

<p><b>Baylor University</b>  <b>Aviation Sciences Department</b>  <b>Renewable Aviation Fuels Development Center</b></p>
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## 1999 Executive Summary

### Airborne Pollution Monitoring Services

Contract Number 582-9-00782 with  
Central States Air Resource Agencies  
(CenSARA)

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# Executive Summary

## 1. Introduction.

This report summarizes the air quality measuring activities undertaken and completed under the terms of this contract by Baylor University, Department of Aviation Sciences, for the Central States Air Resource Agencies.

In April 1999 a fire destroyed the King Air used previously by the RAFDC for air sampling, consequently it became necessary to find, purchase and fit out a new aircraft to undertake the air pollution measuring operation. A deHaviland Twin Otter aircraft was located and purchased.

New measuring equipment was purchased and fitted to the Twin Otter. The measuring capability of the previous year was enhanced by the addition of an improved inlet system and serial data logging capability with a Campbell CR10X data logger.

The inlet system was modified to include a Pyrex glass manifold to reduce residence time, a specially designed NO<sub>y</sub> inlet to prevent loss of nitric acid and other reactive nitrogen species on the wall of the sampling inlet tube and Teflon tubing. A particle sampling inlet for the nephelometer, sulfate particulates and particulate matter less than 2.5 microns in diameter (PM<2.5) was also incorporated into the design.

In addition, the platform was modified to improve instrument cooling by increasing the space between the racks.

This work was completed on July 23<sup>rd</sup>. An audit of the measuring systems took place on August 2<sup>nd</sup> & 3<sup>rd</sup>.

In parallel with the fit-out of the measuring equipment the new aircraft was registered into the USA fleet with the FAA. The airworthiness certificate was issued on Aug 15<sup>th</sup> and the aircraft was declared operational that same day.

The first measuring flight undertaken by this airplane was the 21<sup>st</sup> of August, 1999.

A total of 36 measuring flights were flown during the Summer and Fall of 1999, and these are reported under the following categories:

- Power station investigations                      6 flights
- Urban or City plumes                                      12 flights
- Regional flights    5 flights
- Big Bend related flights                                7 flights
- Others or mixtures of the above                      6 flights

The more interesting flights are reported in greater detail below in sections 3 through 6.

The completed flights for the entire season, including excel spreadsheets and surfer plots, were submitted to TNRCC on November 22, 1999.

## 2. The Twin Otter Aircraft.

The King Air was being operated at the limit of its load carrying capacity and its weight and balance envelope. New equipment could only be added at the expense of fuel capacity so any new data collection devices could only be incorporated by sacrificing mission flight time. On top of that, the aircraft was also being operated close to the rear Center of Gravity (CG) limit, further constraining where any new equipment might be placed within the aircraft. The useful load of the King Air was 2504 lb for fuel and personnel, and the instrument package weighed 902lb. Although the fuel capacity was 384 gal (2573 lb) and the fuel burn 75 gal/hr (503 lb/hr), giving a maximum allowable flight time of 4.3 hr (as 30 minutes reserve is mandated by the FAA), only 289 gal (1936 lb) could be loaded with a crew of three giving a legal flight time of ~ 3.0 hours.



Fig 1 Instrumented Twin Otter Aircraft used for the 1999 measuring season

The Twin Otter on the other hand, has a useful load of 3277 lb for crew plus fuel, and so can always carry full fuel unless training of additional personnel might require leaving 20 to 30 lb of fuel behind. The addition of further measuring equipment (planned for 2000) will limit the crew to three if full fuel is required. Currently, the instrument package in the twin Otter weighs 1192 lb. Although the Twin Otter has essentially the same fuel capacity as the King Air (382 gal or 2559 lb) and the fuel burn is higher at 90 gal/hr (603 lb/hr) giving an endurance of 3.5 hr (after subtracting the 30 minute reserve), this flight time is always available in this aircraft if a crew of three is deployed.

The Twin Otter is a non-pressurized aircraft, which limits the altitude it can be flown without crew oxygen to about 12,000 ft. MSL. This is sufficient for all but very few flights of the type called for in this sampling program. The Otter can still attain a ceiling of 25,000 ft if supplemental oxygen is provided to the crew.

Compared to the systems used in 1998, the Twin Otter had additional measuring capabilities added in preparation for the 1999 season. A Fast Ozone, NO<sub>2</sub> and NO<sub>y</sub>\* systems were added to the instrumentation package, the sulfate system was improved, a molybdenum converter was substituted for the gold converter in the NO<sub>y</sub> system, and a newly developed Sonoma Technology Inc. data collection system was employed. A 47mm URG filter pack system with a flow sensor was also installed.

The entire measuring system capability used in 1999 is shown in Figure 20 at the end of this report.



Fig 2 View of Instrumentation installed in the Twin Otter Aircraft  
Note flight instruments, control yoke and windscreen in the upper center

*The following sections describe chosen flights. Track plots and graphical output from an Excel spreadsheet of the major pollutants are included at the end of the report. These should be consulted in conjunction with the narrative of the flight.*

### **3. Power Station Flights**

A total of 6 flights were undertaken in this category, which includes other large industrial consumers of power such as Cement Works.

In general these flights gave the strongest peak heights of various pollutants such as SO<sub>2</sub> and NO<sub>y</sub>.

Plume dispersal was not as strong as expected on many occasions. One example of the plume persistence is demonstrated as follows. Directly overhead chimney stacks values as high as 195 ppb of SO<sub>2</sub> and 185 ppb of NO<sub>y</sub> were measured, which dispersed in the plumes to 50 ppb SO<sub>2</sub> and 25 ppb NO<sub>y</sub> 5 nm downwind of the stack, and 40 and 20 ppb respectively a further 15 nm downwind. Within the plume the nephelometer readings increased by 25 to 50 percent depending on circumstances. As expected, the plumes could not be detected above the mixing layer.

More specific information for two of these flights is as follows:

**Flight 107 – September, 15 1999**  
**The Midlothian Ozone, NO<sub>x</sub> and SO<sub>2</sub> investigation.**  
**(refer to figure 3)**

Ozone levels reached 89 ppb at the highest peak to the WNW of the Midlothian industrial complex on this day when the winds were light but predominantly from the ESE. A strong and persistent Ozone plume was observed at 2000 ft MSL (1200 ft AGL and 875 ft above the stack heights) and this fanned out from Midlothian, although there was evidence of some drift slightly to the South. Mean Ozone levels in the area were approximately 80 ppb downwind, and 70 ppb upwind of the plume.

The Ozone levels became more persistent once the airplane was tracking to the West of Interstate I35W, but the contribution of traffic to the NO<sub>x</sub> and Ozone levels were not able to be determined. The influence of the Dallas urban plume to the overall ozone levels was also evident as the flight path went slightly south west of the metroplex. However, the Ozone plume from industry in the area was also demonstrably present East of I35W

The NO, NO<sub>y</sub> and SO<sub>2</sub> levels during this flight were probably more interesting than the ozone levels. Background levels of 0, 5 and 2 ppb respectively were noted, but peaks as high as 22, 80 and 42 ppb were observed as the aircraft crossed the plume from combustion of a sulfur containing fossil fuel in the area. There were the expected concomitant drops in Ozone levels at these points in the flight due to the chemical interactions between NO<sub>x</sub> and Ozone.

An attempt to track this plume back into its source late in the flight was partially successful with three peaks in quick succession between 3:30 and 3:45 pm, with the main peak recording 62 ppb of NO<sub>y</sub>.

On this occasion, the mixing layer was never reached despite a climb to 4000 ft MSL late in the flight, and the ozone levels confirm that the flight took place entirely below any inversion which might have been present that day.

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**Flight 115 – October 2, 1999**  
**Big Brown and Limestone Power Stations**  
**(refer to figure 4)**

One of the major points of interest from this flight was the ability to distinguish plumes from adjacent power stations from one another.

Each plume was characterized by a NO<sub>y</sub> and SO<sub>2</sub> peak, and sometimes an NO peak too depending on how long it was since the plume was released from the chimney top. With the wind conditions that were prevailing during this flight, the plumes associated with each power plant could be distinguished out to around 40 miles downwind.

On the day of this flight ozone levels generally ranged between 70 ppb and 90 ppb, but peaked at 108 ppb in one of the plumes emanating from Big Brown power station. Background levels of NO<sub>y</sub> and SO<sub>2</sub> were 3 ppb and of NO, less than 1ppb.

Just overhead and immediately downwind of the Big Brown power station, SO<sub>2</sub> levels reached 100 ppb, and the plume from this power station was crossed again at a distance of 17 and 27 nm where the SO<sub>2</sub> peaks recorded were 36 and 28 ppb respectively. In these plumes nephelometer readings increased by 42 to 50 percent over the values outside the plume, and ozone was increased by 12 to 15 ppb.

The Limestone power station also exhibited persistent and identifiable plumes on this day, although the SO<sub>2</sub> and NO<sub>y</sub> outputs were not nearly as high as for Big Brown. Upwind baseline values for NO and SO<sub>2</sub> were in the 2 to 3 ppb range and a traverse 4 nm downwind peaked at 15 ppb of SO<sub>2</sub>. Subsequent intersections of the flight path and the plume track gave peak heights of 10 and 6 ppb on the way to Big Brown with similar values for NO<sub>y</sub>.

An attempt to track back into Limestone power station from about 350° along the plume was quite successful with heightened SO<sub>2</sub> levels from a distance of 35 nm inbound. A final step climb which crossed this plume at 1000 ft increments from 2000 up to 5000 ft gave identifiable peaks of SO<sub>2</sub> with concentrations of 10, 8, 7, and 5 ppb.

#### 4. Urban and City Plumes

A total of 12 flights were undertaken which fit this category. Of these, 9 were tasked around Houston, 2 around San Antonio, and 1 around the Dallas Fort Worth metroplex. Some flights originally designated as regional investigations also crossed urban plumes.

**Flight 123 a & b – October 21, 1999**  
**Houston Ozone episode**  
**(refer to figures 5, 6, & 7)**

This flight is one of two chosen to illustrate the movements and persistence of urban plumes in the Houston region. Although light winds existed for both flights (the second was on October 26, 2000), the general airflow for flight 123 was from the North East, whereas the airflow for the second flight (flight 126) was generally from the South.

Flight 123(a) departed Waco at 11:07 am and tracked slightly North of Houston to determine the upwind concentrations of Ozone which averaged just under 60 ppb from 1,500 ft to 10,000ft AMSL, except in the near vicinity of point sources where values reached into the 60 to 80 ppb range for short periods. Overhead the industrial areas East of Houston, values rose into the 60 to 80 ppb range with occasional values near 90 ppb, but again dropped to less than 60 ppb South East of the City. A significant plume in the refinery or industrial area was generating considerable emissions and a quite visual plume that was moving to the south west. A strong temperature inversion was also holding these emissions below 5000 ft. Figure 7 below gives a graphic indication of the strength of this plume and the inversion layer preventing it from mixing into the upper airstream.



Fig 7 Plume from a refinery South East of Houston in strong inversion conditions

Traverses of the general plume were made at 18, 28, 36 and 44 nautical miles from this point source and corresponding peak ozone levels of 124, 108, 91 and 75 ppb were measured in the traverses. On a final track directly towards the plume, however, ozone levels approaching 150 ppb were recorded. Coincident with each ozone peak in the plume were corresponding peaks of NO<sub>y</sub> and SO<sub>2</sub>, indicating the point source was a strong contributor to the overall plume.

The mid to late afternoon segment of this flight also tracked the plume downwind of Houston out to a distance of 60 miles from the City (and about 60 miles from the flare point source), although the cohesion of the plume was dissipating by the final traverse despite being reinforced by smaller point sources from time to time.

The traverses made were at 18, 25, 37, 50 and 60 nautical miles with peaks of Ozone with values rising to 100 ppb or slightly higher, from troughs of just 60 ppb. The Ozone peaks during this portion of the flight could not be correlated as easily with peaks of SO<sub>2</sub> or NO<sub>y</sub> indicating a higher proportion of general urban emission in the plume.

Away from Houston on the return trip to Waco later in the afternoon, the background Ozone level measured averaged approximately 70 ppb.

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**Flight 126 b – October 26, 1999**  
**Houston Ozone episode**  
**(refer to figure 8)**

The object of this flight was to characterize ozone production from urban and industrial plumes in the Houston area by comparing upwind and downwind ozone levels on a day declared to be an Ozone Action day. The wind forecast for this day was essentially calm in the morning with a 4 to 6 knot S to SE wind during the afternoon. Measured winds for that day confirmed this general airflow.

The flight departed Waco at 11:53 am. On the trip south towards Houston, ozone levels generally between 60 and 80 ppb were encountered, except in the vicinity of point sources where the presence of oxides of nitrogen drove the values down into the 40 to 60 ppb range momentarily. A similar pattern was observed South and West of Houston, and over the city center where ozone levels at 1500 ft MSL did not exceed 80 ppb and occasionally dipped to less than 60 ppb. However, once to the East and slightly North East of the City in the vicinity of the more industrial areas, Ozone levels increased markedly and reached peak values exceeding 160 ppb.

The afternoon flight made 5 traverses through the Northward moving ozone plume from the urban and industrial emissions. These were made at approximately 9, 17, 32, 48 and 72 nautical miles North of the Houston International Airport (about 22, 30, 45, 61 and 85 nautical miles from the city center).

Ozone values in excess of 80 ppb were measured in a 45° arc right out to the 85 nautical mile traverse, and only lack of fuel for the aircraft prevented the plume being followed further. In the center of the 80 ppb segment of each traverse, much higher ozone levels were recorded, with values exceeding 100 ppb on 4 of the 5 passes, peaking at over 170 ppb and 160 ppb respectively in the first two traverses.

This flight showed that urban plumes persist for great distances given relatively stagnant airflows.

## **5. Big Bend National Park related flights (incorporating regional flights)**

A total of 7 flights were undertaken in this category and four are described below. The first of these was a flight investigating poor visibility in the Big Bend National Park. The second was a planned series of flights over four consecutive days to study air transport and continental haze as an air mass moved from coastal Louisiana up through South West Texas and Mexico into Big Bend National Park. Unfortunately the presence of thunderstorms in the area at the end of the third day prevented the completion of this mission as these storms caused severe disturbances and mixing of the air masses.

### **Flights 99a and 99b – Sept 1, 1999 (8:00am to 11:00am & 1:45pm to ~ 4:45pm) Big Bend National Park investigation. (refer to figures 9, 10, & 11)**

These flights were conducted to help further the understanding of the poor visibility often encountered in the park during summer months. One flight was conducted during the early morning and the other in the afternoon that tracked the morning flight's profile (track and altitude) as closely as possible. Wind conditions during these flights were light and variable tending from the south to east in the morning, but strengthening and steadying during the day to end south easterly at 5 to 10 knots. On both occasions the flights began and ended in Alpine that is at an altitude of 4500 ft MSL.

#### **The morning flight.**

Visibility levels were perceived to be poor on this day and the nephelometer readings confirmed this. The nephelometer readings were, however, extremely altitude dependant with values halving from  $78 \times 10^{-6} \text{ m}^{-1}$  to  $\sim 35 \times 10^{-6} \text{ m}^{-1}$  within the first 1000 ft AGL, and a spiral to almost 13000ft MSL saw values fall to  $7 \times 10^{-6} \text{ m}^{-1}$ . As the wind steadied towards noon and picked up a little, the nephelometer readings began to fall, finishing at  $\sim 50 \times 10^{-6} \text{ m}^{-1}$  at the airport on landing.

No evidence of a temperature inversion was apparent, either by a sudden decrease of pollutant levels at a specific altitude, or from the temperature profile logged during the flight. In contrast to the strong interdependence of nephelometer and altitude data recorded, the ozone values remained relatively unchanged with altitude variation, and lay between 70 and 90 ppb for almost the entire flight.

Preliminary analysis of the sulfate data collected showed a strong correlation to nephelometer as would be expected, and in this case, to altitude also. Values ranged from  $2\mu\text{g}/\text{m}^3$  at 12,800ft to  $12.5\mu\text{g}/\text{m}^3$  at 3,000ft.

During the latter half of this flight where ozone concentrations rose to higher levels,  $\text{NO}_y$  values followed the ozone trends closely, peaking at around 3ppb when the ozone levels exceeded 90ppb.

### **The afternoon flight.**

Due to the increasing wind and temperature, both ozone and nephelometer readings decreased during the afternoon. Again, ozone was relatively independent of altitude and lay almost entirely between 70 and 85ppb, while nephelometer values were still strongly dependant on elevation, peaked under  $60 \times 10^{-6} \text{ m}^{-1}$  and did not fall below  $10 \times 10^{-6} \text{ m}^{-1}$ , even when the aircraft climbed to 11,500ft.

One interesting feature of this flight was the steadily increasing  $\text{NO}_y$  values which reached 4 to 5 ppb by the end of the flight and were relatively independent of the ozone levels. One possibility for this is the increasing wind from the SE, and the presence of electricity generating Power Stations about 100 miles in this direction.

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### **Flights 103, 104 a & b, and 105 – September 10, 11 and 12, 1999 Regional air movement and Big Bend investigations. (refer to figures 12, 13, 14, 15, 16, & 17)**

The purpose of this series of flights was to study air movement in South Central USA. In particular it was proposed that an air mass originating in the Mississippi Valley be followed from the coast off Louisiana through Southwest Texas and Mexico up into the Big Bend National Park region. Meteorological conditions were forecast to be suitable to provide such an airflow during September 10 through 13, 1999. As mentioned above however, thunderstorms in the Big Bend area curtailed the mission.

**Day One.** Louisiana coastal flight. Winds generally light north to north easterly (5 to 10 knots) – (see figure 12)

Ozone levels in the 80 to 100 ppb range were recorded over almost the entire route from Waco to coastal Texas just southeast of Houston except for a sudden increase to 120ppb, accompanied by a sharp increase of both  $\text{SO}_2$  to nearly 20ppb and  $\text{NO}_y$  to 25 ppb over the industrial area just prior to landing for fuel in Beaumont. The same industrial plume was

encountered enroute to the major area of interest for this flight with similar ozone, SO<sub>2</sub> and NO<sub>y</sub> values recorded.

Once over the gulf of Mexico off the Louisiana coast, levels of ozone initially decreased slightly, but then essentially remained within the 80 to 100ppb range at 1000 ft MSL for the remainder of the flight apart from three noteworthy exceptions.

During two climbs, one to 11,000ft, the other to 6,000ft, the ozone levels decreased into the 60 to 80 ppb range with occasional excursions down to 50 ppb, especially during the 6,000ft climb later in the flight. Accompanying these were decreases in the haze level and corresponding decreases in nephelometer values which dropped to almost zero above the mixing layer indicating relatively clear air above about 3,500ft. However, some stratification was encountered during the 11,000ft climb with clear air between 5,000 and 7,000ft, with slight visible haze above 7,000ft and more significant haze below 5,000ft.

The third exception was an encounter with a definite plume where NO<sub>y</sub> values reached 18 ppb with concomitant increases in the nephelometer reading and ozone values peaking at 115 ppb, some 60 nautical miles from the coast. Given the wind direction at the time, it is likely this plume came from the industrial areas to the east of New Orleans.

NO<sub>y</sub> values were generally above 5ppb for this portion of the flight with various small peaks to 8 to 10ppb, while SO<sub>2</sub> levels also showed some corresponding peaks up to 8ppb. These occurred during the time period when nephelometer readings were also elevated into the  $30 \times 10^{-6} \text{m}^{-1}$  to  $65 \times 10^{-6} \text{m}^{-1}$  range.

**Day Two part one.** – Down the Texas coast to Corpus Christi. Winds from the south to south east at around 5 knots. – (see figures 13, 14, & 15)

This segment of the sequence departed Lake Charles at 6:00am for an early flight across the gulf of Mexico maintaining a distance of between 5 and 10 nautical miles from the Texas coastline and an altitude of 1,000ft MSL, arriving in Corpus Christi at 8:05am. Visibility was poor at the flight altitude but became clear above 3,000ft during a climb to 7,000ft in the vicinity of Galveston. Apart from the climb segment, nephelometer readings climbed steadily from a value of  $\sim 30 \times 10^{-6} \text{m}^{-1}$  to peak at  $99 \times 10^{-6} \text{m}^{-1}$  towards the end of the flight. Corresponding increases in sulfate levels accompanied the rise in nephelometer values, and peaked at  $18 \mu\text{g}/\text{m}^3$ .

The local winds during this flight were from the southeast and no sources that would have caused these pollution levels lie in that direction. However, the larger scale air flow as shown on the wind vector map (figs 13 & 14) indicate the origin of the air mass to have more likely been coastal.

SO<sub>2</sub> values were slightly elevated at the start of the flight at 3ppb, but subsided to zero after the climb segment. No SO<sub>2</sub> peaks were observed. NO<sub>y</sub> on the other hand did exhibit two small peaks (8 and 12 ppb respectively) near the start and end of the flight

indicating a small point source plume, but showed background levels of about 3ppb for the entire flight except for the climb portion.

**Day Two part two** – Corpus Christi environs and south to the Rio Grande and return. Light southerly winds generally less than 5 knots at ground level, although some higher velocities were measured aloft. – (see figures 16)

This flight investigated the urban area around Corpus Christi to determine its contribution to the overall pollution levels and the regional aspects over the coast off South Texas and along the Mexican border. The flights were carried out at 1,000ft MSL except for two spiral climbs and a one hour segment from the Rio Grande to Alice at 1,500 ft.

For 85% of this flight, ozone levels remained in the 40 to 60 ppb range with ~9.5% lower between 30 and 40 ppb and ~5.5% over 60 ppb (but less than 68). Within the 40 to 60 ppb band however, actual values were generally higher over the industrialized areas near Corpus Christi and tended to fall near and over the gulf, and near the Rio Grande where they reached their lowest value of 30 ppb. During the spiral climbs however, at places where the nephelometer readings dropped suddenly, indicating a variation in temperature akin to an inversion layer, ozone levels increased markedly (by 15 to 20ppb) indicating the source of this ozone was not local industrial production – rather that it had been carried into the region by higher level air masses. This conjecture is further supported by the stratification of haze noted in the higher altitudes.

Nephelometer values for this flight showed a similar pattern to the ozone values when flying below the mixing layer – i.e. they were higher in the urban areas and progressively fell as the aircraft moved towards the coastal and rural regions. During the two climbs however, values dropped significantly – above 4,000 ft east of Corpus Christi and above 2,500 ft over the gulf. These decreases were accompanied by increases in ozone values as mentioned above.

For the first half of this flight (down to Brownsville) SO<sub>2</sub> and NO<sub>y</sub> values were essentially zero except for one or two small industrial plumes. On the return flight to Corpus Christi, however, elevated NO<sub>y</sub> values (3 to 4 ppb) were detected almost the entire flight and three significant SO<sub>2</sub> peaks were noted, two in the vicinity of small grass fires near the Mexican border (13 and 5 ppb), and the other downwind of a refinery (7 ppb), almost at the end of the flight.

**Day Three** – Corpus Christi and environs, then to Alpine. Winds around 5 knots from the Southeast to South Southeast at the start of the flight, although these shifted more Easterly by the end of the flight as thunderstorms began to emerge. – (see figures 17, 18, & 19)

Three significant features came out of this flight which initially measured levels in and around the Corpus Christi area before departing to record more regional pollution events.

The first of these is the clear evidence of higher ozone levels and decreased visibility in the metroplex area itself with a dramatic reduction of both Ozone and nephelometer readings as the aircraft passed to the west and south of the city, especially as the wind was from the SE to SSE. The influence of industrial installations near the coast and to the south east of the city were again seen as the aircraft reentered this area. The second is the increase in ozone levels during two spiral climbs despite decreases in nephelometer readings indicating this ozone is not being produced locally, but is being carried from afar. Finally, the presence of power generating facilities in Mexico are evident with significant increases in ozone, SO<sub>2</sub> and NO<sub>y</sub> as the airplane flew through a visible plume, even though it was some 90 miles away, but directly downwind of the installation.

Away from the influence of local factors and at altitudes below any possible mixing layer, the background levels of ozone lay between 35 and 45 ppb with nephelometer readings between  $10 \times 10^{-6} \text{m}^{-1}$  and  $20 \times 10^{-6} \text{m}^{-1}$ . At the start of this flight at Corpus Christi International airport, ozone levels of 60 ppb and nephelometer readings peaking at  $70 \times 10^{-6} \text{m}^{-1}$  were noted. The nephelometer reading fell slightly as the airplane flew briefly over the Gulf of Mexico, but quickly resumed high readings as urban and industrial emissions were encountered to the east and north and northwest of the city. A sudden decrease to background levels in both ozone (by about 25 ppb) and Nephelometer reading (by around  $40 \times 10^{-6} \text{m}^{-1}$ ) was recorded as the aircraft flew west of Corpus Christi and these depressed values persisted for the next 30 minutes of flight while the aircraft remained south and west of the city. As the airplane reentered the smog plume, these values rose again.

A box climb over the gulf to 7,000ft saw both nephelometer and ozone fall initially, but above the mixing layer, ozone values once again rose indicating this ozone was from sources external to the region. No layering was evident as the nephelometer readings continued to fall to the top of the climb, further indicating this was well mixed air also. On a second climb to 8,500ft later in the day, ozone values again rose to 65 ppb (or ~30ppb above the background levels), whilst nephelometer values dropped to almost zero, although from a lower background level apparent in this area. Good visibility was noted even at altitudes as low as 1,000ft AGL following the climb.

Visible emissions from the stacks of electricity generating facilities, Carbon 1 and Carbon 2 were noted from a distance of about 60 nautical miles, and 10 minutes later a cohesive plume was encountered with four indicators increasing simultaneously. SO<sub>2</sub> increased from 0ppb to 10ppb, NO<sub>y</sub> from ~1ppb to 3ppb, ozone from 40ppb to 55ppb and the nephelometer reading increased from  $12 \times 10^{-6} \text{m}^{-1}$  to  $52 \times 10^{-6} \text{m}^{-1}$  over the period of a minute or two. The evidence of the plume persisted for approximately 18 minutes after which time, readings returned to background levels. The coherence of this plume is not surprising when one studies the archived wind information for the previous three days which shows very steady conditions persisting over that time. This, coupled with the mountainous terrain to the west provides ideal conditions for keeping the plume intact.

## **6 Reliability of Results**

The information collected by Baylor University under this contract is subject to a Quality Assurance Project Plan (QAPP). The QAPP in place for the 1998 season needed modification to adapt its application to the Twin Otter aircraft. The quality assurance plan details the objectives of the measurements to be taken and execution methodology to ensure these objectives are met. In particular the operating procedures for each instrument and the details of how this data is to be processed, including the chain of custody protocol, is documented, and this plan is carefully followed.

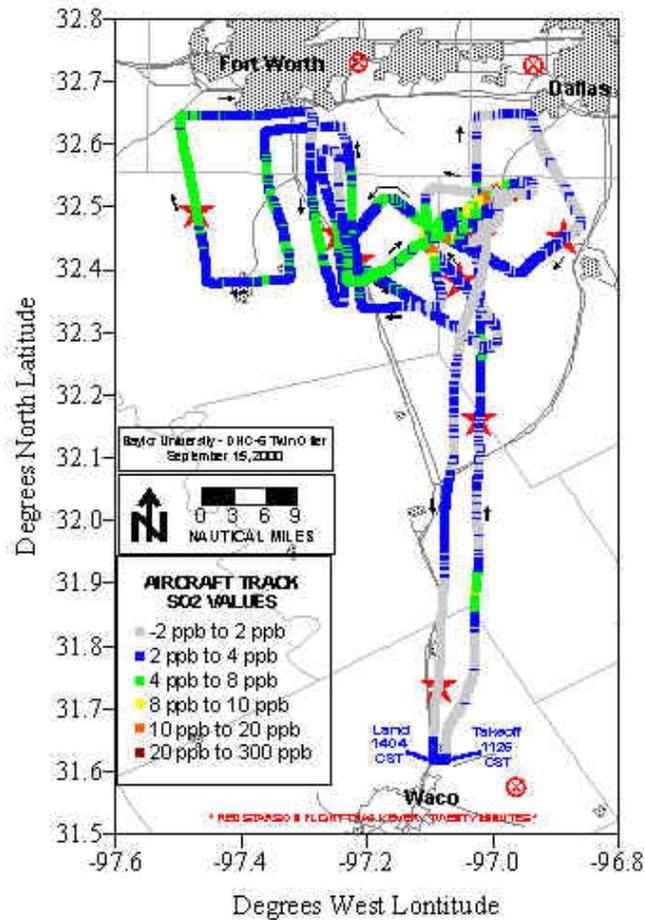
In general, the resolution called for is 0.1 ppb or  $0.1\mu\text{g}/\text{m}^3$  for the chemical parameters measured, and full details can be found in the QAPP document at appendix A, table A6a. This table is reproduced in this report as Figure 20. The detection limits, precision and accuracy required for the measurements are listed in the QAPP at appendix C, table A7. With a few exceptions, it can be seen from these sources that the accuracy required is listed as  $\pm 20\%$  while within that, the precision called for is  $\pm 15\%$ . A quality audit carried out at regular intervals indicates all parameters are generally well within these tolerances.

## **7 Concluding remarks**

The move from the King Air to the Twin Otter provides the Baylor Air Sampling effort increased weight carrying and space capabilities. The space available in the fuselage provides better access to instruments. In the King Air, in order to work on the instruments, it was necessary to remove the instruments from the racks, which took considerable time. In the Twin Otter, it is possible to work on the instruments without removing them. The Twin Otter has larger capacity generators providing a surplus of electrical power for instrument operation. The increase in size also results in a cooler environment inside the aircraft for both the crew and the instruments.

The aircraft provides a means to collect data in three dimensions and at locations not covered by ground measuring stations. This gives a powerful tool to assist in the analysis of Texas' air pollution problems. The validity of the Baylor University information is assured by the quality control procedures in place.

## COMBINED TRACK PLOT AND POLLUTANT CHART SEPTEMBER 15, 1999



### 9/15/99 Baylor Aircraft Flight 107 - Validated Data (5 Second Intervals)

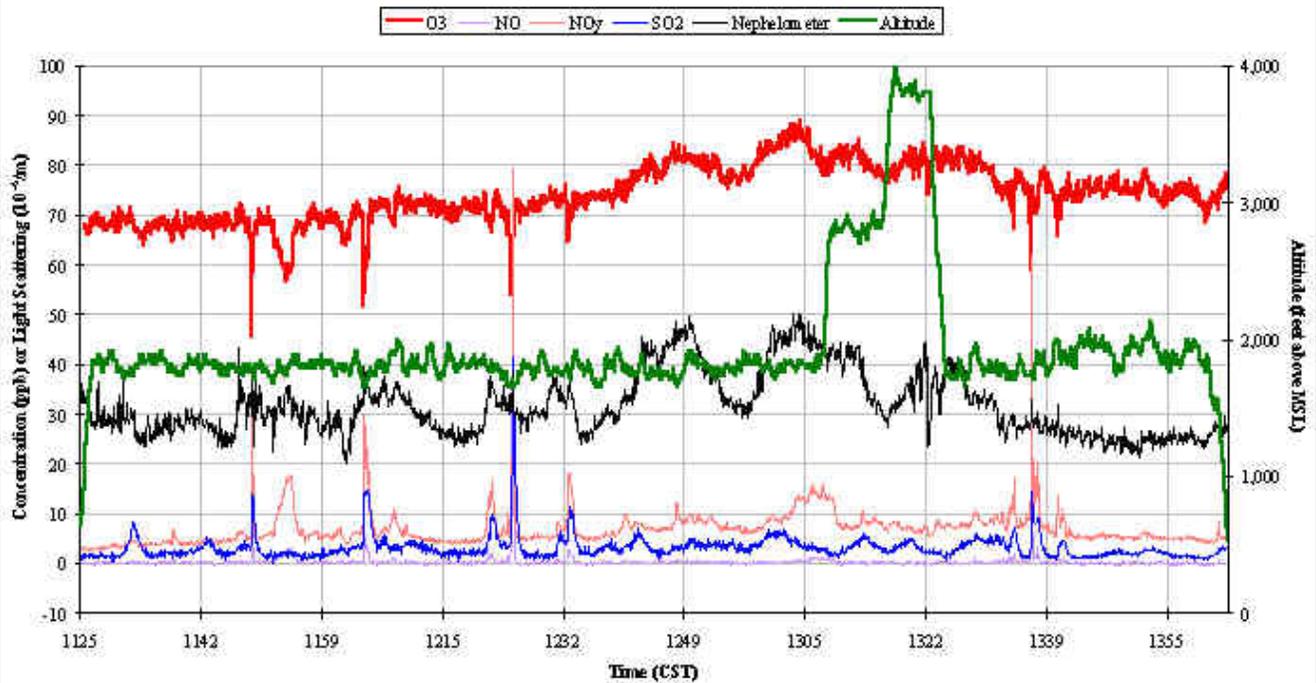
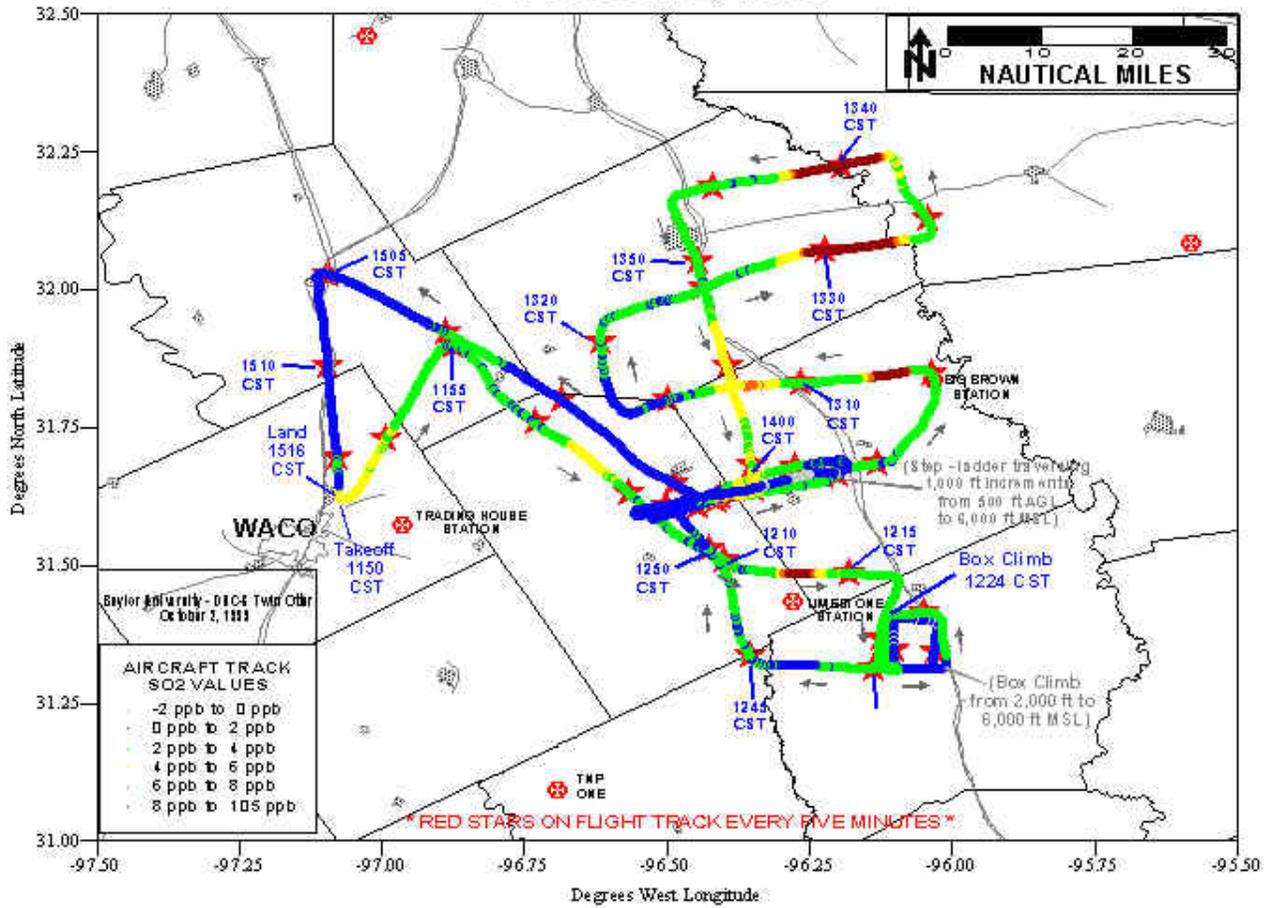
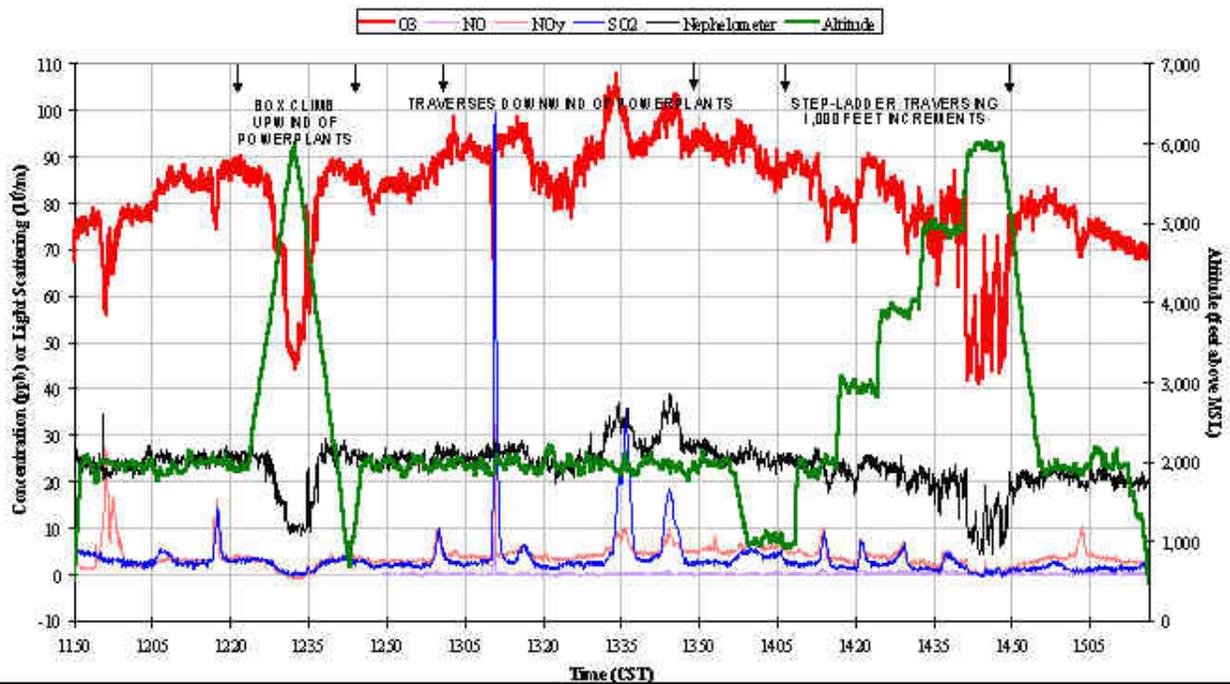


Figure 3 - Flight 107

# COMBINED TRACK PLOT AND POLLUTANT CHART OCTOBER 2, 1999

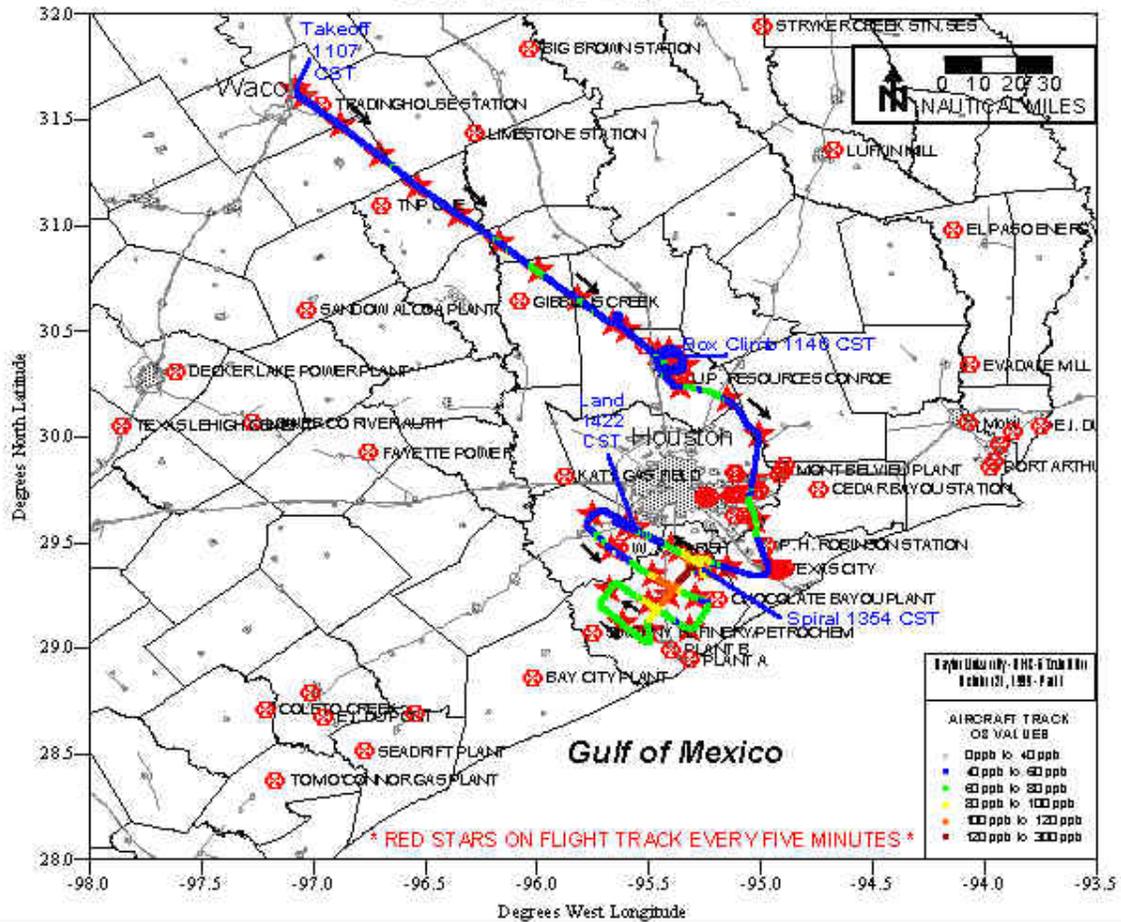


**10/2/99 Baylor Aircraft Flight 115 - Validated Data (5 Second Intervals)**



**Figure 4 - Flight 115**

# COMBINED TRACK PLOT AND POLLUTANT CHART OCTOBER 21, 1999



10/21/99 Baylor Aircraft Flight 123a - Validated Data (5 Second Intervals)

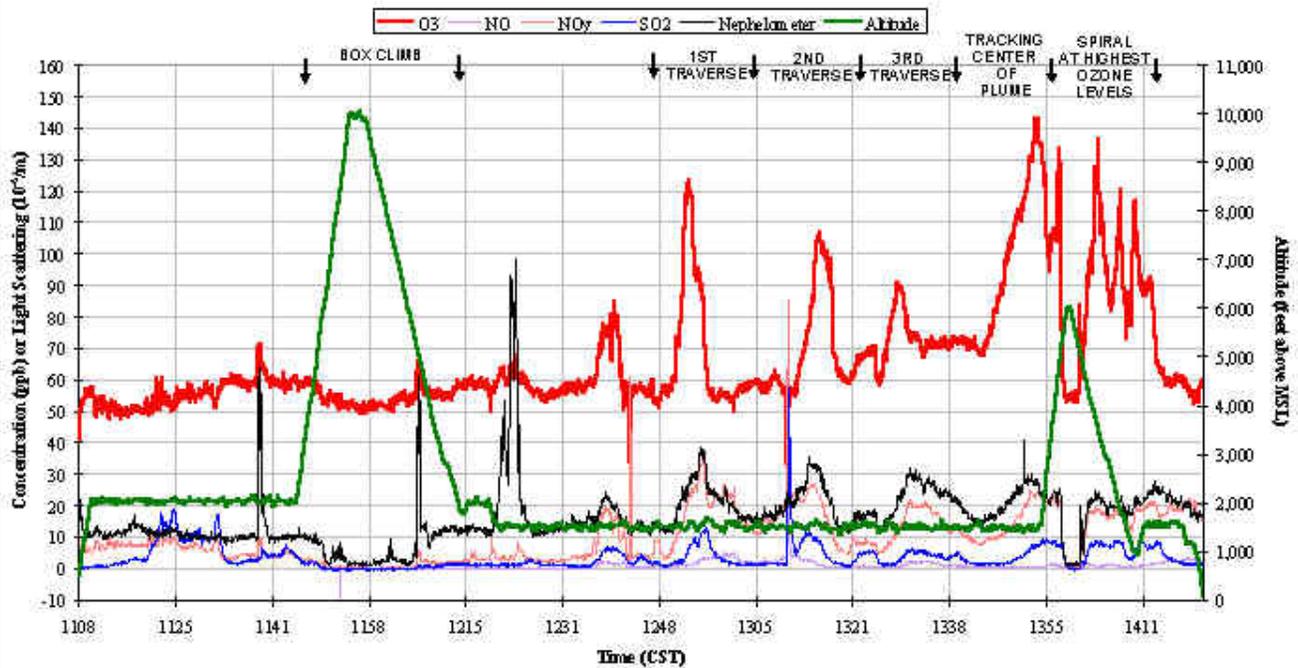
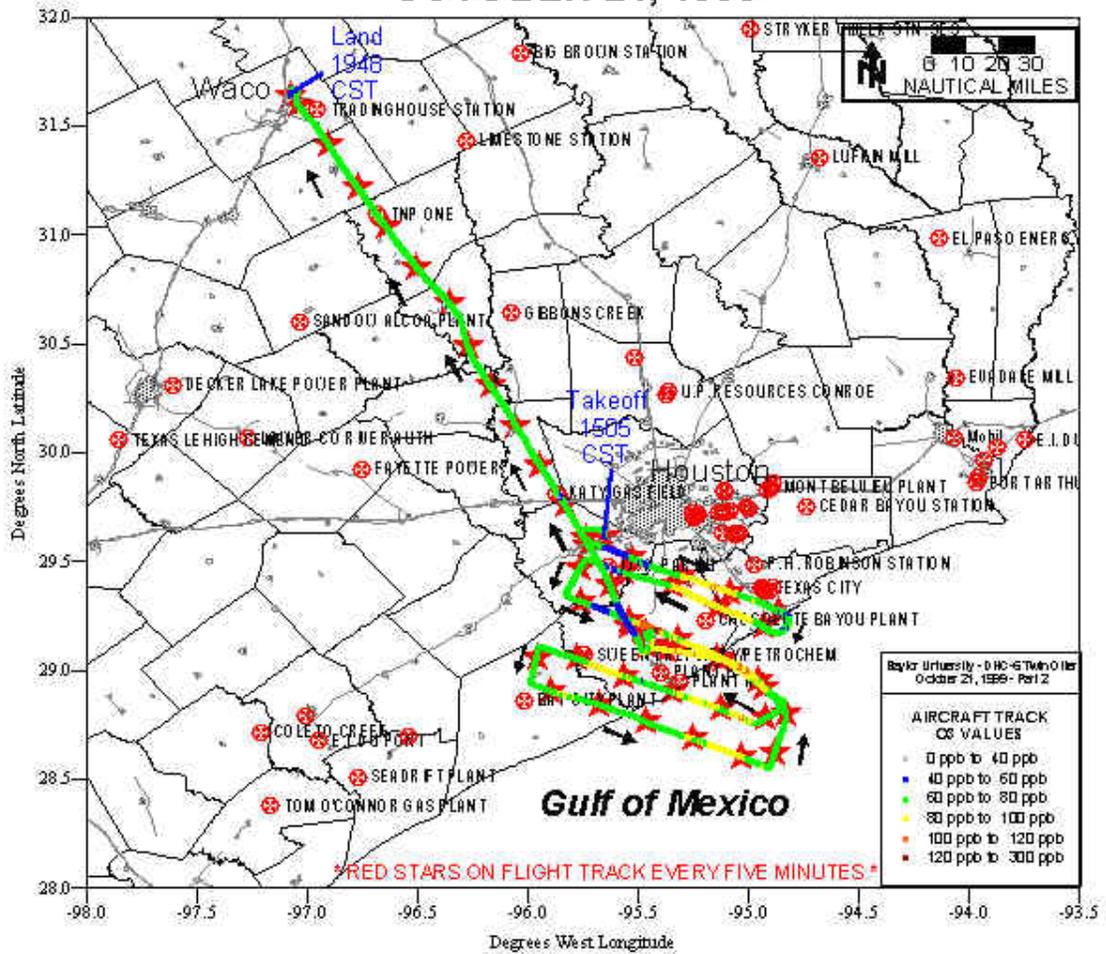


Figure 5 - Flight 123a

# COMBINED TRACK PLOT AND POLLUTANT CHART OCTOBER 21, 1999



**10/21/99 Baylor Aircraft Flight 123b - Validated Data (5 Second Intervals)**

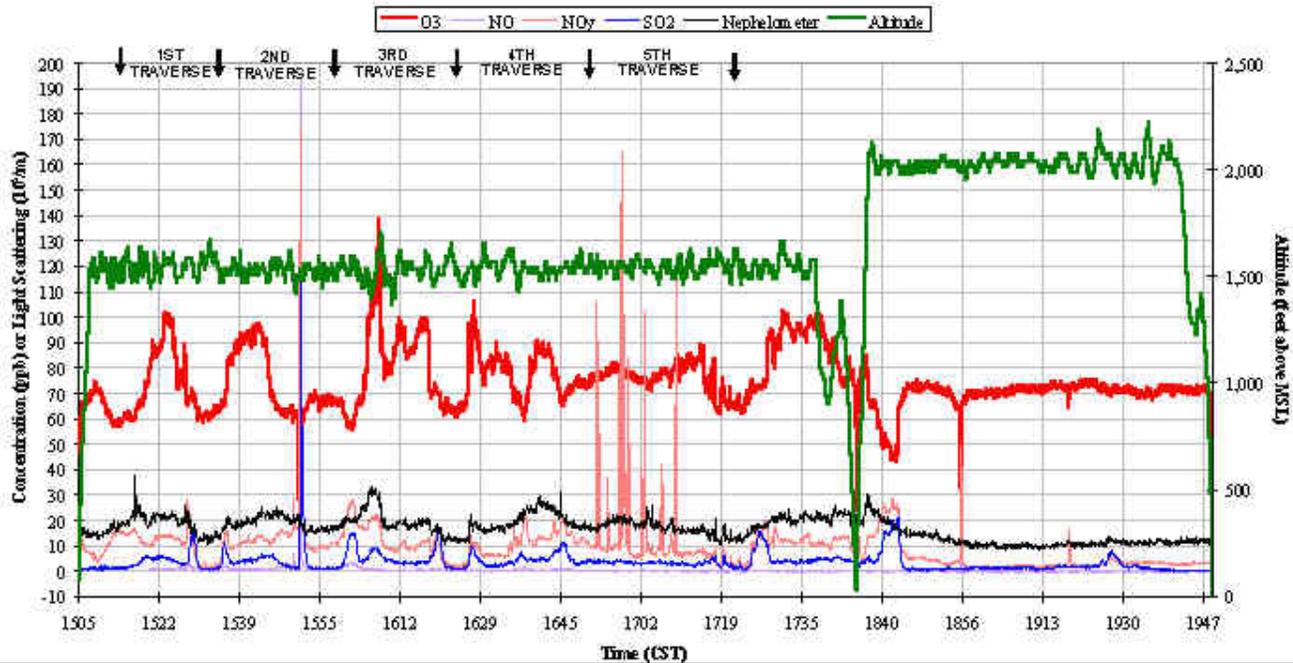


Figure 6 - Flight 123b

# COMBINED TRACK PLOT AND POLLUTANT CHART OCTOBER 26, 1999

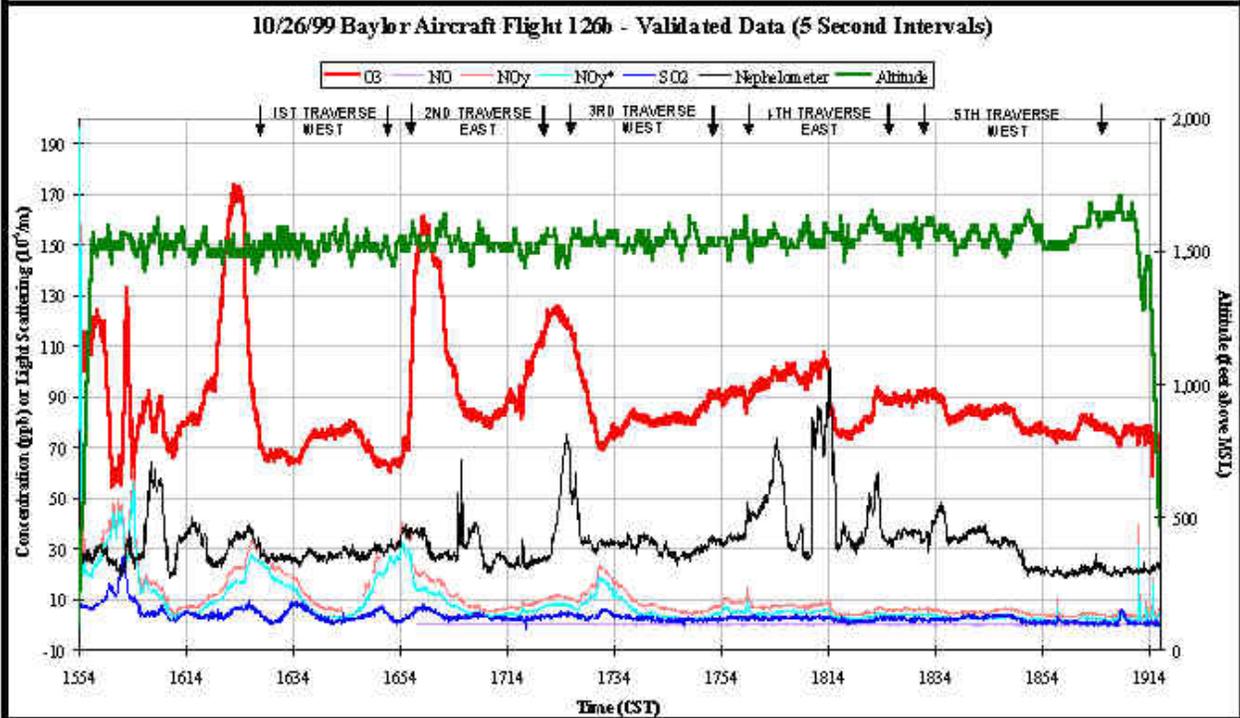
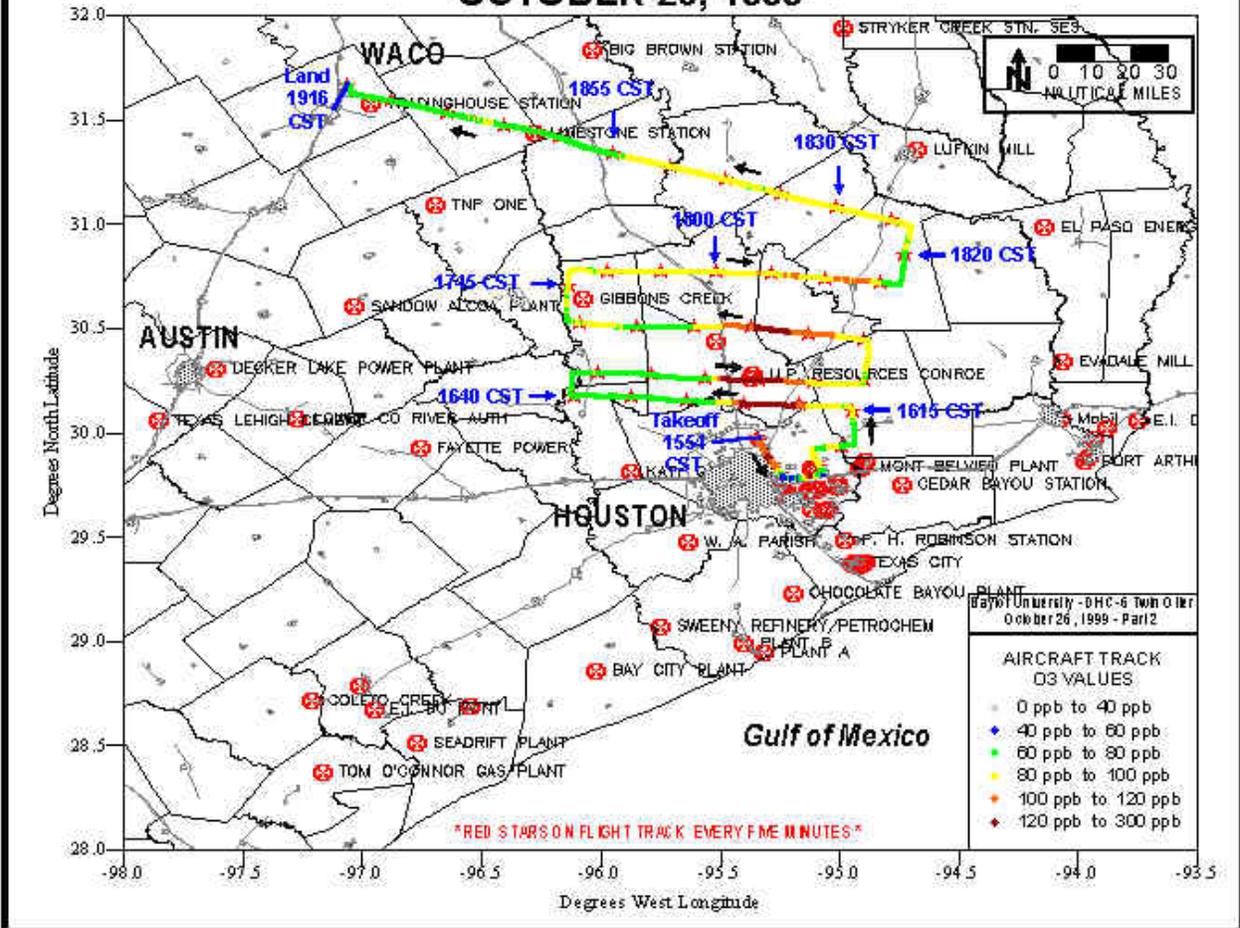
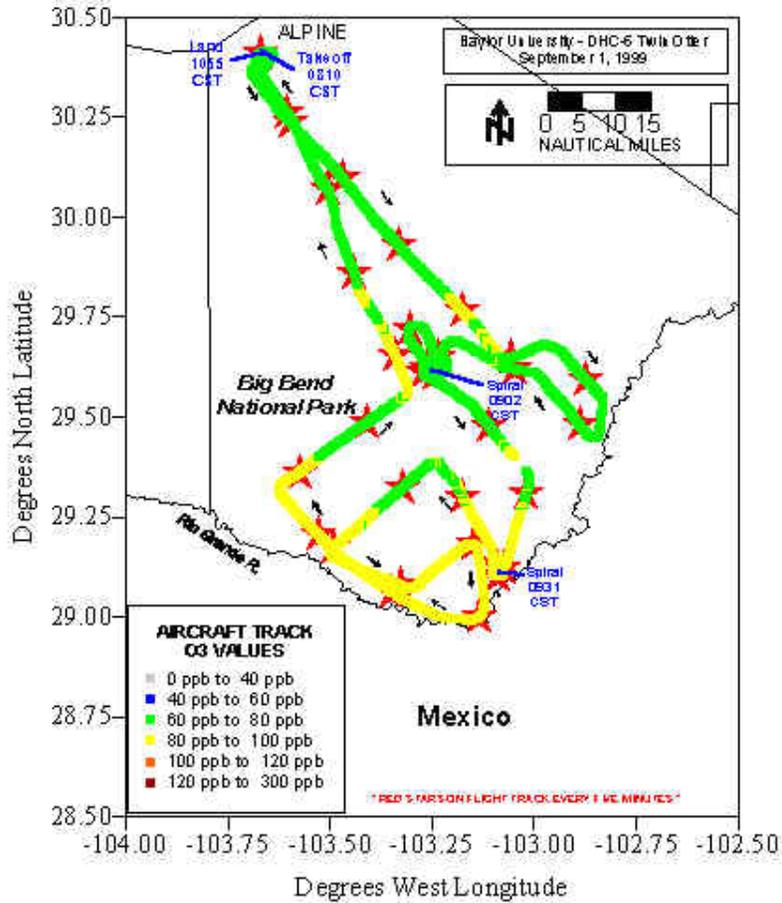


Figure 8 - Flight 126b

# COMBINED TRACK PLOT AND POLLUTANT CHART SEPTEMBER 1, 1999



9/1/99 Baylor Aircraft Flight 99a - Validated Data (5 Second Intervals)

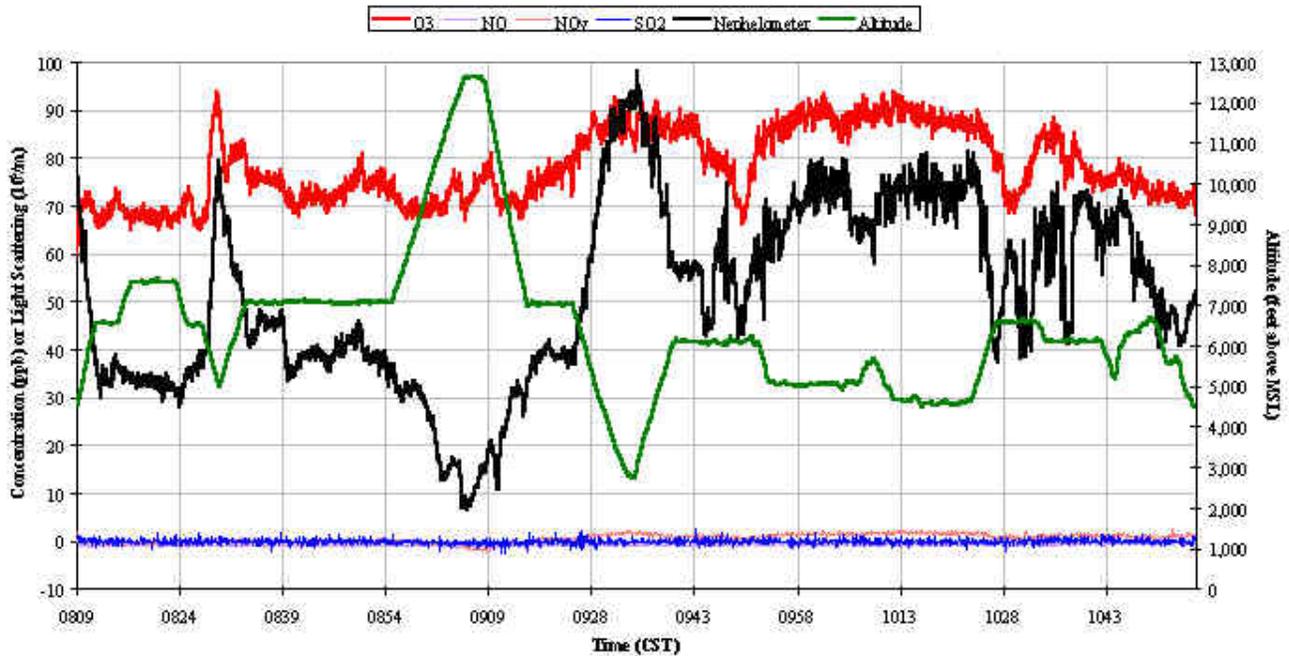
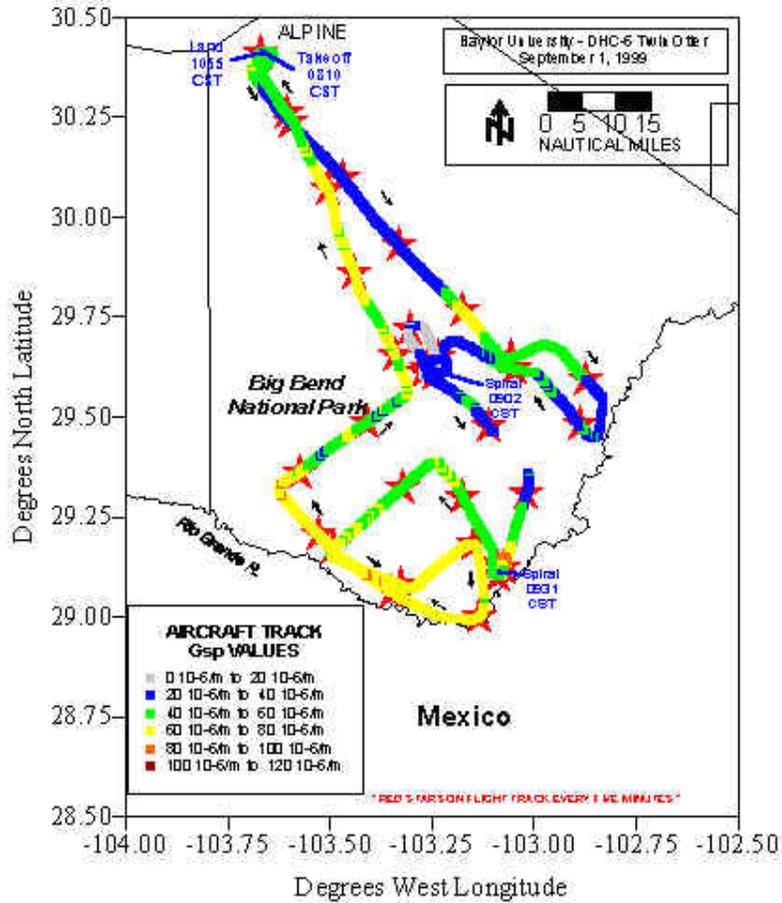


Figure 9 - Flight 99a

# COMBINED TRACK PLOT AND POLLUTANT CHART SEPTEMBER 1, 1999



9/1/99 Baylor Aircraft Flight 99a - Validated Data (5 Second Intervals)

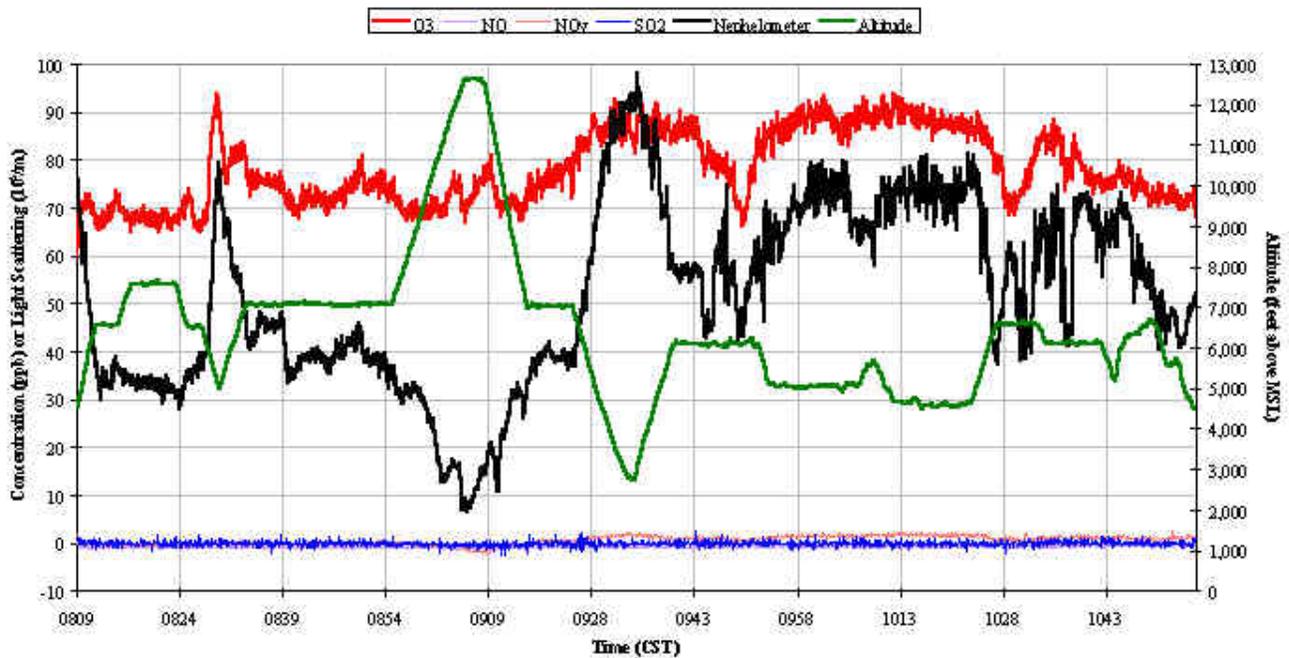
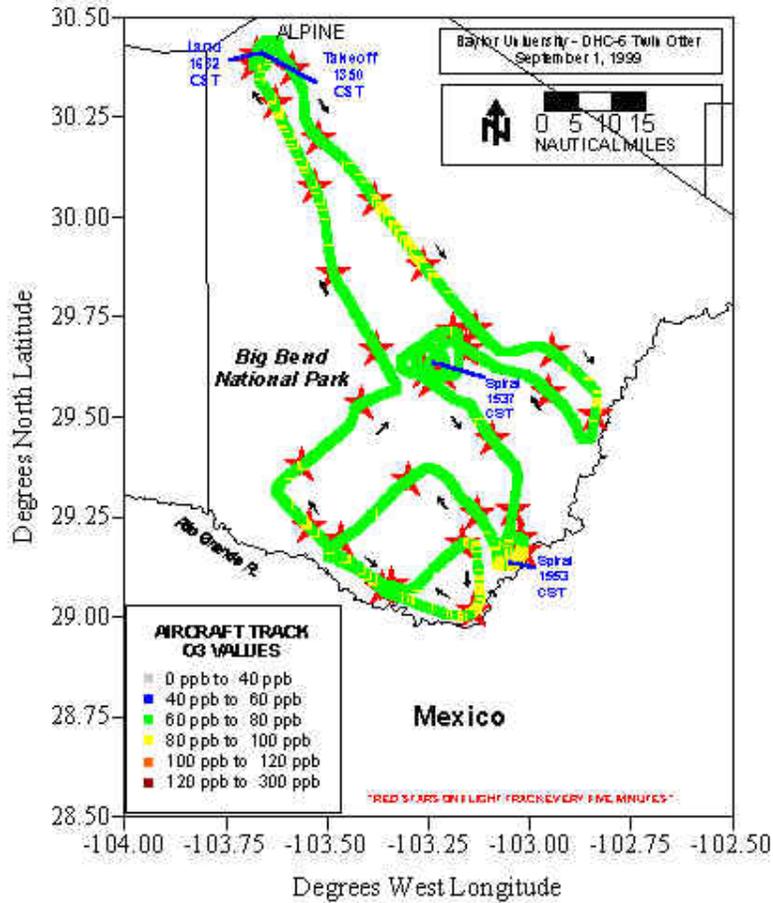


Figure 10 - Flight 99a

# COMBINED TRACK PLOT AND POLLUTANT CHART SEPTEMBER 1, 1999



## 9/1/99 Baylor Aircraft Flight 99b - Validated Data (5 Second Intervals)

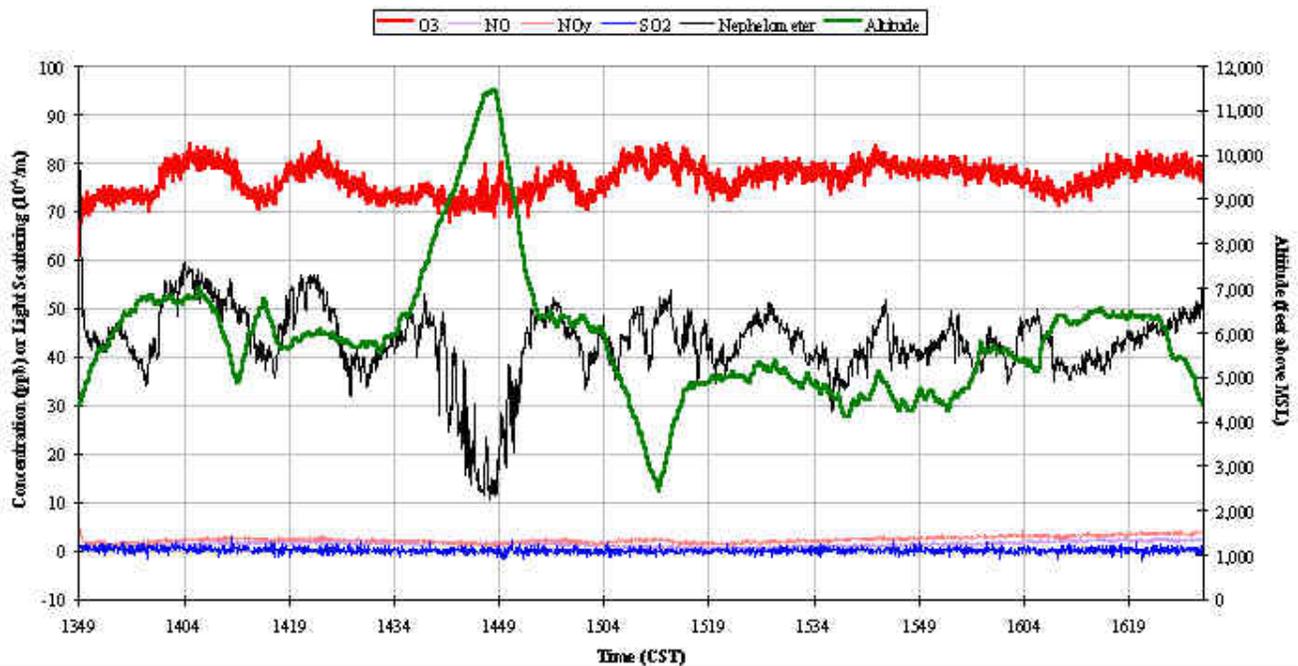
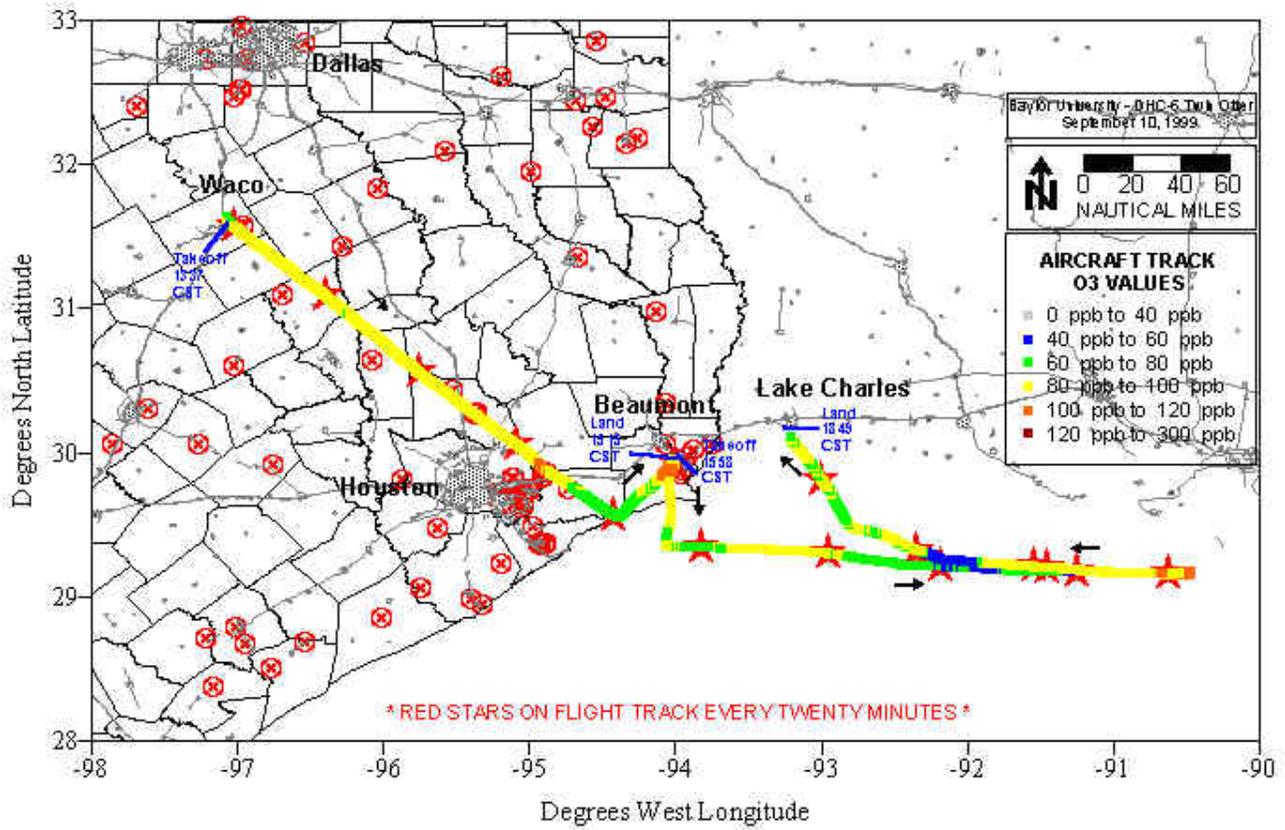


Figure 11 - Flight 99b

# COMBINED TRACK PLOT AND POLLUTANT CHART SEPTEMBER 10, 1999



9/10/99 Baylor Aircraft Flight 103 - Validated Data (5 Second Intervals)

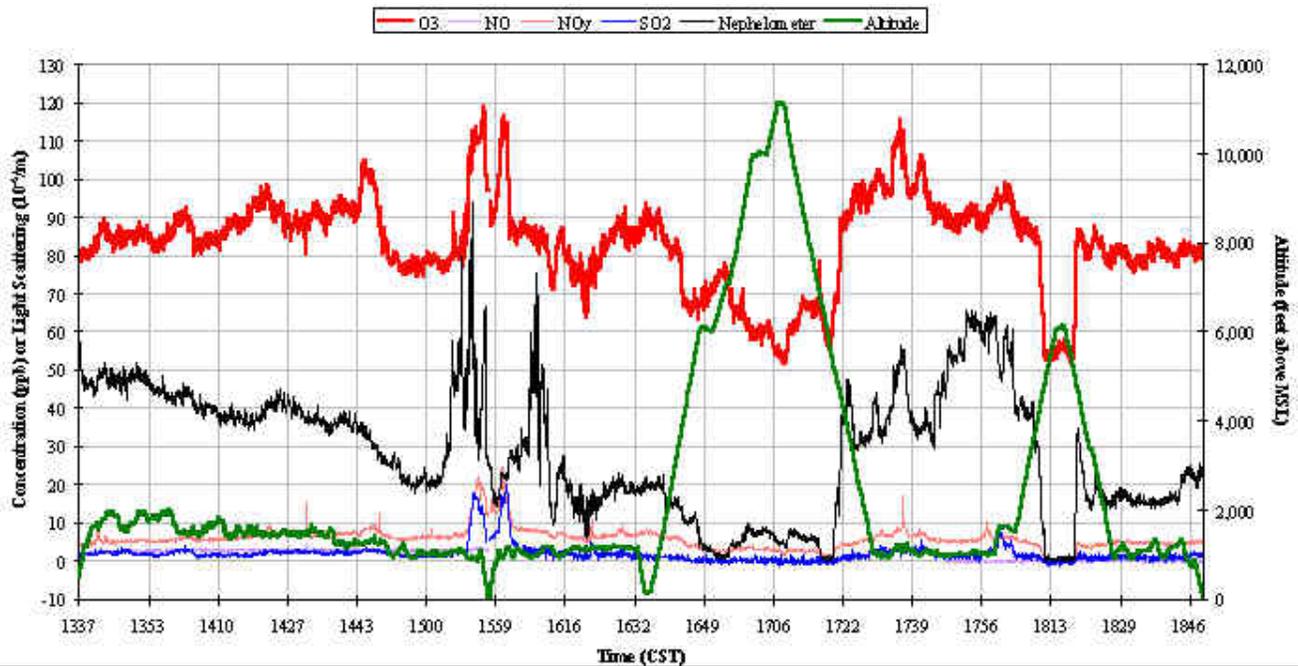


Figure 12 - Flight 103

# SOUTHWEST REGION SURFACE WIND PLOT SEPTEMBER 11, 1999

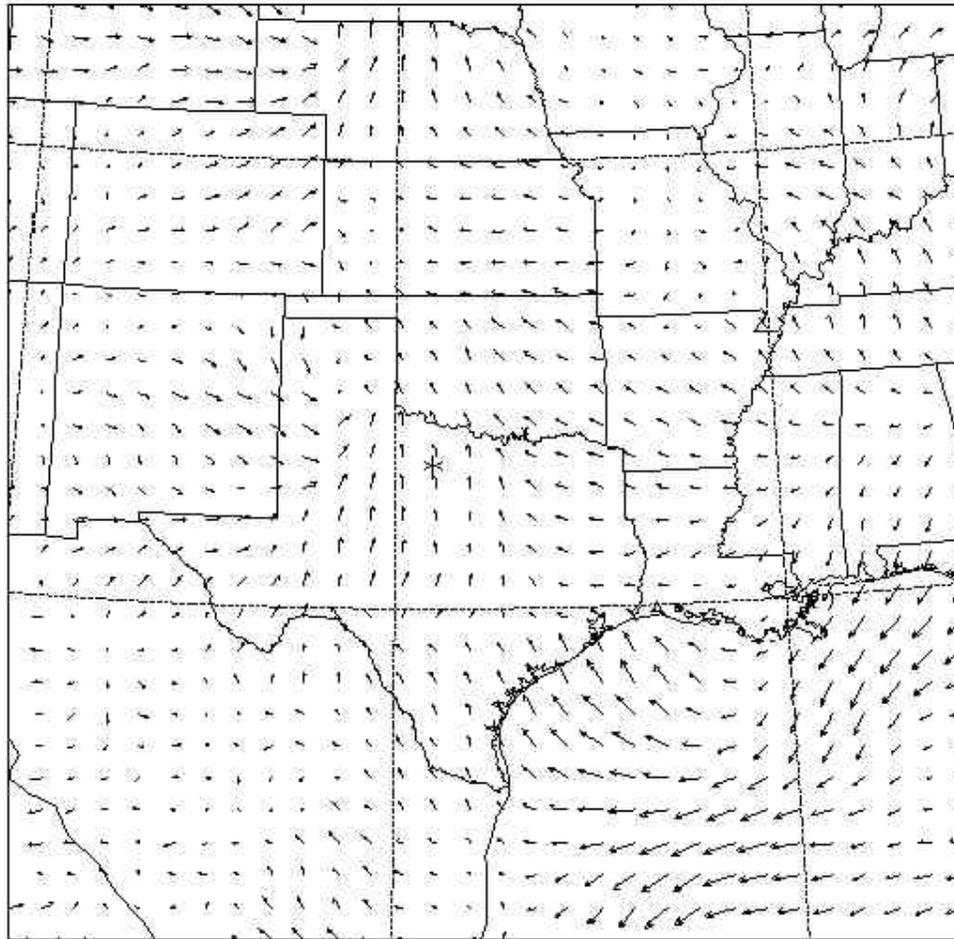


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Initialization time: 00 UTC 01 SEP 99



NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION - AIR RESOURCES LABORATORY

WIND VECTORS

WVCT (KNTS), LVL= SFC , 12 UTC 11 SEP 99 (+ 00 H ) .136E+02  
MAXIMUM VECTOR

Figure 13 - Flight 104a

# SOUTHWEST REGION SURFACE WIND PLOT SEPTEMBER 11, 1999

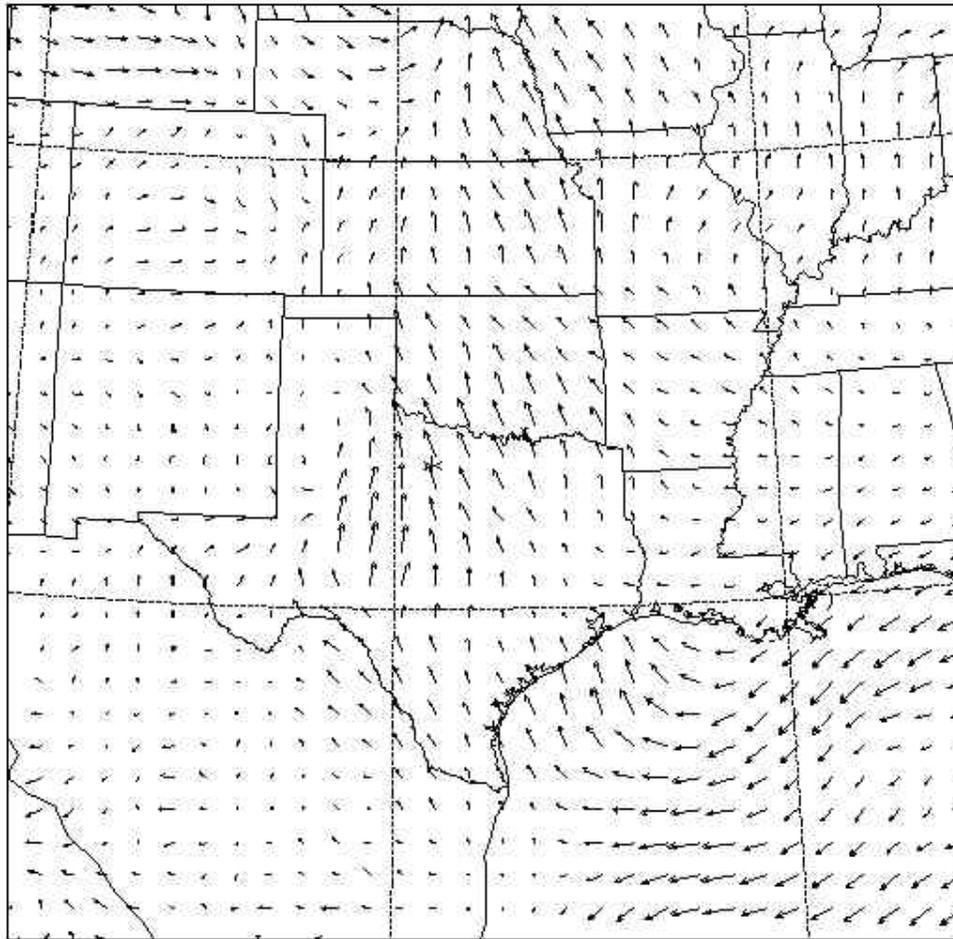


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METEOROLOGICAL DATASET INFORMATION  
Initialization time: 00 UTC 01 SEP 99



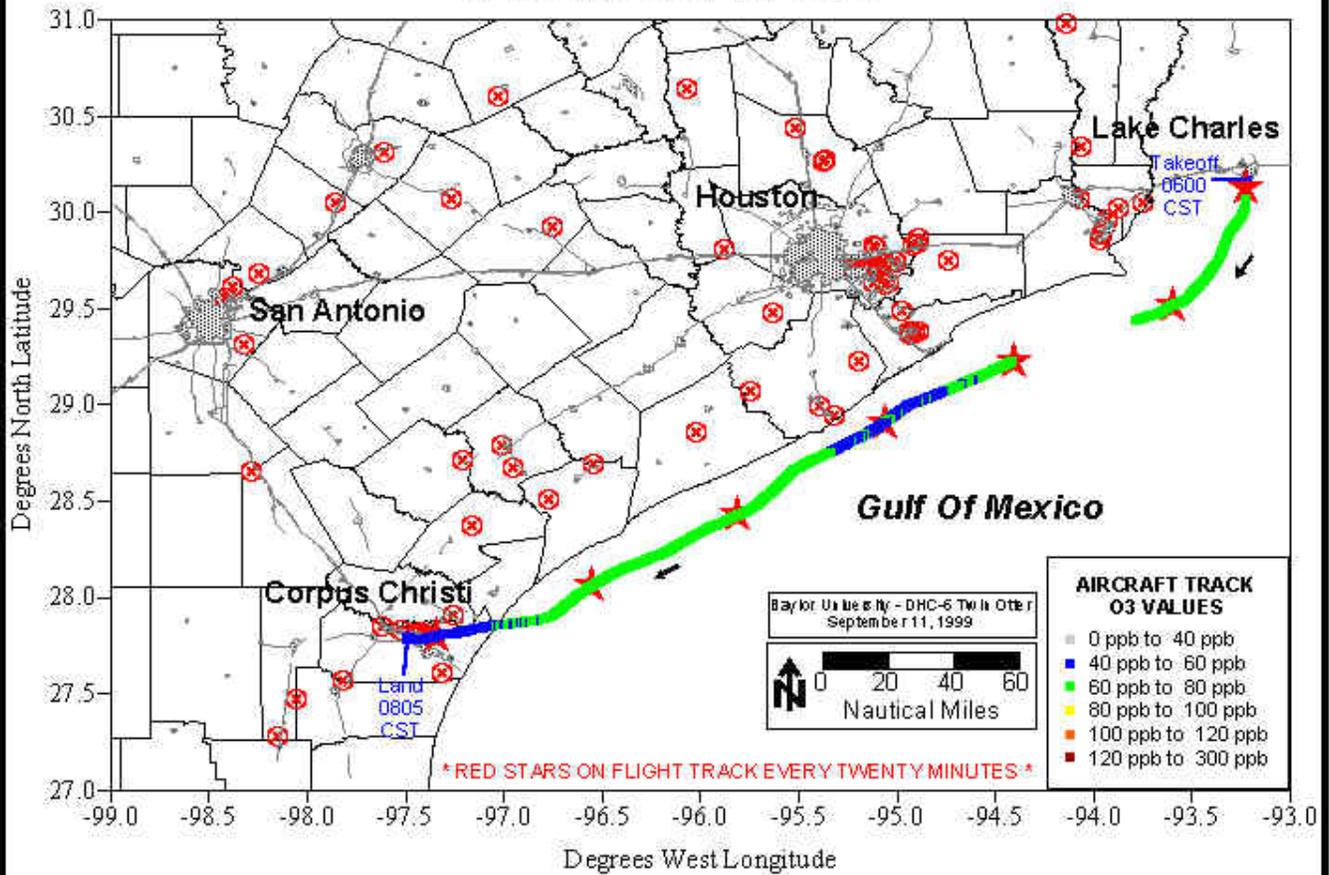
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION - AIR RESOURCES LABORATORY

WIND VECTORS

WVCT (KNTS), LVL= SFC , 18 UTC 11 SEP 99 (+ 00 H )  $\overrightarrow{132E+02}$  MAXIMUM VECTOR

Figure 14 - Flight 104b

## COMBINED TRACK PLOT AND POLLUTANT CHART SEPTEMBER 11, 1999



9/11/99 Baylor Aircraft Flight 104a - Validated Data (5 second intervals)

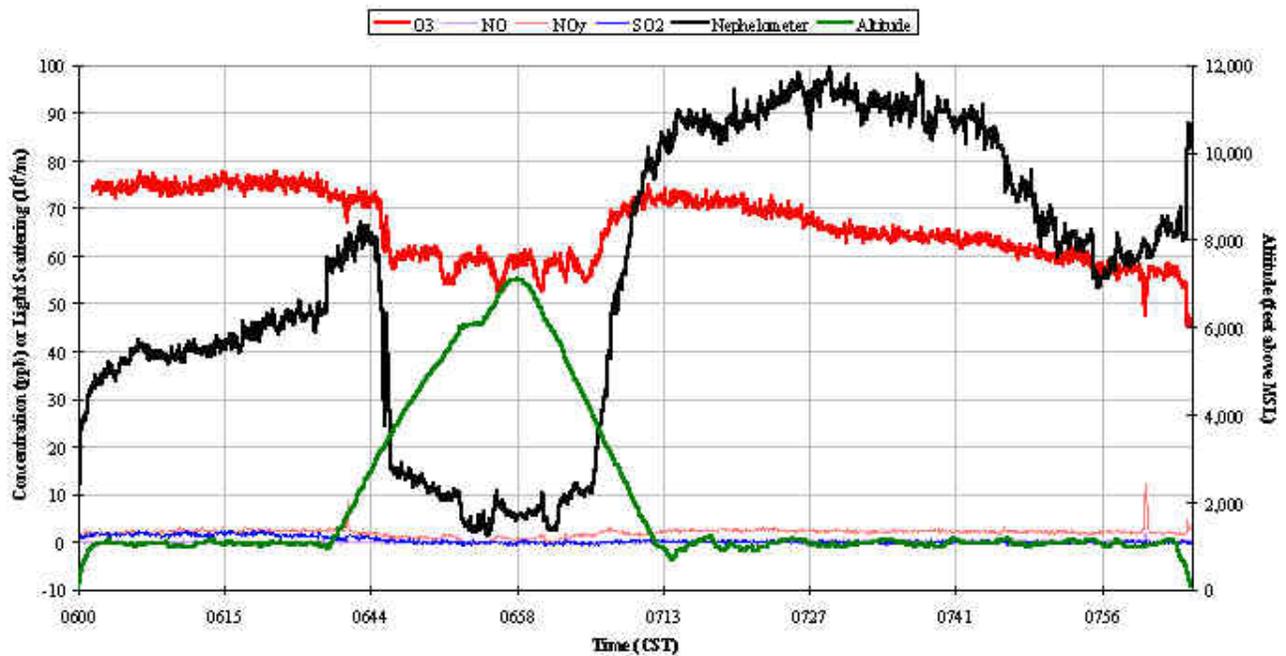
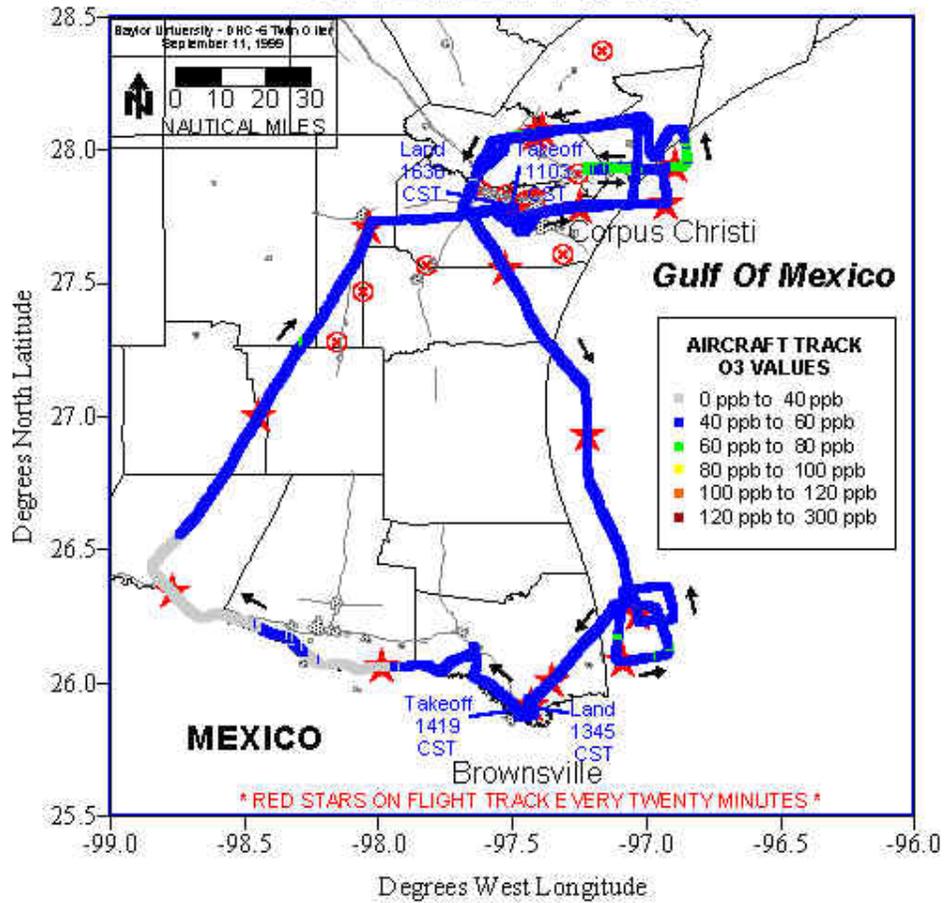


Figure 15 - Flight 104a

# COMBINED TRACK PLOT AND POLLUTANT CHART SEPTEMBER 11, 1999



9/11/99 Baylor Aircraft Flight 104b - Validated Data (5 Second Intervals)

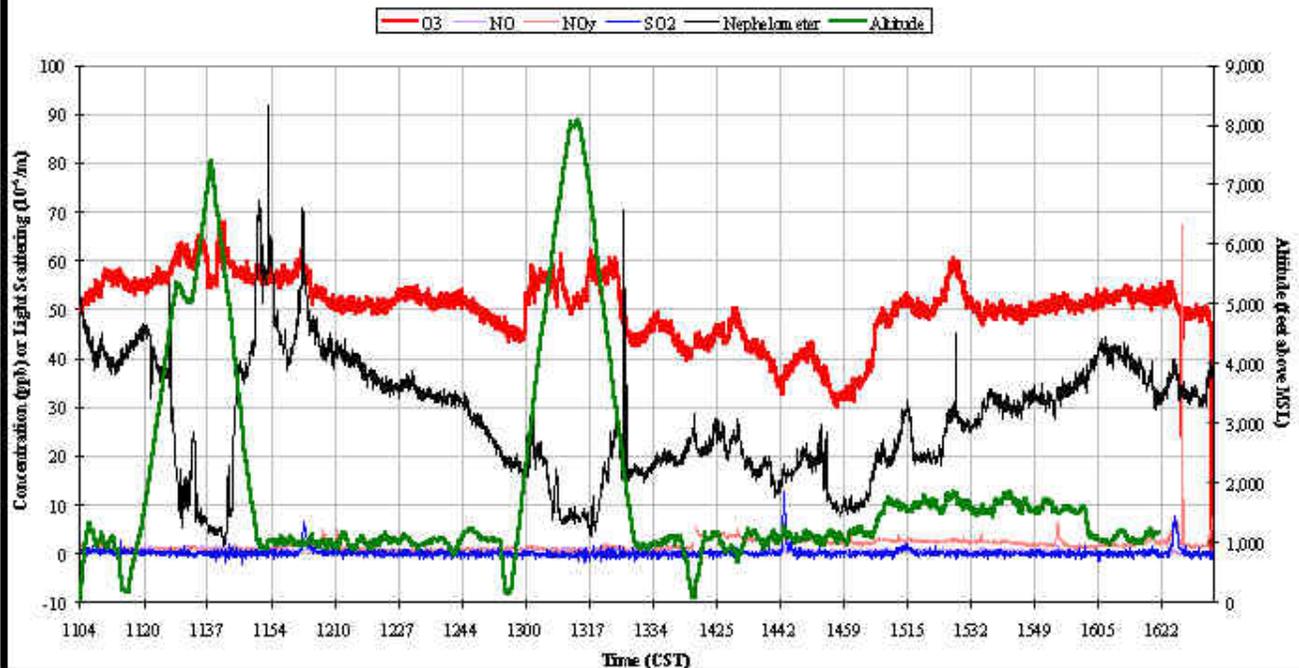
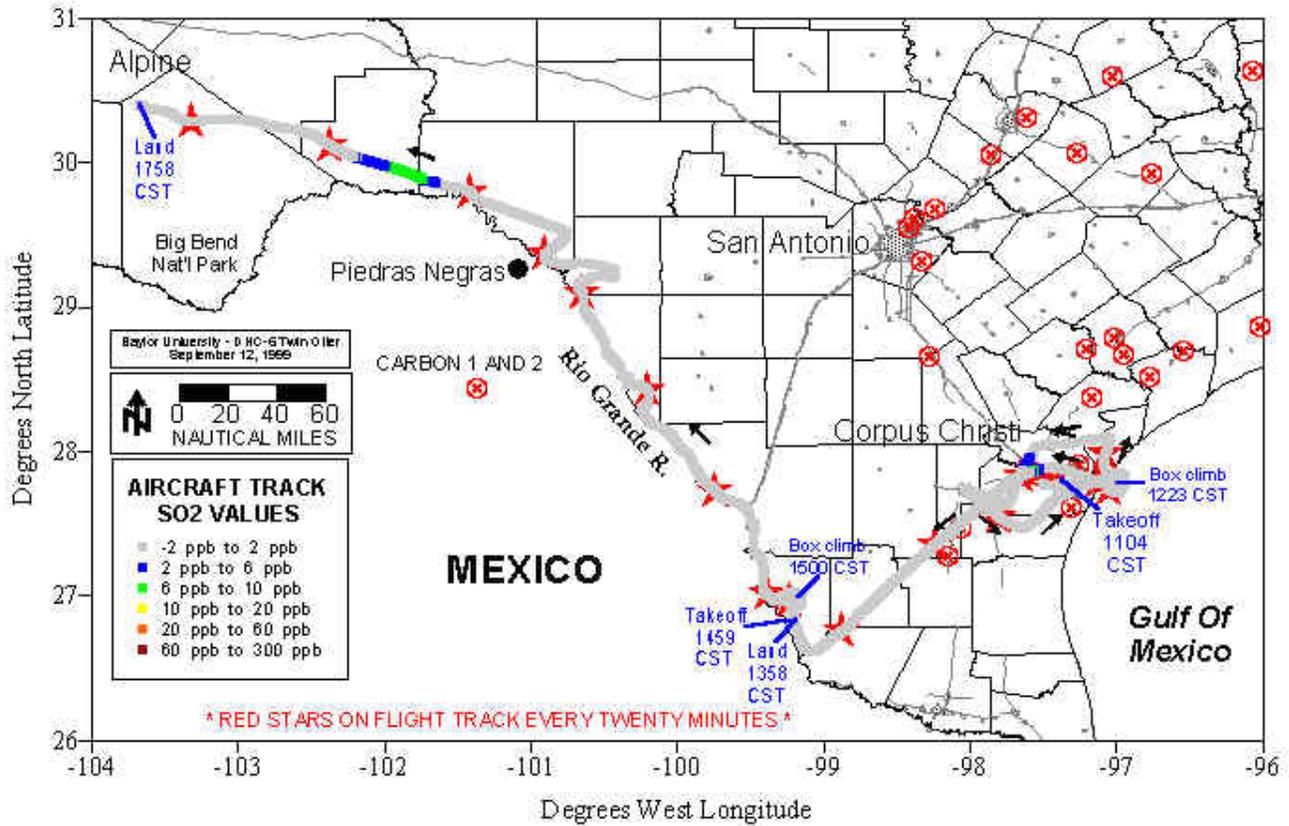


Figure 16 - Flight 104b

## COMBINED TRACK PLOT AND POLLUTANT CHART SEPTEMBER 12, 1999



### 9/12/99 Baylor Aircraft Flight 105 - Validated Data (5 second intervals)

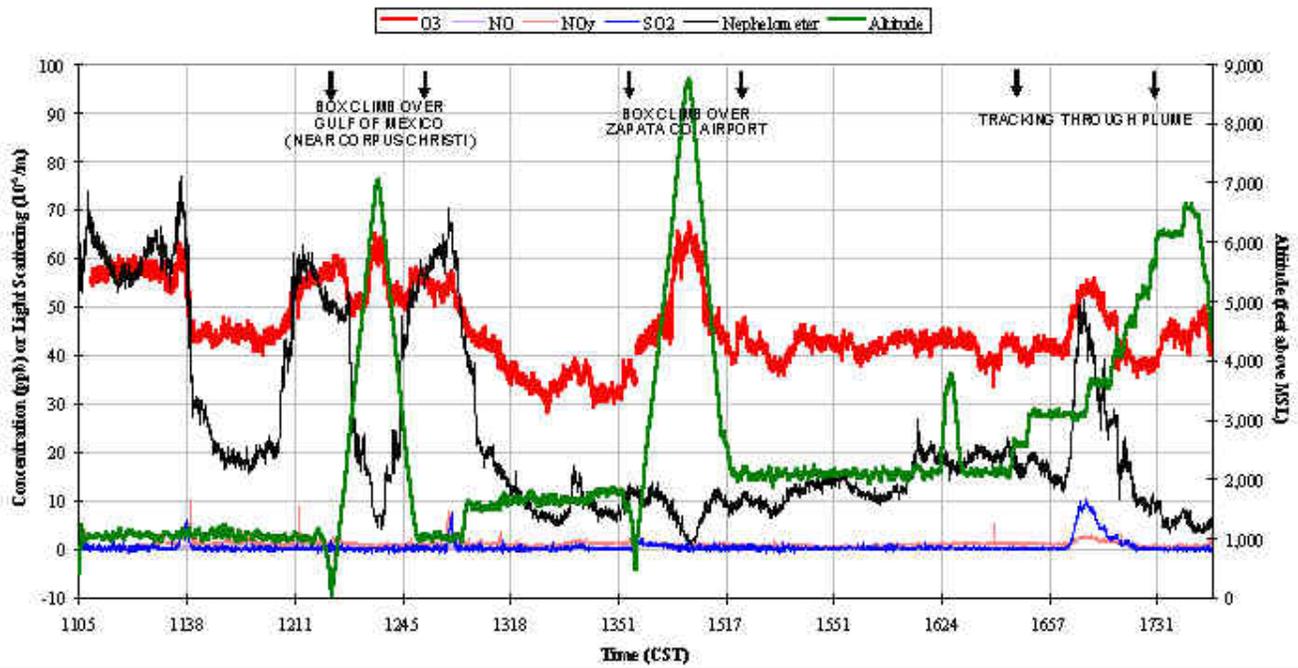
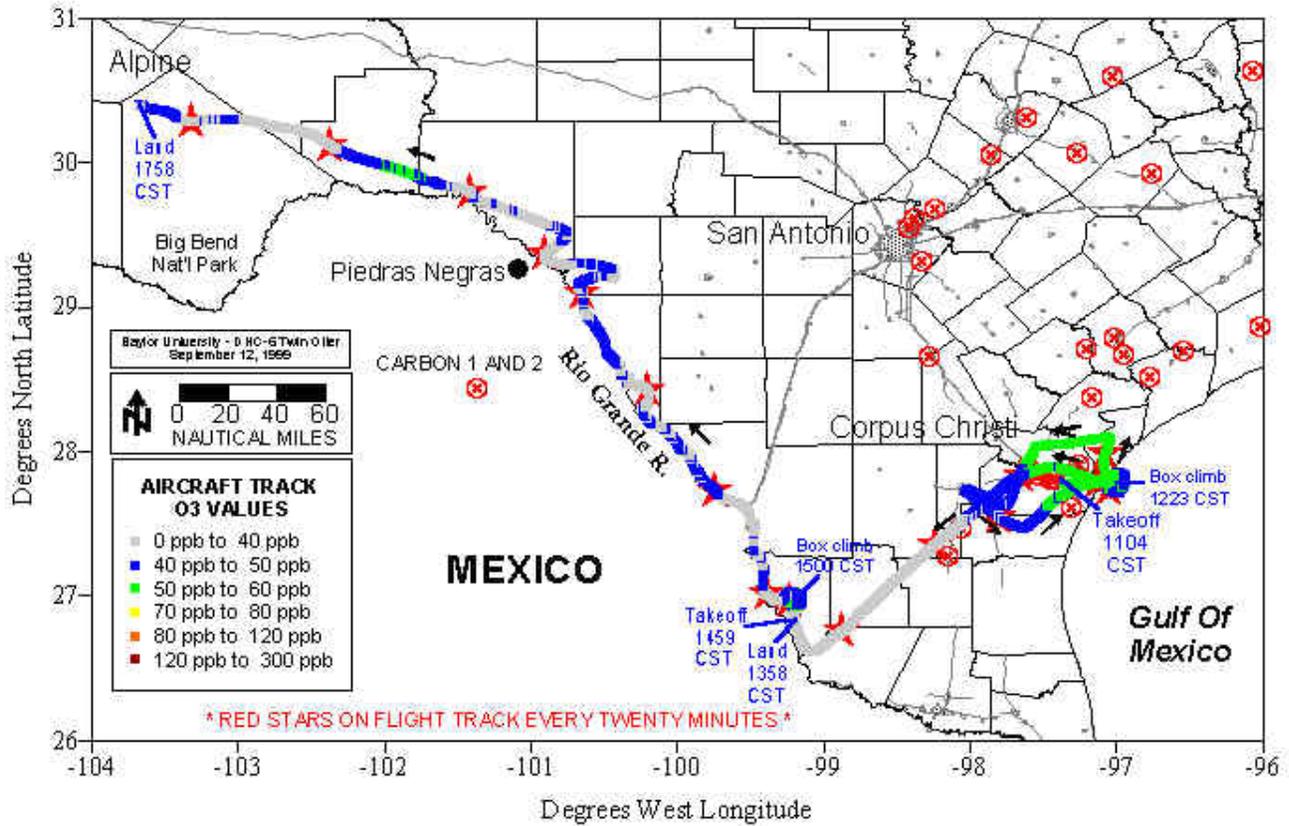


Figure 17 - Flight 105

# COMBINED TRACK PLOT AND POLLUTANT CHART SEPTEMBER 12, 1999



## 9/12/99 Baylor Aircraft Flight 105 - Validated Data (5 second intervals)

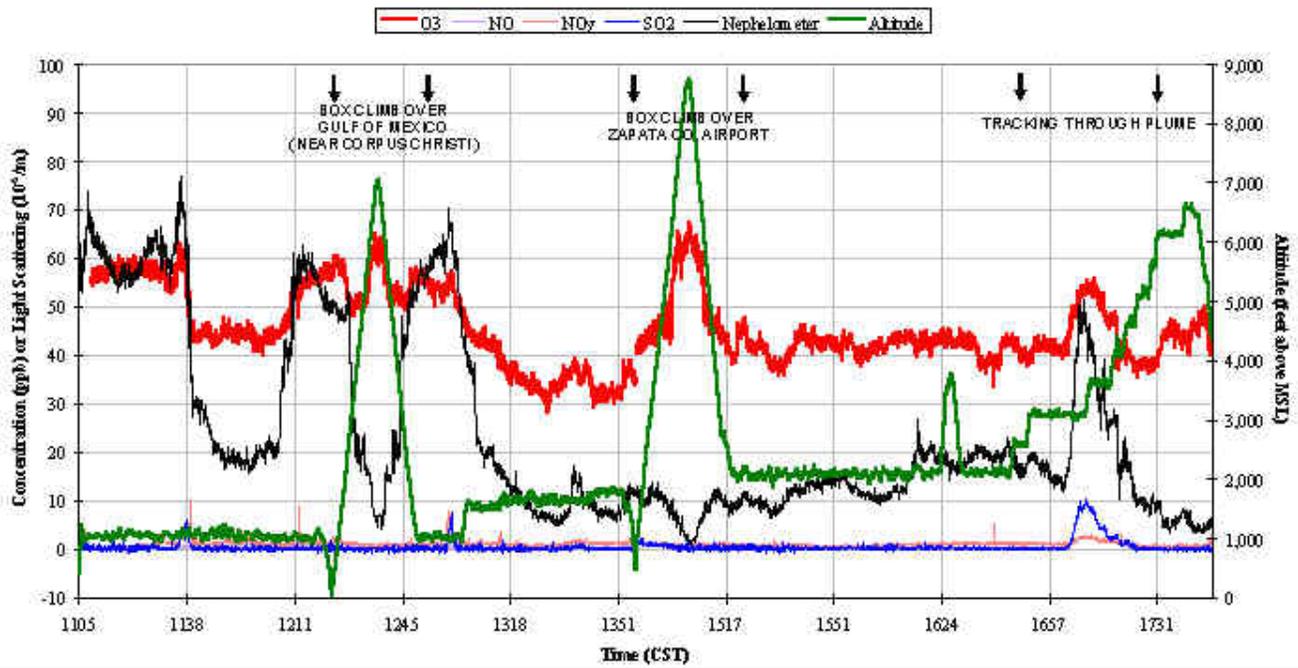
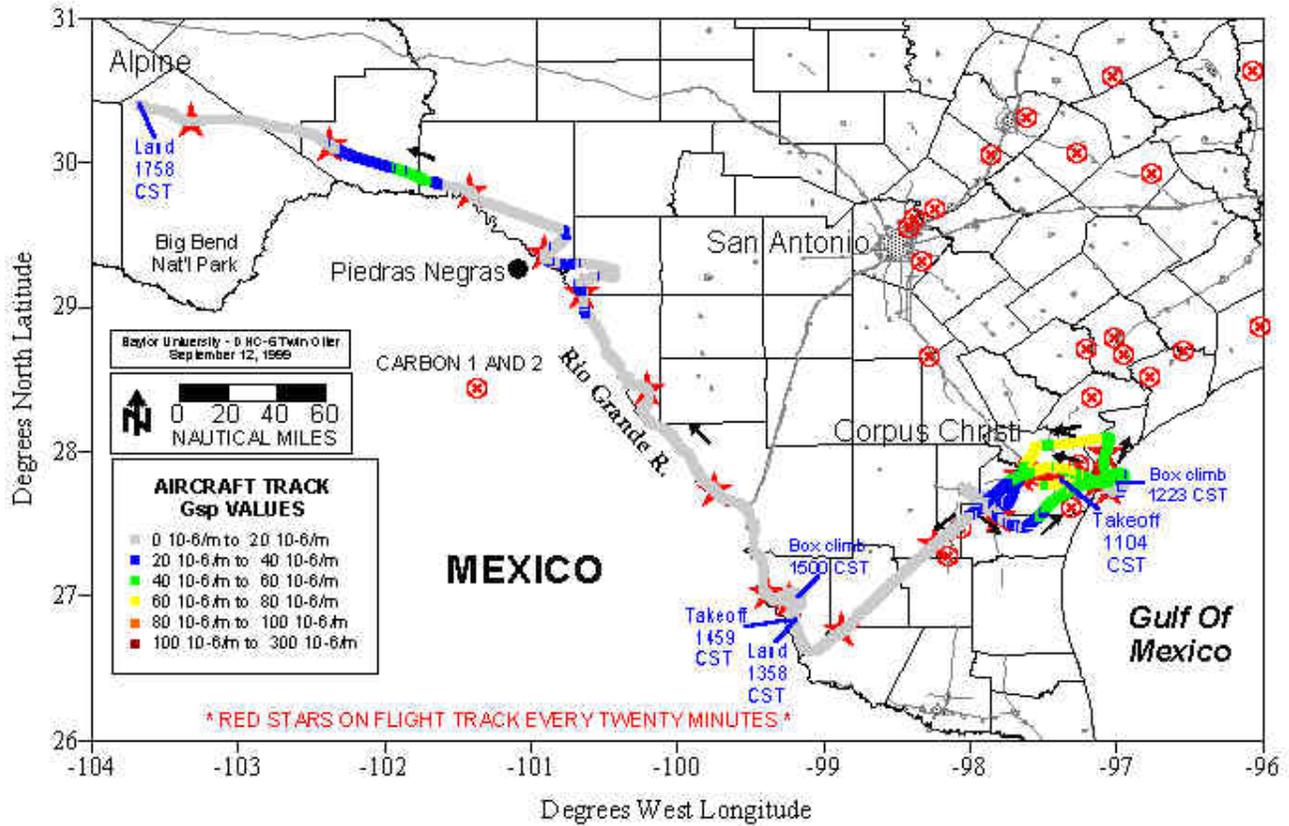


Figure 18 - Flight 105

# COMBINED TRACK PLOT AND POLLUTANT CHART SEPTEMBER 12, 1999



## 9/12/99 Baylor Aircraft Flight 105 - Validated Data (5 second intervals)

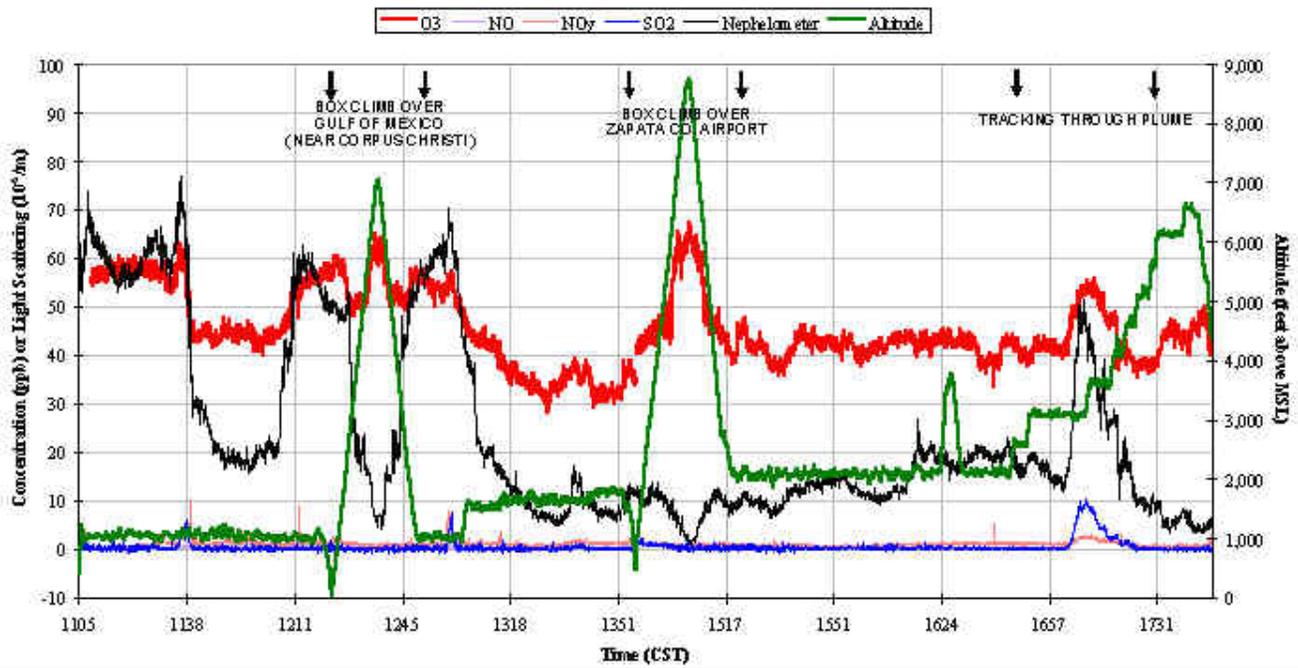


Figure 19 - Flight 105

**Table A6a Overview of Sampling Matrix**

**Baylor Aircraft Monitoring Capability – de Havilland DHC-6 Twin Otter**

<b>Target Compound/Group (Unit of measure)</b>	<b>Analytical Method</b>	<b>Sampling Period</b>	<b>Frequency</b>
<b>Physical / Chemical</b>			
Ozone (O <sub>3</sub> as ppb)	Ultra Violet (UV) Photometry	5 second poll of 10 second updates	Continuous
Ozone (O <sub>3</sub> as ppb)	Sample reacted in a constant concentration nitric oxide (NO) gas stream, (i.e. NO titration), and Chemiluminescence	1 Second poll of 2 second updates	Continuous
Sulfur Dioxide (SO <sub>2</sub> as ppb)	Fluorescence	1 second poll of 2 second updates	Continuous
<b>Oxides of Nitrogen</b>			
Nitrogen Oxide (NO as ppb)	Chemiluminescence	1 second poll of 2 second updates	Continuous
<b>Total “Odd” or Reactive Nitrogen (NO<sub>y</sub> as ppb)</b>	Molybdenum (Mo) catalytic sample reduction at 320 °C and Chemiluminescence	1 second poll of 2 second updates	Continuous
Total Nitrates (i.e. Nitric acid plus particulate and / or aerosol nitrates) (Tot NO <sub>3</sub> <sup>-</sup> as ppb)	Nylasorb filter then molybdenum (Mo) catalytic sample reduction at 320 °C and Chemiluminescence. The resulting measurement, NO <sub>y</sub> <sup>*</sup> , (i.e. NO <sub>y</sub> less the nitric acid and particulate / aerosol nitrates) is subtracted from the NO <sub>y</sub> measurement result. The difference equals the total nitrates.	1 Second poll of 2 second updates	Continuous
Light scattering (red, green and blue wavelengths) bsp as 10 x e <sup>-4</sup> m <sup>-1</sup> )	TSI 3λ Nephelometer	5 seconds	Continuous
Particulate Sulfates (SO <sub>4</sub> <sup>2-</sup> as ppb)	Flash Volatilization	Semi-continuous 2 minute updates	Semi-Continuous
Particulate matter < 2.5 μm in diameter (PM 2.5)	Filter Pack	discrete filter	As specified in the flight profiles
Volatile Organic Compounds (VOC as ppbv)	Gas Chromatography/Mass Spectroscopy	discrete grab	As specified in the flight profiles

Figure 20 (part 1) Measuring capability of the Twin Otter aircraft

**Table A6a Overview of Sampling Matrix (Continued)**  
**Baylor Aircraft Monitoring Capability – de Havilland DHC-6 Twin Otter**

<b>Target Compound/Group</b> <b>(Unit of measure)</b>	<b>Analytical Method</b>	<b>Sampling Period</b>	<b>Frequency</b>
<b>Altitude and Geographical Location</b>			
Altitude (feet above mean sea level)	Barometric pressure	1 second	Continuous
Latitude and Longitude (degrees, minutes, and fractions of minutes )	Global Positioning System (GPS) Garmin Model 150 interfaced to the air data computer	5 seconds	Continuous
<b>8</b>	<b>Meteorology</b>	<b>9</b>	<b>10</b>
			<b>11</b>
Wind Direction (degrees azimuth)	Shadin ADC 200	5 seconds	Continuous
Wind Speed (knots)	Shadin ADC 200	5 seconds	Continuous
Outside (Ambient) Air Temperature (degrees Celsius [(°C)])	Shadin ADC 200	5 seconds	Continuous
Outside (Ambient) Air Temperature (degrees Celsius [(°C)])	Type "T" Thermocouple	5 seconds	Continuous
Cabin Temperature (degrees Celsius [(°C)])	Type "T" Thermocouple, integral with the Campbell Scientific CR 10X datalogger	5 seconds	Continuous
Dew Point (degrees Celsius [(°C)])	Chilled mirror optical hygrometer (Buck Model 1101B)	5 Seconds	Continuous
Relative Humidity (percent absolute)	From the inlet of the TSI 3λ Nephelometer	5 Seconds	Continuous

Figure 20 (part 2) Measuring capability of the Twin Otter aircraft
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