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New Technology Research & Development Program
Grant Contract 582-5-70807-0016

Tasks 1, 2, 3, 4, 5, & 6 Deliverable Report
Final Report

The preparation of this report is based on work funded in part
by the State of Texas through a Grant from the
Texas Commission on Environmental Quality.

Valparaiso University **Contract Number: 582-5-70807-0016**

Principal Investigator: Gary A. Morris

Grant Activities

Pursuant to the agreements between Rice University, the University of Houston, Valparaiso University, and the Texas Commission on Environmental Quality (TCEQ) the following report demonstrates that each has fulfilled the obligations outlined in the Scope of Work (Appendix B) as delineated below from the existing contracts. Where work could not be completed, an explanation is provided.

Task 1: Scheduling of Ozonesonde launches for 2005

2.1. Task Statement: Rice University scheduled, trained, and coordinated ozonesonde launches.

2.1.2. Rice University scheduled lunch dates and number of lunches.

2.1.3. Rice University trained undergraduate students at Rice University to prepare and launch ozonesondes.

2.1.4. Rice University coordinated launches and gained clearance from the Federal Aviation Administration.

2.1.6. Deliverables: Rice University submitted the schedule of ozonesondes launches to the TCEQ and Valparaiso University.

Task 2: Launching of Ozonesondes in 2005

2.2. Task Statement: Rice University launched ozonesondes in Houston, Beaumont, and other East Texas locations.

2.2.1. Rice University launched 38 ozonesondes during 2005.

2.2.1.1. Rice University acquired, prepared, and launched 38 ozonesondes during the TexAQS 2005 study period.

2.2.1.2. Most (30) launches occurred during the requested May through August period of 2005.

2.2.2. Rice University provided periodic ozonesonde launches from Houston throughout 2005.

2.2.2.1. Rice University acquired, prepared, and launched ozonesondes.

2.2.2.2. Due to delays in the processing of the TCEQ contract and other difficulties, we could not meet the proposed schedule for launches. However, we were able to successfully launch one ozonesonde in April, three in September, three in October, and two in November to provide profiles at times of the year other than Summer.

2.2.3. Rice University, in collaboration with Lamar University in Beaumont, TX, provided periodic ozonesonde launches from Beaumont in 2005.

2.2.3.1. Rice University acquired, prepared, and launched ozonesondes in Beaumont.

2.2.3.2. Due to delays and scheduling difficulties, Rice University was only able to launch once from Beaumont in 2005 during August. TCEQ did not make requests for launches at other times.

2.2.4. Rice University provided periodic ozonesonde launches from other locations in East Texas in 2005.

2.2.4.1. Rice University acquired, prepared, and launched ozonesondes at Texas A&M University in College Station, TX and Stephen F. Austin State University in Nacogdoches, TX.

2.2.4.2. Rice University performed these launches during July of 2005, again delayed from the original proposal due to funding delays and scheduling problems.

2.2.5. Schedule: Rice University and Valparaiso University have completed this task within 12 months of the signed Notice to Proceed Date as issued by TCEQ.

2.2.6. Deliverables: Rice University and Valparaiso University have provided all data from the launches (including ozone, temperature, pressure, and relative humidity) to the TCEQ. All data appear on the website: www.rice.edu/ozone.

Task 3: Scheduling of Ozonesonde launches for 2006

2.3. Task Statement: Rice University and the University of Houston (from August – December) provided a schedule for launches, trained students in ozonesonde preparation and calibration, and coordinated ozonesonde launches.

2.3.1. Valparaiso University ordered 40 ozonesondes and had them shipped to Houston.

2.3.2. Rice University scheduled lunch dates and number of launches.

2.3.3. Valparaiso University, Rice University, and the University of Houston (from August – December) trained undergraduate students at Rice University and the University of Houston to prepare and launch ozonesondes.

2.3.4. Rice University (January – August) and the University of Houston (August – December) coordinated all launches and gained clearance from the Federal Aviation Administration.

2.3.5. Schedule: Rice University, the University of Houston, and Valparaiso University completed this task within 14 months of the signed Notice to Proceed Date as issued by TCEQ.

2.3.6. Deliverables: Valparaiso University submitted the schedule of ozonesondes launches to the TCEQ.

Task 4: Launching of Ozonesondes in 2006

2.4. Task Statement: Rice University and the University of Houston launched ozonesondes in Houston, Beaumont, and other East Texas locations.

2.4.1. Rice University and the University of Houston provide intensive, frequent ozonesonde launches during summer in Houston as part of TexAQS 2006, numbering 7 launches in July, 22 in August, and 17 in September.

2.4.1.1. Rice University and the University of Houston acquired, prepared, and launched ozonesondes during the TexAQS 2006 study period.

2.4.1.2. Rice University and the University of Houston launched most frequently in the May through August period of 2006, with 43 of the 84 launches in 2006 occurring during these summer months and another 17 occurring in September, upon request from TCEQ for extending the intensive launch period later in the year to better correspond to other measurements during TexAQS 2.

2.4.2. Rice University (January – August) and the University of Houston (August – December) provided periodic ozonesonde launches from Houston throughout 2006.

2.4.2.1. Rice University and the University of Houston acquired, prepared, and launched ozonesondes.

2.4.2.2. Rice University and the University of Houston launched in January (1), March (17), and October (2) of 2006, as well as February (2), April (3), and November (4) in addition to the launches during the intensive period of TexAQS 2 noted above.

2.4.3. Rice University provided periodic ozonesonde launches from Beaumont in 2006.

2.4.3.1. Rice University acquired, prepared, and launched ozonesondes in Beaumont at Lamar University.

2.4.3.2. Rice University launched in May (2) and July (1) during 2006. No other times were requested by TCEQ.

2.4.4. Rice University provided periodic ozonesonde launches from other locations in East Texas in 2006, including College Station and Nacogdoches.

2.4.4.1. Rice University acquired, prepared, and launched ozonesondes in College Station (2) at Texas A&M University and Nacogdoches (2) at Stephen F. Austin State University.

2.4.4.2. Rice University performed launches from both sites (one each) during June of 2006. The second launch from each site was performed in July due to scheduling and staffing issues.

2.4.5. Schedule: Rice University, the University of Houston, and Valparaiso University have completed this task within 24 months of the signed Notice to Proceed Date as issued by TCEQ.

2.4.6. Deliverables: Rice University, the University of Houston, and Valparaiso University have provided all data from the launches (including ozone, temperature, pressure, and relative humidity) to the TCEQ. All data appear on the website: www.rice.edu/ozone.

Task 5 Investigate ozone profiles from Ozonesondes

2.5. Task Statement: Valparaiso University has investigated ozone profiles from ozonesondes.

2.5.1. Valparaiso University has investigated seasonal cycles of ozone profiles above Houston.

2.5.1.1. Valparaiso University examined the seasonal variability in the ozone data gathered as part of this proposal. Figure 2.5.1.1 shows the seasonal variability of ozone over Houston. Seasons are divided as follows: January/February/March (JFM), April/May/June (AMJ), July/August/September (JAS), and October/November/December (OND).

2.5.1.2. Valparaiso University has investigated the seasonal changes in meteorology affect the vertical distribution of ozone. Modified potential vorticity (MPV – Figure 2.5.1.2a), potential temperature (theta – Figure 2.5.1.2b), wind direction frequency (Figure 2.5.1.2c), and wind speed (Figure 2.5.1.2d) are all shown as functions of season. The MPV data indicate strongest northerly transport into Houston during the winter season, when ozone levels are at their lowest. The theta data show that summer conditions produced the most well mixed boundary layer with the highest ozone conditions. Westerly winds aloft dominate the observations for all seasons except summer in the Houston area. Warm advection is indicated by the turning of the winds from southerly to westerly during winter and spring, with surface ozone concentrations beginning to increase during spring. Wind speeds are strongest in winter, when ozone levels are low, and weakest during summer, when ozone levels are high.

2.5.1.3. Valparaiso University has investigated the impact of seasonal changes on air quality in Houston. At this point, summer (JAS) and spring (AMJ) show the largest levels of ozone in the boundary layer. The AMJ shows more ozone aloft, with a near constant profile up to 4 – 5 km while the JAS profile shows a strong negative gradient of ozone from the boundary layer to the lower free troposphere. The results suggest enhanced importance of transport during the spring season, although they argue for additional launches during the AMJ period to achieve better statistics for a stronger conclusion.

2.5.2. Valparaiso University has investigated transport versus local production of ozone using profiles from East Texas.

2.5.2.1. Valparaiso University has examined the vertical mixing of ozone from the free troposphere into the boundary layer. Figure 2.5.2.1 shows the difference between the average ozone value in the boundary layer (500 – 1500 m) and the lower free troposphere (2500 – 3500 m) for all midday or afternoon profiles (launches after 10 am) from Houston. Again, the viewer should note that the statistical robustness of results outside of March, July, August, and September is lacking. Each "*" in the figure represents the difference from one flight. The thick solid line is the monthly mean, while the thinner, dashed lines are the mean plus and minus one standard deviation. The results are suggestive of the following: interpretation: transport of ozone from the lower free troposphere appears more important (positive values) during the spring (April and May), while local production appears more important during the late summer (August and September). These results suggest more launches during April and May are necessary to solidify the above interpretation of the data.

2.5.2.2. Valparaiso University tracked air masses downwind from remote areas to Houston for two case studies. One case study found the transport of air from Louisiana to Houston. Figure 2.5.2.2a shows large changes in ozone concentration detected between 3 and 5 km altitude between two ozonesondes launched just under 2 hours apart. The HYSPLIT model was used to track air arriving in Houston on June 21 back to Louisiana, as shown in Figure 2.5.2.2b,

indicating that region can impact ozone levels in Houston. A second case study found air transported from Alaska and Western Canadian forest fires into the Houston area on July 19 and 20, 2004, resulting in enhancements of up to 150% in ozone from the surface to 4 km altitude, as shown in Figure 2.5.2.2c. Trajectories shown in Figure 2.5.2.2d link the air mass to the forest fire region. Peter Colarco of NASA Goddard Space Flight Center computed these trajectories using NASA Goddard Trajectory Model. The connection between Houston boundary layer ozone and the remote forest fires during this event in 2004 has been published in the Journal of Geophysical Research (Morris, G.A., S. Hersey, A.M. Thompson, S. Pawson, J. Eric Nielsen, P.R. Colarco, W.W. McMillan, A. Stohl, S. Turquety, J. Warner, B.J. Johnson, T.L. Kucsera, D.E. Larko, S.J. Oltmans, and J.C. Witte, Alaskan and Canadian forest fires exacerbate ozone pollution over Houston, Texas, on 19 and 20 July 2004, *J. Geophys. Res., 111*, D24S03, doi:10.1029/2006JD007090, 2006. In the future, coordinated launches to examine transport from Houston to the remote sites would be of value. However, to accomplish this task, additional personnel and equipment for the remote sites will be necessary.

2.5.2.3. Valparaiso University was unfortunately unable to coordinate ozonesonde launches in Task 2 and Task 4 based on meteorological predictions of transport due to scheduling issues at the remote sites and the availability of sufficient staff to support such coordinated activities. A future study with multiple sites funded to perform coordinated ozonesonde launches would be well worthwhile and is recommended by the preliminary, yet suggestive results of the profile differences between Houston and the three other sites (Beaumont, Nacogdoches, and College Station) in East Texas.

2.5.3. Valparaiso University has investigated the impact of meteorology on boundary layer ozone.

2.5.3.1. Valparaiso University will correlate meteorological variables with the ozone profile. Using the GEOS-4 analysis from NASA Goddard Space Flight Center's Global Modeling and Assimilation Office, we examined the impact of the following meteorological variables on the ozone profiles for the July/August period during 2004, 2005, and 2006: wind speed, wind direction, potential temperature, and potential vorticity We focused on this time period since it was the only two-month period during the three years of launches for which a significant number of ozonesondes was launched each year. Only wind direction corresponded to changes in the ozonesonde profiles.

2.5.3.2. Valparaiso University will investigate the impact of different meteorological conditions on the vertical distribution of ozone. Figure 2.5.3.2a shows the mean ozone profiles for all launches in 2004, 2005, and 2006 during the months of July and August. The figure demonstrates that 2006 was a low year for boundary layer ozone as compared to 2004, with 2005 being an intermediate case. Figure 2.5.3.2b shows the fraction of the time the winds were blowing from each direction. "Calm" indicates wind speeds of 2.5 m/s or less. The left-hand panels show the results for all 62 days each year while the right-hand panels show the subset of the GEOS-4 data on just the days we launched. In most every case, we see good correspondence between the two panels, indicating that the flight days are representative of the July/August period in general. We see that in 2006, the winds in the boundary layer were more frequently from the South, bringing clean air from the Gulf of Mexico over the City of Houston. In 2004, by contrast, winds in the boundary layer were more frequently from the North, bringing more polluted continental air into the region.

2.5.4. Valparaiso University has compared and contrast ozone profiles above Beaumont with those above Houston.

2.5.4.1. Valparaiso University and Rice University prepared and launched sondes in Beaumont and Houston.

2.5.4.2. Valparaiso University has compared the profiles observed over Beaumont with those observed over Houston. Figure 2.5.4.2 shows comparisons of the mean ozone profiles above Beaumont (5), College Station (3), Houston (52), and Nacogdoches for the May/June/July period during which sondes were launched from these 4 sites. The thicker lines (to the right) show the mean profiles while the thinner lines (to the left) show the variability of the data at the one standard deviation level.

2.5.4.3. Valparaiso University will investigate the vertical layers of these two cities. As Figure 2.5.4.2 indicates, the boundary layer is well defined at about 2 km in the mean Houston profile and at about 1.5 km in the Beaumont data, both suggestive of local production. The College Station mean profile shows nearly constant ozone up to 3 km, suggesting transport in and above the boundary layer, although substantially more launches are needed from this site to draw any significant conclusions. The Nacogdoches data show higher levels aloft than at the surface, suggesting that transport is a more important factor in ozone than local production. Again, however, the limited number of launches restricts our analysis to only interpretation at this stage. More concrete results could be achieved with additional launches from this site.

2.5.4.4. Valparaiso University will investigate how the emissions from these two cities interact. Because of a lack of resources (personnel and equipment), this investigation could not be completed. Simultaneous or coordinated launches at both sites would be helpful in addressing this important research question. We hope that future funding will allow for a full exploration of the interaction of pollution plumes from Beaumont and Houston.

2.5.5. Valparaiso University has examined inter-annual variability in ozone profiles

2.5.5.1. Valparaiso University has compared ozone profiles gathered in 2005 with those in 2006. See the discussion above in Section 2.5.3 for detailed results. Unfortunately, only the July/August period has sufficient launches each year to produce statistically meaningful comparisons. As has been noted earlier in this report, additional launches at other times of the year, particularly in the spring season (March/April/May) would be well worthwhile. The limited data available suggest greater impacts of transported ozone during this time of year. This season corresponds to the biomass-burning period in Mexico. Previous years have witnessed significant pollution transported from these fires into Texas. Additional ozonesonde launches during this spring period could better quantify the portion of the local pollution budget attributable to this remote biomass burning transported from Mexico.

2.5.5.2. Valparaiso University has commented on any trends observed in ozone loading, distribution, or transport. From the three years of data we have gathered, we can detect no significant trends. Several more years of launches will be necessary to identify any statistically significant trends. The data set of 170 launches is an important one and needs to be continued in future years. As noted above, there are differences from year-to-year, with wind direction being the only meteorological variable strongly related to ozone profile differences.

2.5.6. Schedule: Valparaiso University has completed this task within time period of the contract issued by TCEQ.

2.5.7. Deliverables: Valparaiso University submits this final report containing but not limited to the following to the TCEQ:

2.5.7.1. Climateological ozone profiles above Houston: annual and seasonal. The annual variability for the months of July and August can be found in Figure 2.5.3.2a. The seasonal climateology can be found in Figure 2.5.1.1.

2.5.7.2. Determine the fraction of ozone transported versus that produced locally. Unfortunately, we are unable to determine quantitatively this fraction from the dataset at this time. However, as we suggested in the report, our profiles suggest that transported ozone is more important in April/May/June than July/August/September, with local production dominating the latter season. We also noted the enhancements of up to 150% in ozone below 5 km due to the influx of biomass burning smoke from Alaskan and Canadian forest fires during July 2004. Such remote events can have significant impacts on ozone pollution levels in the Houston area.

2.5.7.3. Identify the meteorological conditions under which ozone pollution will be most severe at the ground level locally. Identify the meteorological conditions under which ozone pollution will be transported vertically and under which the potential exists for its transport to remote locations downwind. Our analysis to this point suggest that winds at the surface blowing predominantly from the North or East, as in 2004, lead to enhanced boundary layer ozone while winds blowing from the South, as in 2006, lead to lower boundary layer ozone concentrations. More launches from remote sites such as College Station and Nacogdoches will be required to examine the transport of pollution from Houston to remote areas. Additional funding to launch in a coordinated fashion from both Houston and one or more remote sites downwind of Houston would be extremely valuable in further exploring this question.

2.5.7.4. Climateological profiles for each city in the months during measurements are made in both locations (May and July). Due to the limited number of launches from the remote sites, one climateological comparison is provided for the May/June/July period including both 2005 and 2006 data, as shown in Figure 2.5.4.2.

2.5.7.5. Analysis of any observable trends in ozone between the two years of this project. As noted earlier, we cannot determine trends over such a short period of observation. We do note, however, that 2006 was year with lower ozone amounts at the surface during the July/August period shown in Figure 2.5.3.2a, more likely due to enhanced southerly flow that brought in clean air off of the Gulf of Mexico.

Task 6: PROGRAM MANAGEMENT AND REPORTING

2.6. Task statement: Valparaiso University has prepared and submitted monthly detailed project reports and supplies this comprehensive final report while ensuring compliance with all TCEQ program requirements.

2.6.1. Valparaiso University coordinated all project resources to ensure compliance with NTRD program requirements while providing deliverables on-schedule and on budget. In

fact, we have come in below budget for this project and delivered 134 profiles during 2005 and 2006, 54 more than in the original proposal thanks to additional funding from NASA.

2.6.2. Valparaiso University has generated monthly progress reports and this final report summarizing all aspects of the project based on data from the monthly reports.

2.6.3. Schedule: Valparaiso University has submitted monthly reports to TCEQ for each month of the grant. Valparaiso University submits this final report to complete this task within 30 days of the end of our extended (amended) contract that expired May 31, 2007.

2.6.4. Deliverables: Valparaiso University has submitted monthly progress reports with associated billing statements and submits this final project summary report to the TCEQ in completion of this task.

Figures

Figure 2.5.1.1

Mean (thick) and one standard deviation (thin) ozone profiles over Houston as a function of season using ozonesonde data from 2004 – 2006. January/February/March (JFM); April/May/June (AMJ); July/August/September (JAS); and October/November/December (OND) data are grouped together and shown below.

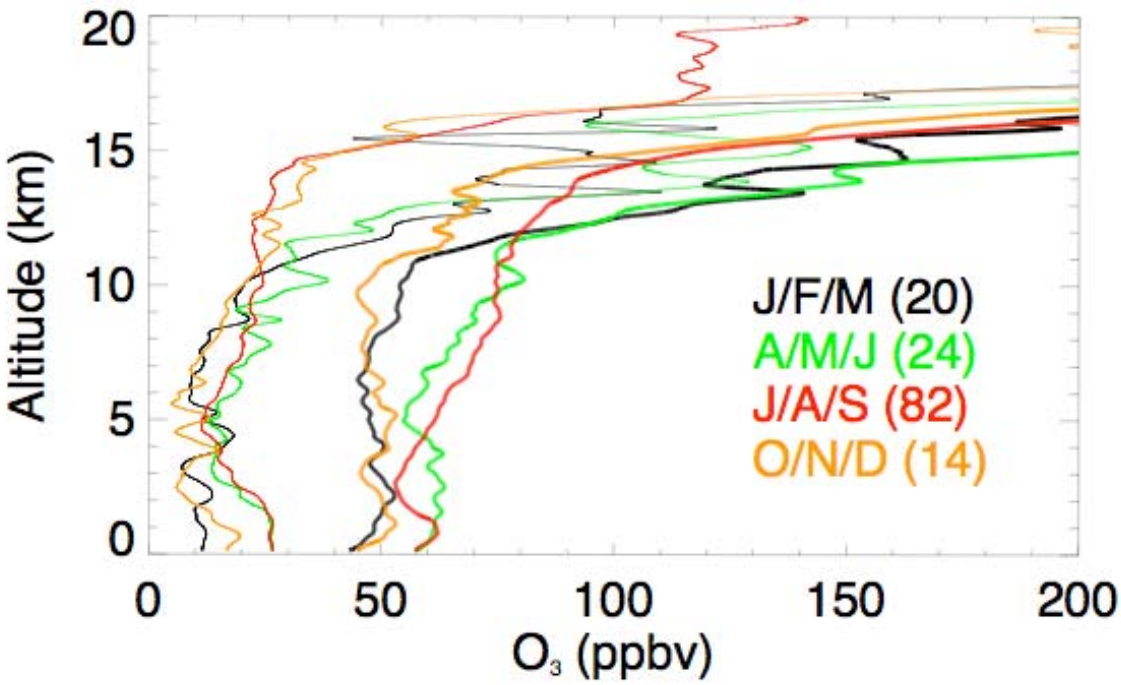


Figure 2.5.1.2a

Seasonal variability in Modified Potential Vorticity (MPV) is plotted using data from the GEOS-4 (1^0 lat $\times$ 1.25^0 lon) analyses produced by NASA Goddard's Global Modeling and Assimilation Office. MPV removes the variability in PV caused by altitude, so it indicates N-S transit. The left-hand panel shows data for all days each season from July 1, 2004 through December 31, 2006 while the right-hand panel shows the difference between the Houston launch days and all days (i.e., the mean MPV values for the launch days minus the profiles shown in the left-hand panel). Our flight data are fairly representative, as indicated by the right-hand panel, although MPV on flight days tends to be lower, indicating an overrepresented southerly flow condition. The higher MPV values are found in winter (January/February/March) and fall (October/November/ December), while the lower values are found in summer (July/August/September), indicating more northerly transport into the Houston area during the winter and fall seasons as weather system fronts make their way through Houston more frequently during these times of year.

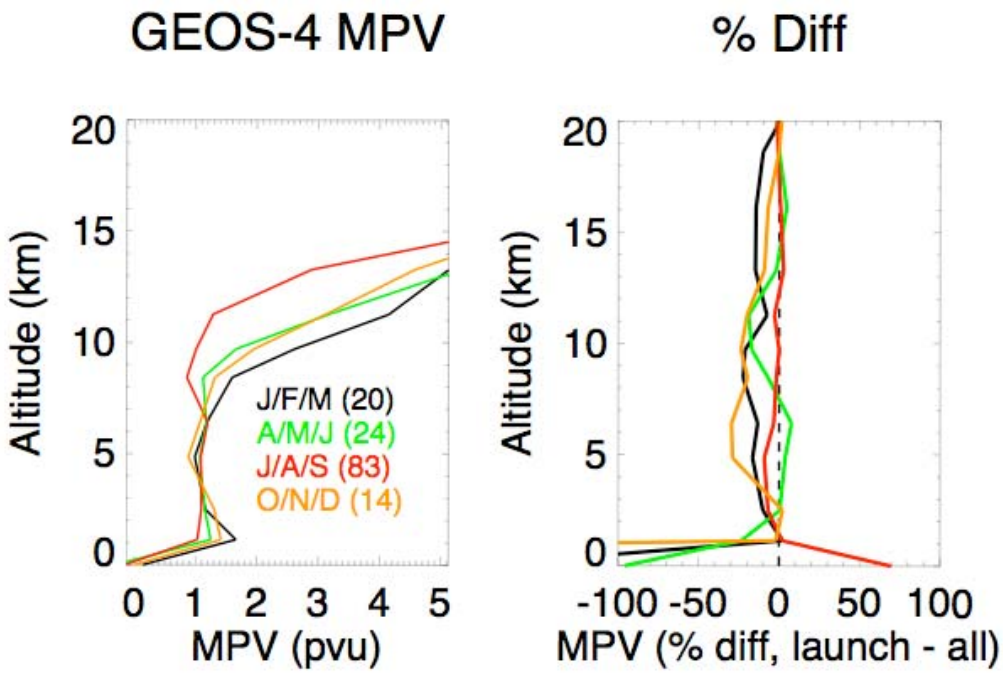


Figure 2.5.1.2b

Seasonal variability in Potential Temperature (Theta) is plotted using data from the GEOS-4 (1^0 lat $\times$ 1.25^0 lon) analyses produced by NASA Goddard's Global Modeling and Assimilation Office. The left-hand panel shows data for all days each season from July 1, 2004 through December 31, 2006 while the right-hand panel shows the difference between the Houston launch days and all days (i.e., the mean Theta values for the launch days minus the profiles shown in the left-hand panel). Our flight data are fairly representative, as indicated by the right-hand panel, although Theta on flight days tends to be higher at the surface in all seasons except summer, indicating an overrepresented warm condition. The lower Theta values are found in winter (January/February/ March) and fall (October/November/December), while the higher values are found in summer (July/August/September), as is expected given the annual temperature variation. Vertical gradients in Theta in the first 2 km are also strongest in winter and weakest in summer, indicating the presence of a better-defined boundary layer during summer when ozone values are at their peak levels. More uniform theta values indicate a well-mixed atmosphere.

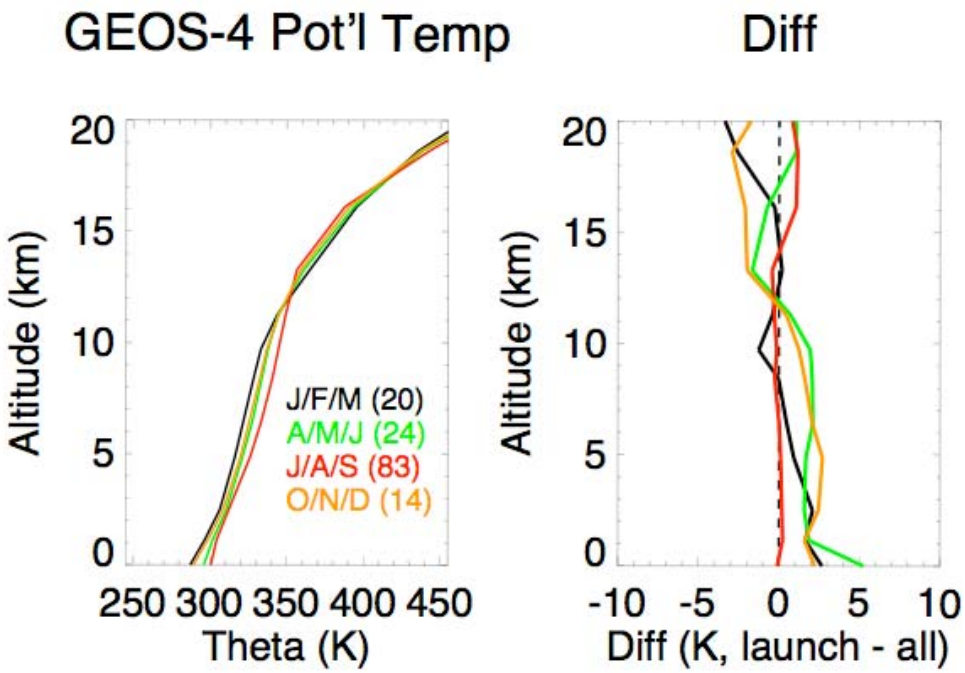


Figure 2.5.1.2c

Seasonal variability in wind direction is plotted using data from the GEOS-4 (1^0 lat $\times$ 1.25^0 lon) analyses produced by NASA Goddard's Global Modeling and Assimilation Office. The left-hand panel shows data for all days each season from July 1, 2004 through December 31, 2006 while the right-hand panel shows values for the Houston launch days only. The percentage of the time the wind blows in each direction or is calm (< 2.5 m/s) is plotted as a function of season: winter = "J/F/M" = January/February/March; spring = 'A/M/J" = April/May/June; summer = "J/A/S" = July/August/September; and winter = "O/N/D" = October/November/December. Our flight data are fairly representative, as indicated by the right-hand panels, although in J/A/S, our data seem to over represent easterly winds aloft at the expense of westerly winds. Westerly conditions aloft dominate all seasons with the exception of summer, during which easterly and southerly flow regimes are also significant. The clockwise turning of the winds from the boundary layer (< 2 km) into the lower free troposphere (3 – 5 km) during winter and spring indicate warm advection of air from the south. Winter conditions show turning of the wind on launch days from both northerly to westerly and easterly to westerly, indicating both warm and cold advection conditions. Summer conditions are more variable, with easterlies aloft and winds from north, south, and east are roughly equally represented at the surface.

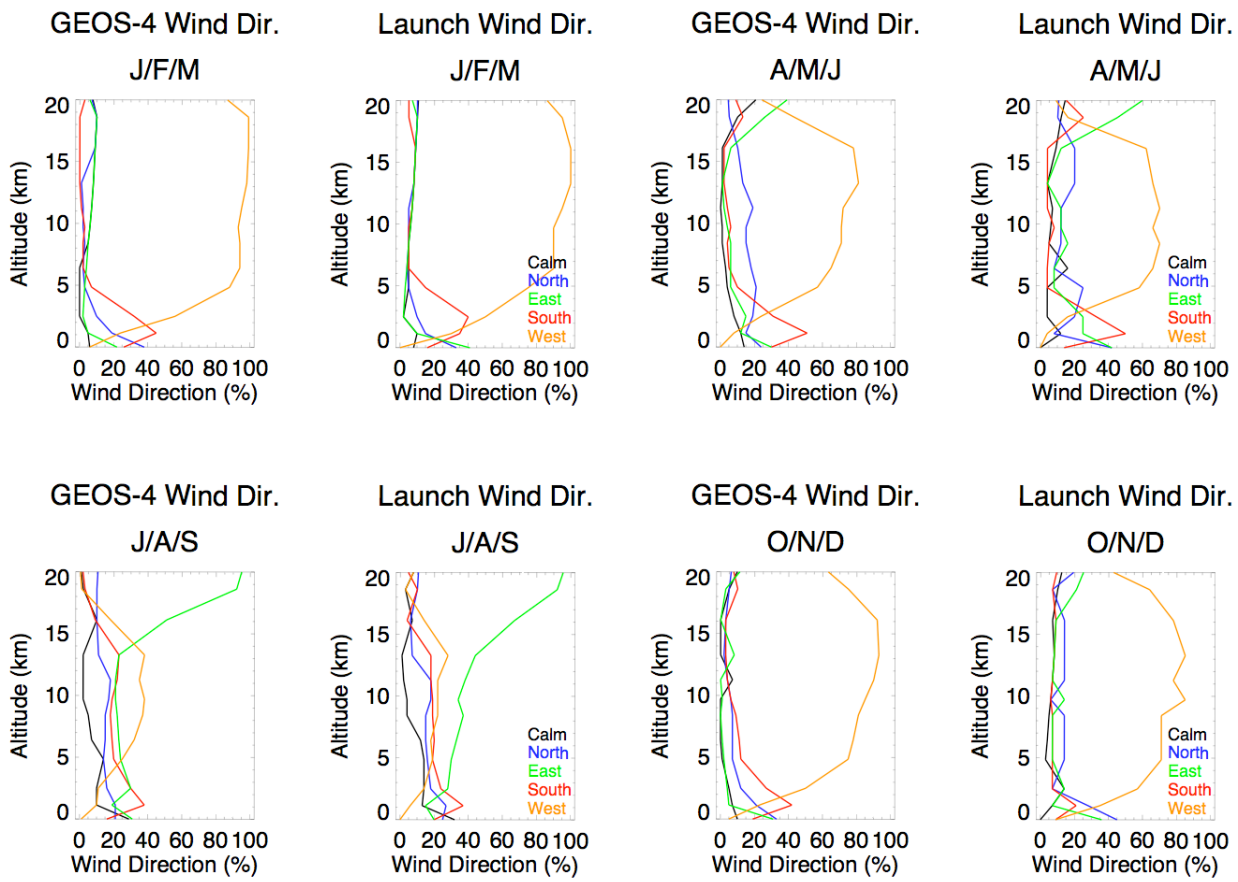


Figure 2.5.1.2d

Seasonal variability in mean wind speed is plotted using data from the GEOS-4 (1^0 lat $\times$ 1.25^0 lon) analyses produced by NASA Goddard's Global Modeling and Assimilation Office. The left-hand panel shows data for all days each season from July 1, 2004 through December 31, 2006 while the right-hand panel shows the percent difference between the Houston launch days and the overall data set. The wind speed is plotted as a function of season: winter = "J/F/M" = January/February/March; spring = 'A/M/J" = April/May/June; summer = "J/A/S" = July/August/September; and winter = "O/N/D" = October/November/December. Our flight data very representative in summer (throughout the profile) and winter (below 8 km), as indicated by the right-hand panels. In the spring and especially the fall, we under-sample windy days. Launches on windy days are difficult if not impossible, which explains the observed differences. The calmest winds are observed during summer and spring when boundary layer ozone is high. The strongest winds are seen during the winter, when boundary layer ozone is low.

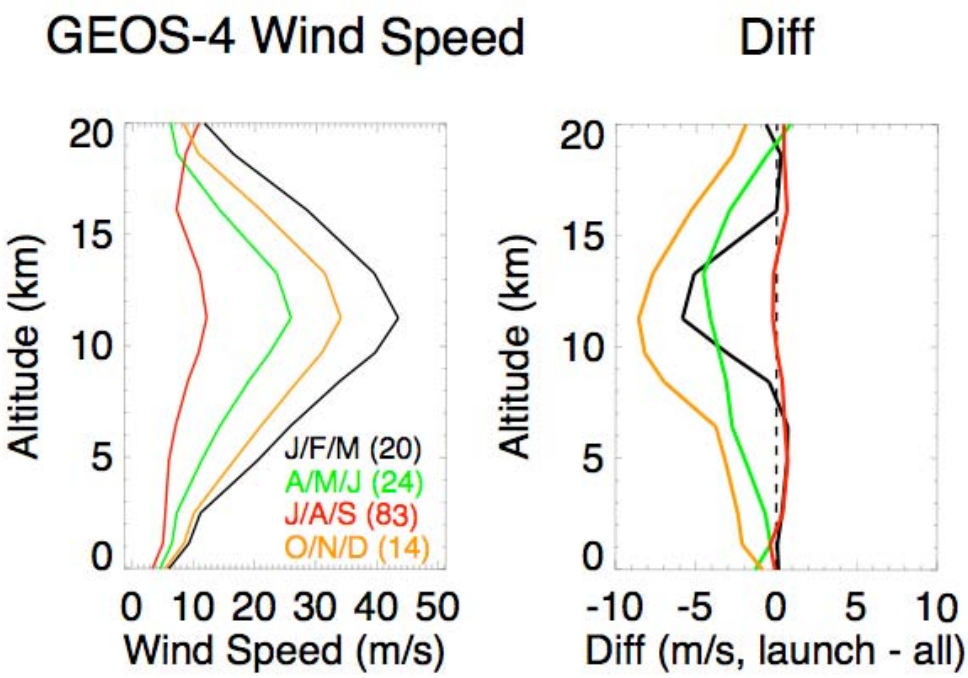


Figure 2.5.2.1

The figure shows the annual variation in the vertical gradient of ozone above Houston using only afternoon ozonesonde profile data. The * represent each flight; the thick curve is the mean difference; and the dashed curves one standard deviation about the mean. In each case, the mean ozone between 500 and 1500 m is subtracted from the mean ozone between 2500 and 3500 m. The difference is suggestive of the relative importance of transported ozone (positive numbers) versus locally produced ozone (negative numbers).

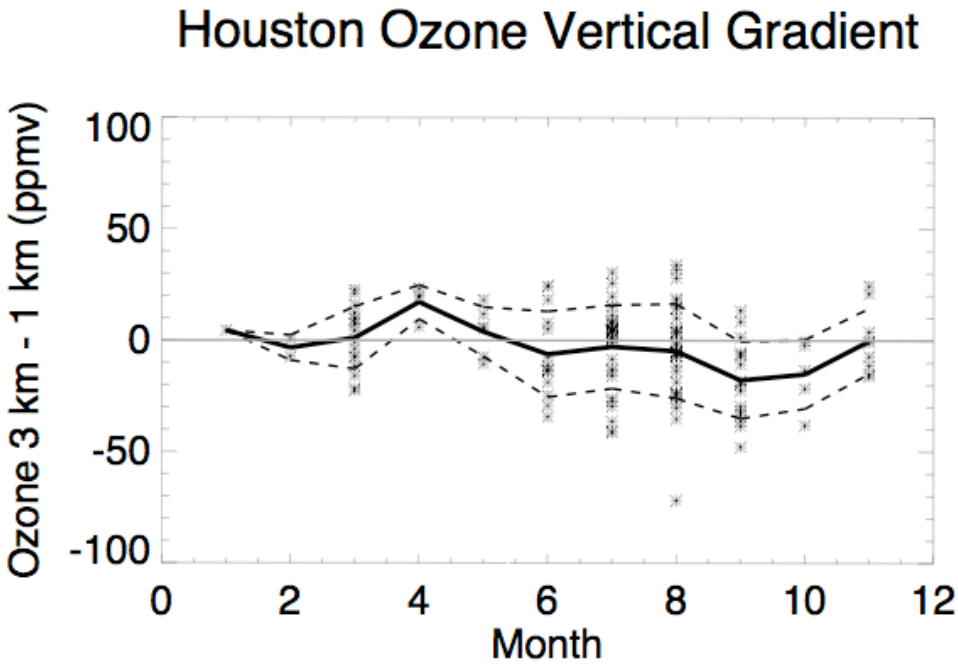


Figure 2.5.2.2a

Two ozonesonde launches about 2 hours apart on June 21, 2005 reveal large changes in ozone concentrations measured aloft (3 – 5 km), suggesting transport of pollutants.

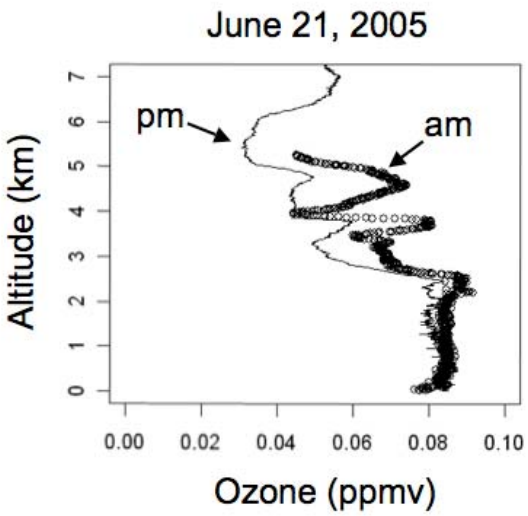


Figure 2.5.2.2b

Trajectories computed from the HYSPLIT model suggest air from Louisiana arrives in Houston on June 21 (local time), contributing to changes in ozone concentrations seen over the period of ~2 hours between launches as shown in Figure 2.5.3.2a

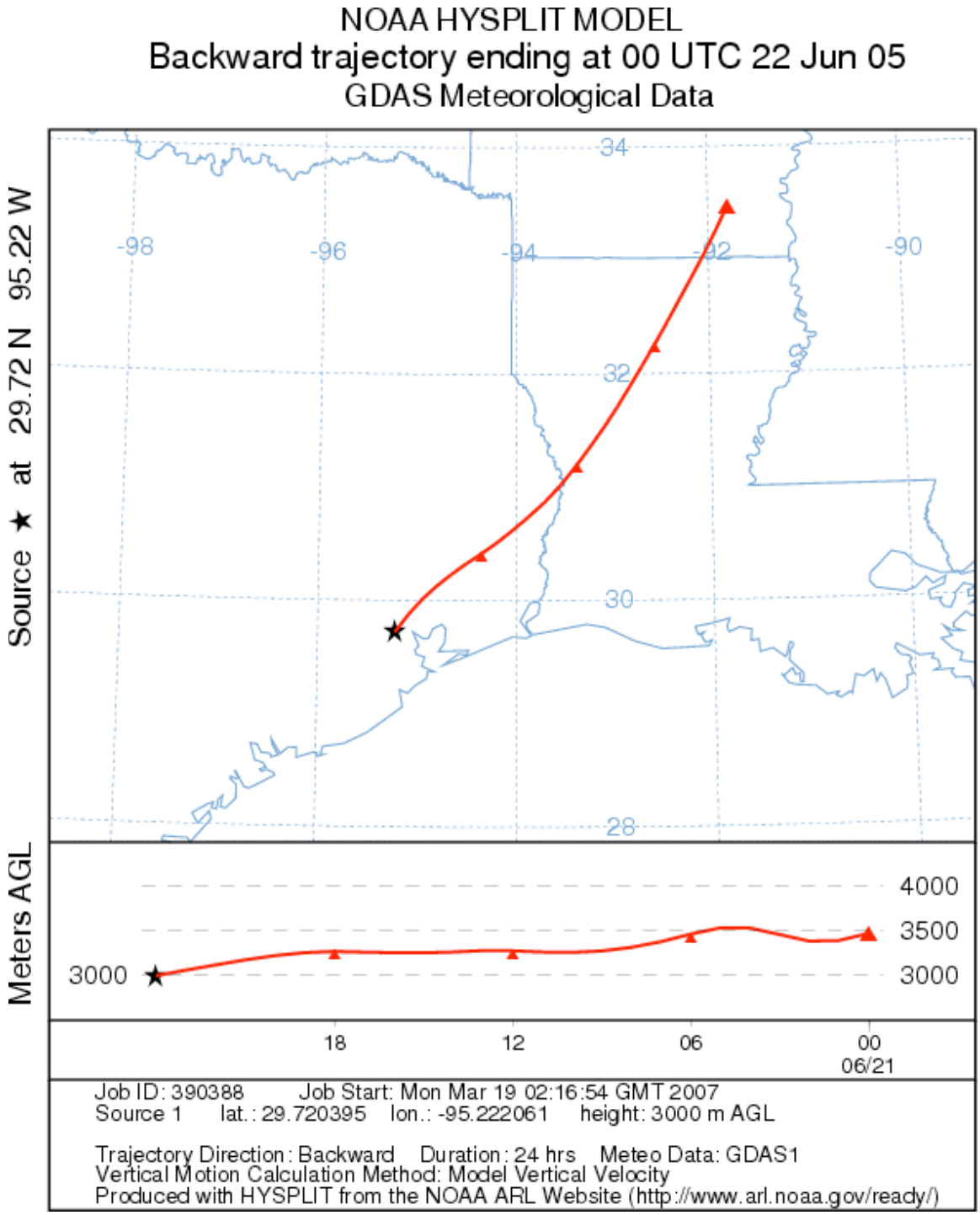


Figure 2.5.2.2c

The figure shows the impact of arriving forest fires smoke from Alaska and Western Canada in July 2004. The black curve is the mean of the July/August 2004 data. The gray shaded region represents one standard deviation about the mean. The blue curve is the last profile before the arrival of the smoke. The green curve is the first profile after the smoke leaves the Houston area. The orange and red curves were profiles from the two days on which the smoke was in the Houston area. Note the high levels of ozone on both days, with ozone increases of 50 – 200%. Also note the positive ozone gradient as a function of height, very unusual for Houston this time of year when local sources usually dominate yielding a negative gradient as seen in Figure 2.5.2.1.

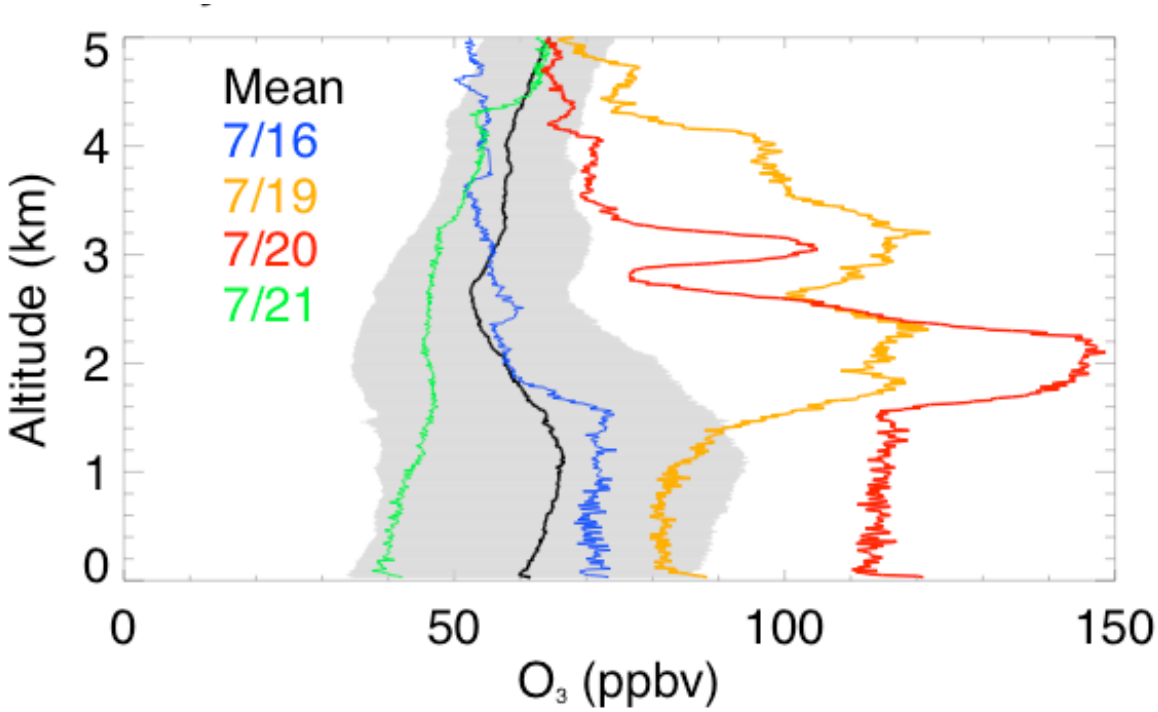


Figure 2.5.2.2d

Air mass trajectories computed using the Goddard Trajectory Model (courtesy Peter Colarco) linking air arriving in Houston to air in Western Canada and Eastern Alaska 7 days earlier.

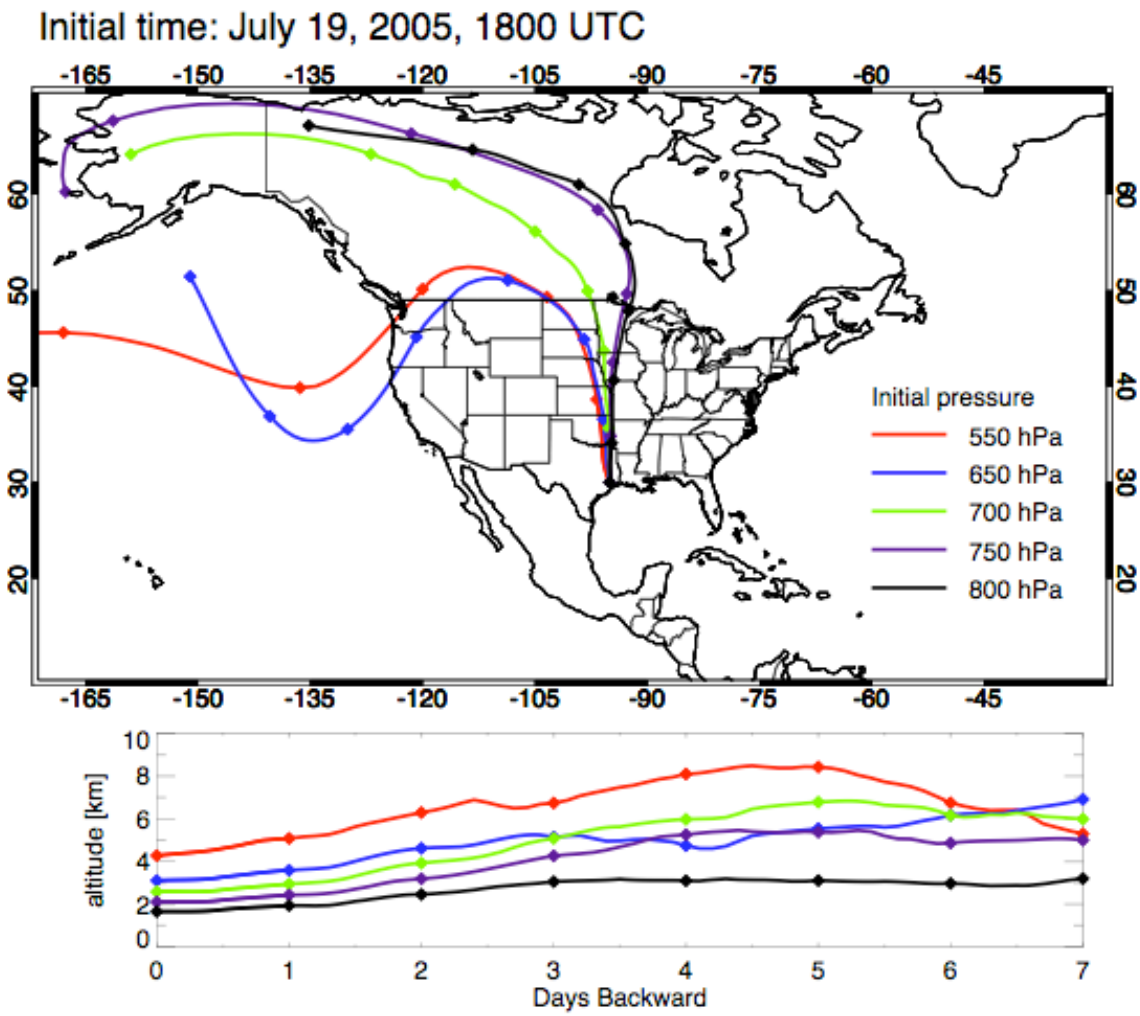


Figure 2.5.3.2a

Mean (thick lines) and one standard deviation (thin lines) of afternoon ozone profiles over Houston during July and August from 2004 – 2006.

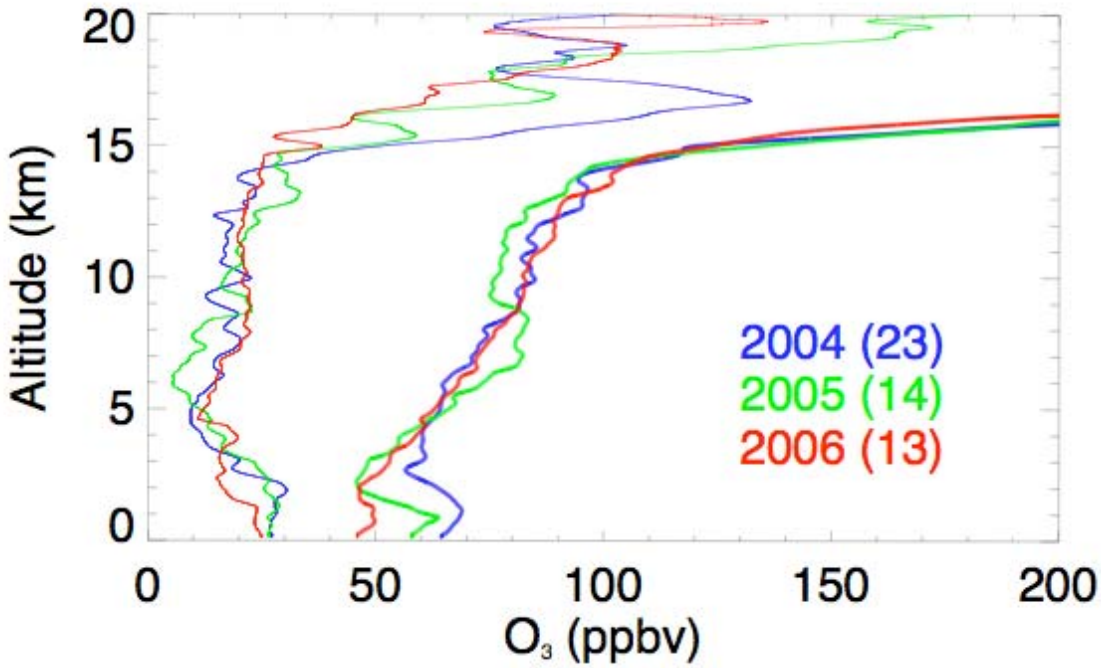


Figure 2.5.3.2b

Wind direction percentages are shown as a function of year. Note that in 2004, winds were predominately from the North and East at the surface, corresponding to higher ozone levels in the boundary layer seen in Figure 2.5.3.2a. During 2006, winds were predominantly from the South at the surface, corresponding to lower ozone levels in the boundary layer.

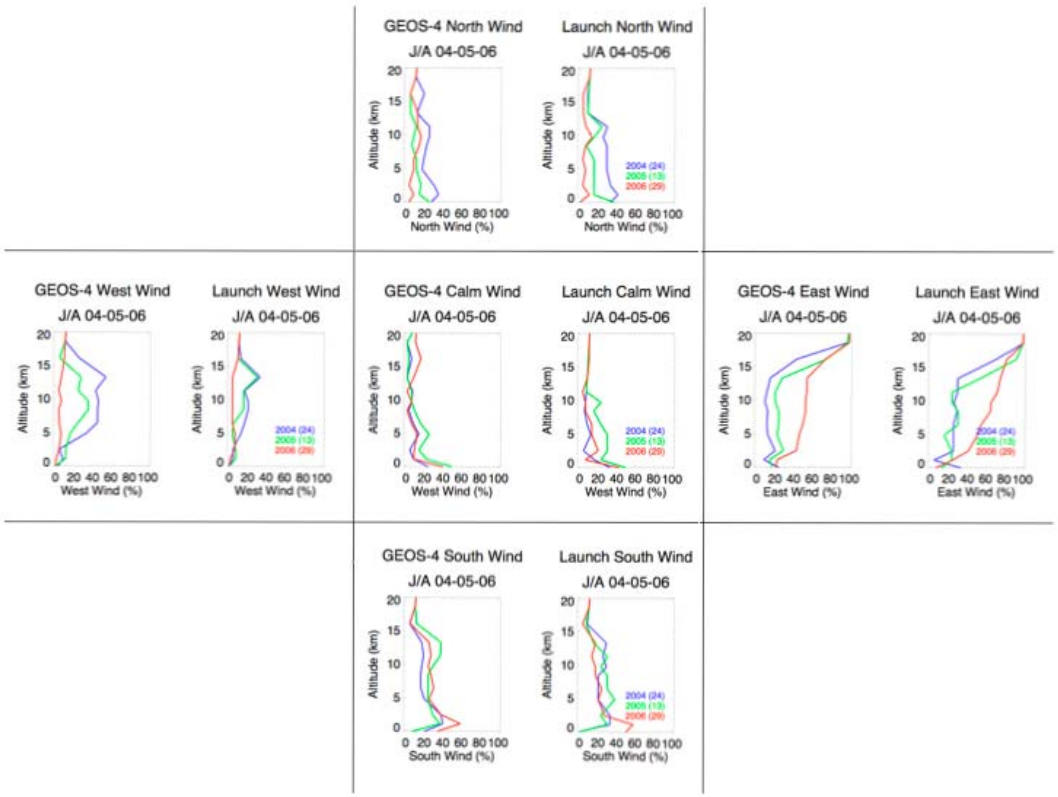
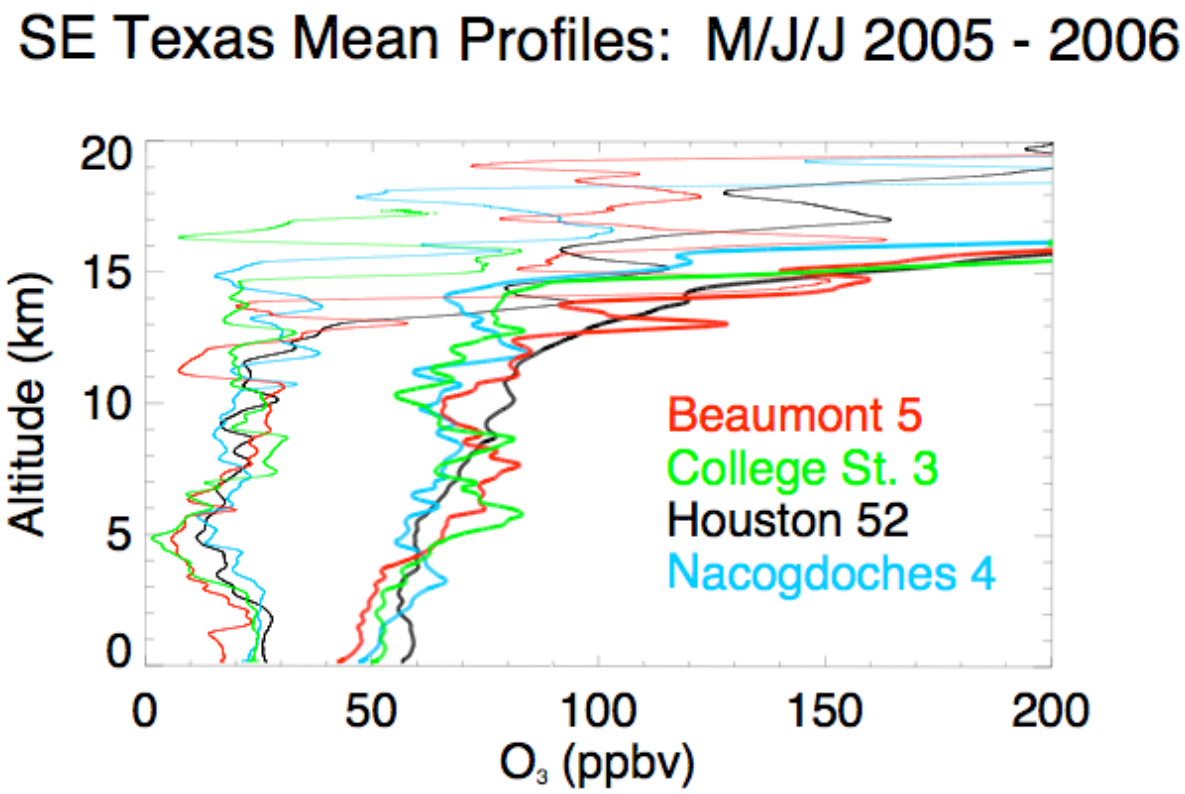


Figure 2.5.4.2

Mean (thick) and one standard deviation (thin) ozone profiles over four sites in Southeast Texas using data from ozonesonde launches in May, June, and July during 2005 and 2006.