and to more definitively answer questions addressed using the existing data. These flight modifications are discussed below. In addition, **Table 5-1** summarizes types of analyses, flight patterns, and supplemental data suited to address various objectives. For example, plots of air quality data collected during early morning vertical profiles, combined with estimates of daytime vertical mixing (when available) and morning surface air quality data, are well-suited for estimating the contribution of local carryover pollution from one day to the next.

5.3 SPECIFIC RECOMMENDATIONS

- On some flight days, the Jacko aircraft performed several vertical spirals around Saint Louis a few times each day. This flight track was good and should be performed on several more days to obtain a more representative data set. However, the Jacko aircraft did not collect NO_x data. Monitoring this pollutant is recommended to better characterize the vertical and horizontal distribution of ozone precursors.
- Often, the WDNR aircraft flew offshore over Lake Michigan from Oshkosh to the southern end of the lake off Chicago and back again. On the southbound leg, the aircraft flew at about 500 m above the lake (agl); and on the return leg, the aircraft flew at about 100 m agl. This flight pattern was repeated up to four times daily from early morning until evening. Often, while the WDNR aircraft flew over Lake Michigan, the Jacko aircraft flew from La Crosse, Wisconsin, to Lafayette, Indiana, at about 500 m agl. The Jacko flights typically occurred one or two times a day, midmorning and afternoon. The combination of these flight patterns and flight times provided good data to address many technical questions. However, the data might be enhanced if the WDNR aircraft performed 4 to 6 vertical spirals from the surface to about 1000 m agl at several points along the current Lake Michigan flight track. In addition, the WDNR should also perform vertical spirals at the shoreline and about 1 to 2 miles inland near Chicago and Milwaukee. All spirals should be repeated at the same place at several times of day and on many flight days. This information will allow scientists to better address the relationship among local flow patterns, boundary layer structure, and the horizontal and vertical distribution of pollutants, especially in the complex transition between the lake and the land.
- On the same days that the WDNR aircraft flies over Lake Michigan, another aircraft (Jacko?) should collect air quality data to the south and west of Chicago and Milwaukee similar to the La Crosse/Lafayette flights, but only about 20 miles from Chicago and Milwaukee. The flights should occur during the morning and afternoon and should include at least four spirals from the surface to about 1000 m agl. A traverse flight altitude of 500 m agl is appropriate, although a dolphin track might provide additional

vertical information. This new flight track will provide better upwind or downwind (depending on wind direction) air quality information for the Chicago and Milwaukee areas and allow scientists to better address the distribution of air quality in the upwind or downwind Chicago/Milwaukee boundaries.

- Occasionally the WDNR aircraft flew a route to Lake Superior. The few days that were analyzed in this project showed good air quality, and the data provided information about natural background air quality conditions. However, these sparse data do not imply that air quality is always good in this area. Therefore, flights to this region on days when there are southerly winds might provide data to assess transport of pollution to the Lake Superior region from source areas to the south.

- Neither the WDNR nor Jacko aircraft collected air quality data directly downwind and near major point sources. Collection of ozone, NO_y, and wind data at several points downwind of point sources can be used to quantify how much ozone is generated from a given point source and address the quantity and role of ozone produced from point source plumes in the context of regional-background ozone. This is important because regional-background ozone concentrations can contribute to peak urban ozone concentrations. In addition, since most large rural point sources of NO_x do not emit VOCs (a key ingredient for ozone formation), rural point source NO_x may not produce ozone to the same extent as NO_x emitted in VOC-rich urban areas. Therefore, it is also important to determine how much NO_x emitted from rural point sources in the upper Midwest contributes to regional ozone. A sample of a good point source plume flight is shown in **Figure 5-1**, from MacDonald et al. (1999).

- The WDNR aircraft collected flight-integrated $PM_{2.5}$ and VOC data. Although the integrated data is useful for assessing general boundary conditions, flight-leg, as opposed to total flight, integrated samples would provide data useful for addressing $PM_{2.5}$ and VOC vertical and horizontal characteristics and allow scientists to address such issues as the relationship among local flow patterns, boundary layer structure, and the horizontal and vertical distribution of $PM_{2.5}$ and VOCs. Therefore, we recommend that integrated samples be taken during several flight legs, such as during individual vertical spirals, when the aircraft is on a constant altitude traverse, in a particular area such as southern Lake Michigan, etc.

- The WDNR collected NO_y data from 1996 through 2003. The accuracy of the NO_y data might be improved by configuring the sampling system so that the inlet line to the NO_y converter is minimized and with the addition of the facility to calibrate the NO_y converter through the inlet. The current configuration almost certainly leads to loss of reactive species (HNO_3 in particular), limiting the interpretability of the data collected in photochemically aged air masses. Addition of a photolytic NO_2 converter to the system, possibly in concert with an additional NO monitor, would allow measurement of NO_2 and, consequently, NO_x. If this species were available, analyses of photochemical processing taken as the NO_x/NO_y ratio would be possible.

Table 5-1. Analysis objective, the types of analyses, flight patterns, and supplemental data suited to address each objective. X denotes that a flight pattern is well-suited and Z denotes that a flight pattern is potentially suited to address the objective.

		Flight Pattern										
Objective	Analysis tools using aircraft air quality data	Repeated vertical profiles over many days	Non-repeated vertical profiles	Upwind traverses	Down-wind traverses	Urban area traverses and spirals	Morning flights	After-noon flights	Dolphin flight pattern	Point Source Plume flights	Random flights	Supplemental Data
Amount of pollution transported from upwind areas	Spatial plots	X	Z	X			X	X	X		Z	Trajectories, synoptic weather charts
Local verses regional contribution	Spatial plots, volume averaging, and fluxes	X	Z	X	X		X	X	X		Z	Surface air quality data, trajectories
Boundary conditions	Spatial plots and tabular summaries	X	Z	X			X	X	X		Z	Trajectories
Vertical distribution for model verification and initial conditions	Vertical profiles and volume averaging	X	Z	Z if at multiple altitudes	Z if at multiple altitudes	X	X	Z	X			Temperature profiles
Precursor and pollutant carryover	Vertical profiles plots and volume averaging	X	Z			X	X					Temperature profiles, daytime vertical mixing, and surface air quality data
Region of influence of urban ozone	Spatial plots	Z	Z		X	X		X	X		Z	Trajectories, local wind data
Extent and role of ozone produced from point source	Spatial plots and ozone production equations									X		Wind data near point source
Relationship between local flows and pollution	Spatial plots, vertical profiles, and wind field plots	X	Z	Z	X	X	X	X	X		Z	Trajectories and local wind data
Surface monitor evaluation	Spatial plots and scatter plots	X over ground stations	Z over ground stations	X	X	X		X	X		Z	Surface air quality and meteorological data
Relationship among pollutants	Spatial plots, scatter plots, and correlation	X	Z	X	X	X	X	X	X	X	Z	Trajectories
Atmospheric conversion rates	Plots of data sequentially along trajectories			X	X	X	X	X	X	X		Trajectories

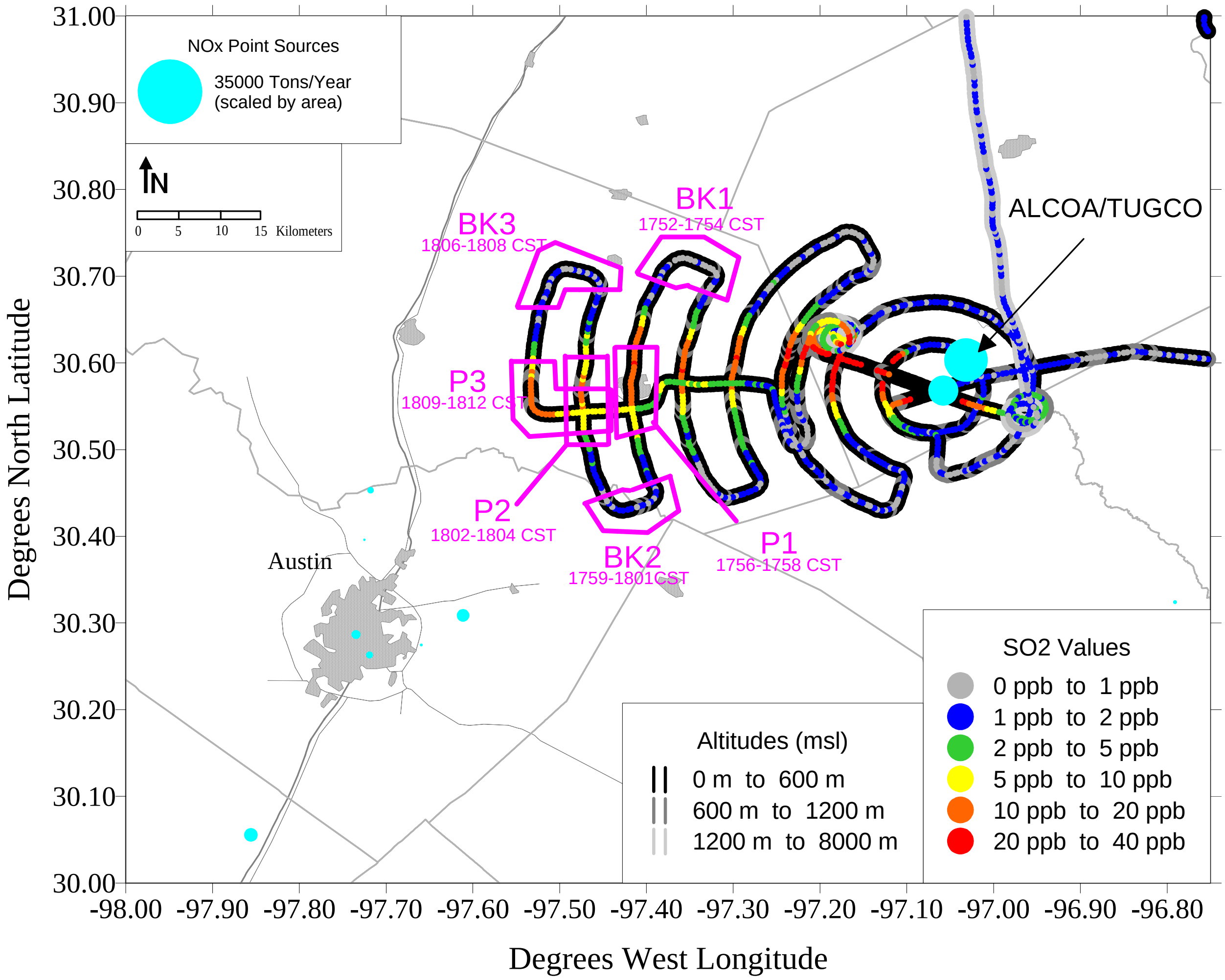


Figure 5-1. Sample point source plume flight showing the Baylor University Flight 39 position, altitude, and sulfur dioxide concentrations on the afternoon of August 25, 1997, downwind of the Alcoa–Tugco point sources. The purple boxes indicate the flight segments used to assess ozone yield (MacDonald et al., 1999).

6. REFERENCES

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