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Ozone profile observations in Houston, Texas (1994 - 2010) from aircraft, balloons, and satellites

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Abstract

Houston, Texas has long been an urban area plagued with high levels of surface ozone, particularly in spring and late summer. The combination of a large commuter population and one of the largest concentrations of petrochemical plants in the world results in abundant and nearly co-located sources of NOx and hydrocarbons. The location of Houston on the South Coast of the United States in a subtropical climate results in meteorological conditions that favor ozone production. Using MOZAIC (1994 - 2004), ozonesonde (2000, 2004 - 2010), and TES (2005 – 2010) data, we examine the evolution of ozone profiles over Houston during a period in which various strategies have been implemented to alleviate the ozone pollution problem. Using meteorological data from associated soundings and analyses, we identify and evaluate influences on the ozone profiles from natural and anthropogenic sources, as well as local and remote sources. We further investigate how these various influences have changed with time.

Houston Surface O_3 Observations

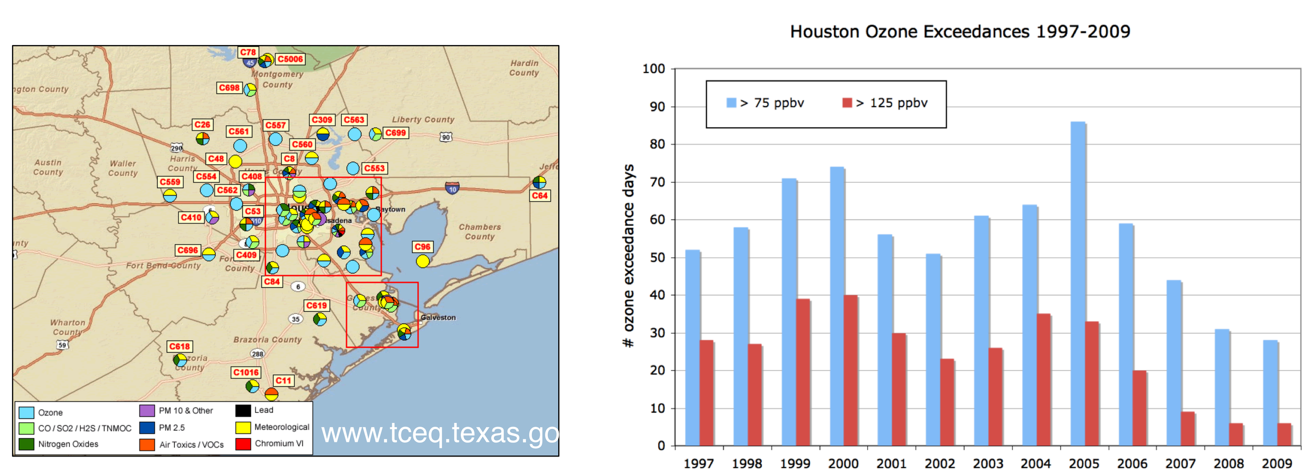

Figure 1. (Left) The distribution of > 40 Continuous Air Monitoring Stations (CAMS) in the Houston-Galveston-Brazoria County region (HGBR), courtesy Texas Commission on Environmental Quality (TCEQ). (Right) The number days on which at least one surface monitor in the HGBR registered O_3 concentrations in excess of the the EPA 1-hour (red) and 8-hour (blue). The trend has been strongly downward since 2005.

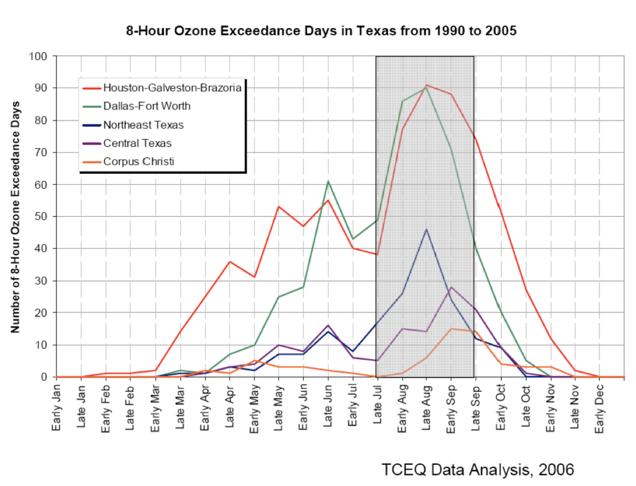

Figure 2. The number of days semi-monthly with O3 exceeding EPA standards from 1990 – 2005 for sites in Texas – Houston is in red. The seasonal cycle of O_3 in Houston shows a double peak, with the first centered on May and the second on August-September. July shows a relative minimum. The former peak is dominated by transport behind frontal passages while the latter results from a combination of local production and transport (Morris et al., 2011, in preparation)

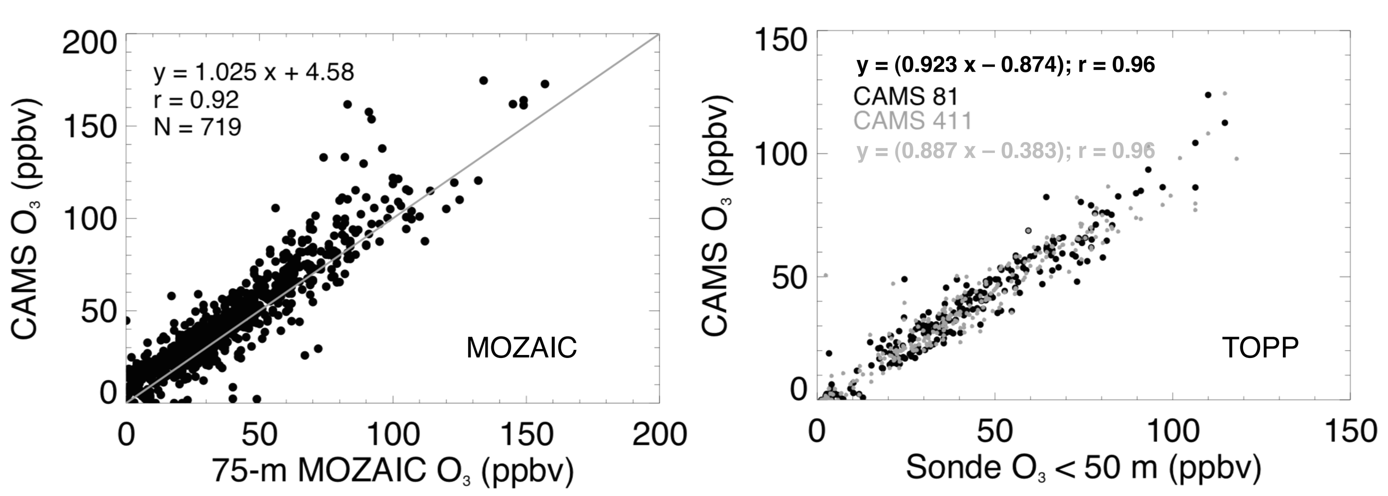

Figure 3. (Left) CAMS 8 (Aldine: 29.91⁰N, 95.33⁰W) is compared with the lowest altitude (75 m) MOZAIC O_3 (IAH: 29.98⁰N, 95.34⁰W) for all flights from 1994 – 2004. (Right) CAMS 81 (Polk Ave.: 29.74⁰N, 95.32⁰W) and CAMS 411 (Texas Ave.: 29.75⁰N, 95.35⁰W) are compared with mean 0 – 50 m ozonesonde O_3 concentrations from the Tropospheric Ozone Pollution Project (TOPP) Houston flights (Rice U.: 29.72⁰N, 95.40⁰W; U. of Houston: 29.72⁰N, 95.34⁰W).

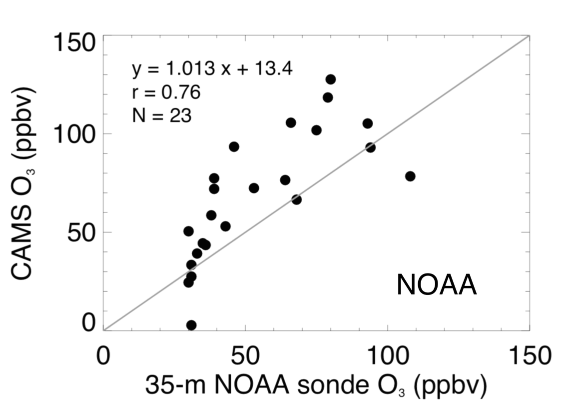

Figure 4. CAMS 35 (Deer Park: 29.67⁰N, 95.13⁰W) near Ellington Field is compared with the 35-m (lowest level reported) for the NOAA sondes in August – September 2000.

Houston Ozone Profile Observations

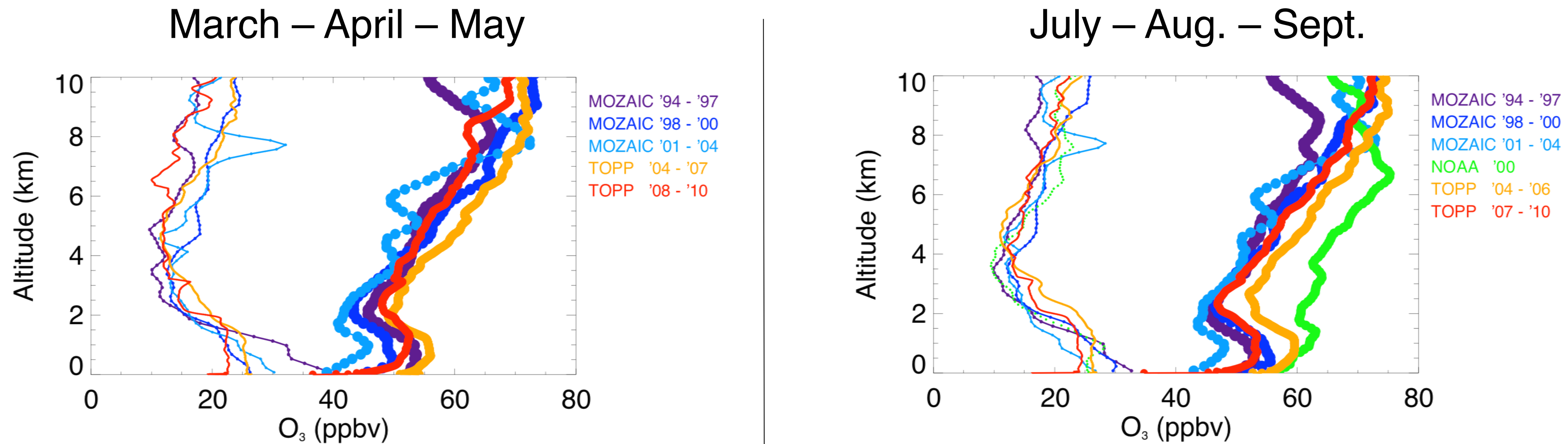

Figure 5. Mean (thick) and 1σ (thin) O_3 profiles in Houston during (Left) Spring (March – May) and (Right) Summer (July – September). MOZAIC means are computed in three periods: 1994 – 1997, 1998 – 2000, and 2001 – 2004. TOPP means are computed for two periods: 2004 – 2007 and 2008 – 2010. NOAA observations occurred in August – September 2000 as part of the Texas Air Quality Study (TexAQS). For Spring these mean profiles indicate the highest O_3 throughout the profile during the 2004 – 2007 period, with no clear trend over time. For Summer these mean profiles indicate the highest O_3 throughout the profile in 2000, with amounts in the lowest 2 km generally increasing from the mid 1990's to 2000 and decreasing since. Any interpretation of trends, however, must take into account differences in meteorological conditions and sampling biases (see Table 1 at right for some comment on the latter).

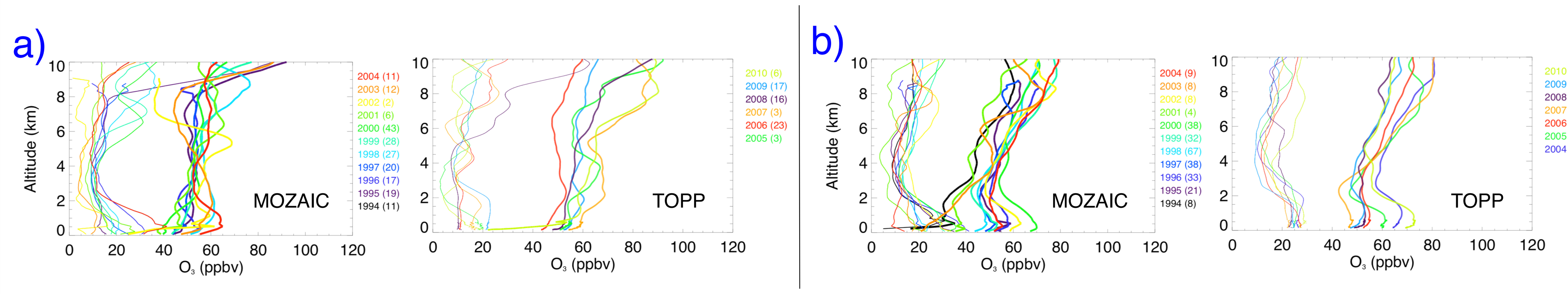

Figure 6. Annual mean (thick) and 1σ variability (thin) of O_3 profiles in Houston during (a) Spring and (b) Summer. The left in each pair of Figures corresponds to the MOZAIC data (1994 – 2004) while the right corresponds to the TOPP (2004 – 2010) data. The number of soundings in each year is found in parentheses. Variability in the conditions sampled, including meteorological factors and mean O_3 concentrations, can result in apparently large year-to-year profile differences. Table 1 (at right) provides insight into the latter. Morris et al. (2011) found that total seasonal rainfall can account for 30 – 50% of the variability in year-to-year differences in the seasonal mean O_3 profiles. Only profiles corresponding to samples after 16:00 GMT except Spring TOPP 2010.

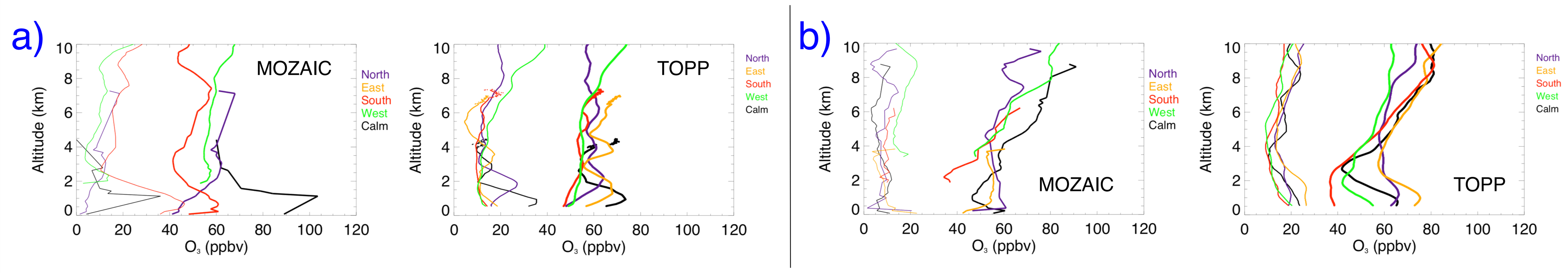

Figure 7. Mean (thick) and 1σ (thin) of O_3 profiles in Houston during Spring 2005 – 2010. Overall annual means are shown (left) with the number of soundings in parentheses. All profiles are taken after 1500 UTC, except Spring 2010 which includes all profiles. Means by wind direction are shown (center), with Calm winds (< 2.5 m/s) and East winds resulting in the largest BL O_3. Annual mean profiles with South winds are shown (right), with 2010 showing somewhat higher O_3. All profiles are taken after 1500 UTC, except Spring 2010 which includes all profiles. Means by wind direction are shown (center), with Calm winds (< 2.5 m/s) and East winds resulting in the largest BL O_3. Annual mean profiles with South winds are shown (right), with 2010 showing somewhat higher O_3.

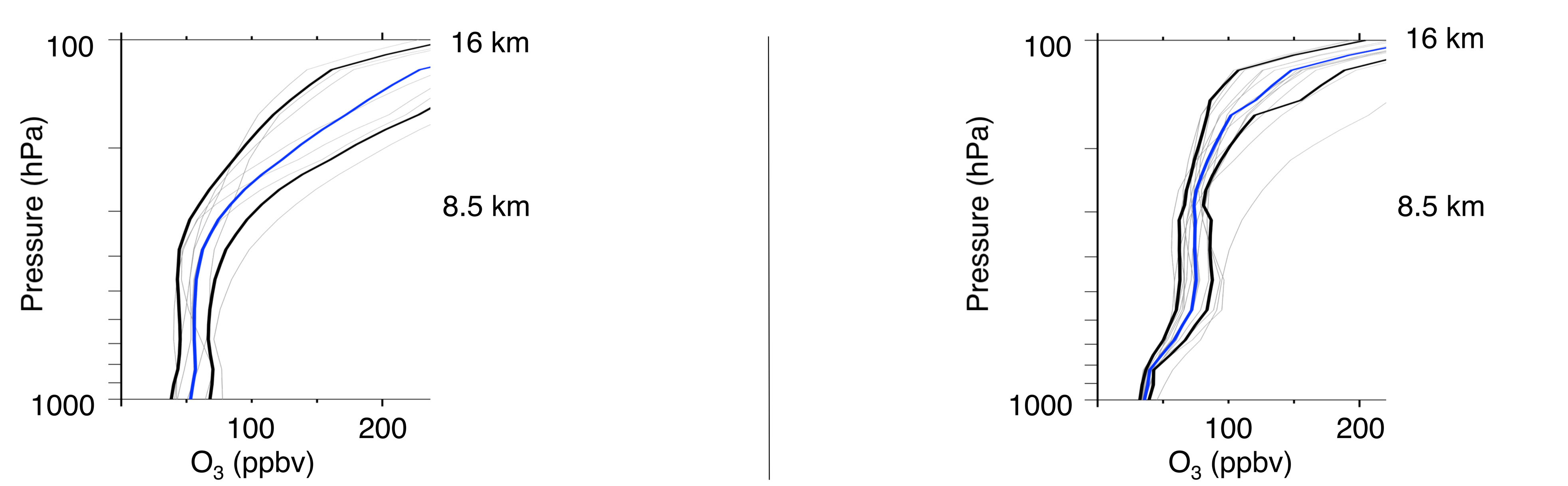

Figure 8. Mean O_3 (blue), mean ±1σ (black), and individual (gray) profiles near Houston from the Tropospheric Emission Spectrometer (TES) aboard the NASA Aura Satellite, 2005 – 2010. Profiles are shown for (Left) Spring (March – May, 7 profiles) and (Right) Summer (June – August, 15 profiles).

Estimating Sampling Biases

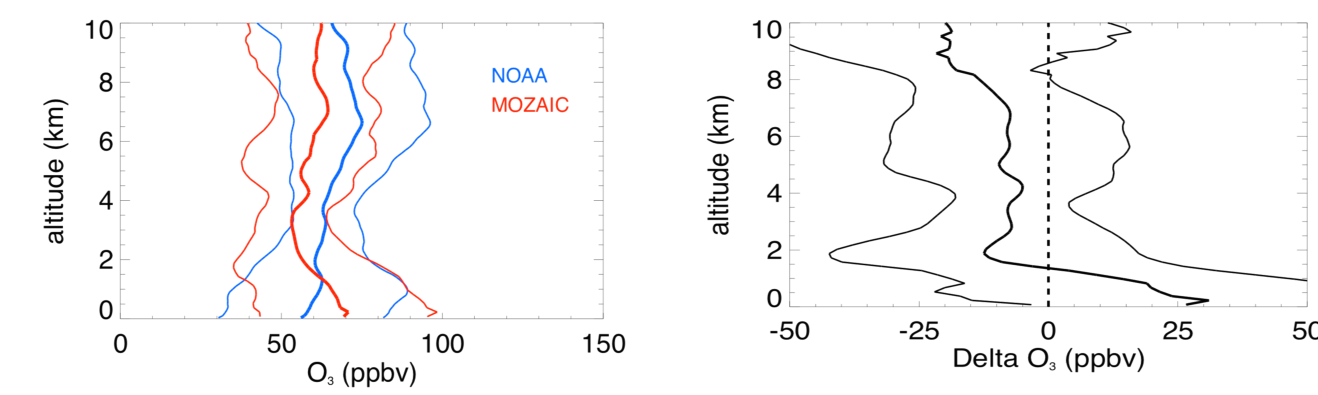

Figure 9. (Left) Mean and (mean ± 1σ) O_3 profiles for MOZAIC at IAH and NOAA ozonesondes during the Texas Air Quality Study (TexAQS) from 15 August – 15 September 2000. (Right) Mean and (mean ± 1σ) of the differences between the MOZAIC profiles and the NOAA profiles on the 6 days from 25 August – 10 September 2000 with both sets of observations.

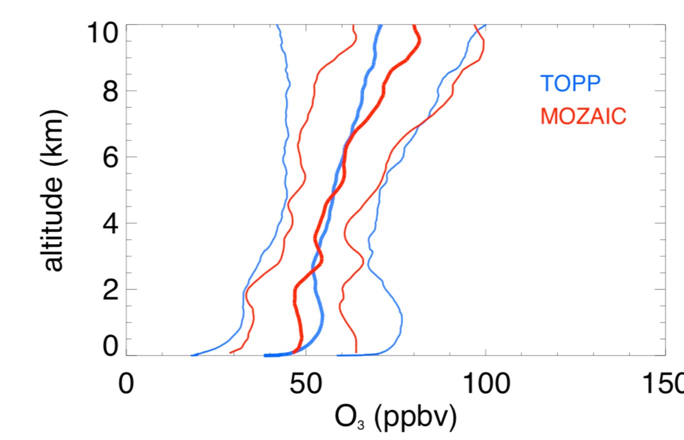

Figure 10. Mean and (mean ± 1σ) O_3 profiles for MOZAIC ascents and descents into IAH and TOPP ozonesondes from 24 July – 10 October 2000. During this timer interval, there were 11 MOZAIC profiles on 6 different days and 25 TOPP profiles The agreement between the two data sets is very good. Unfortunately, no days during this period had observations from both.

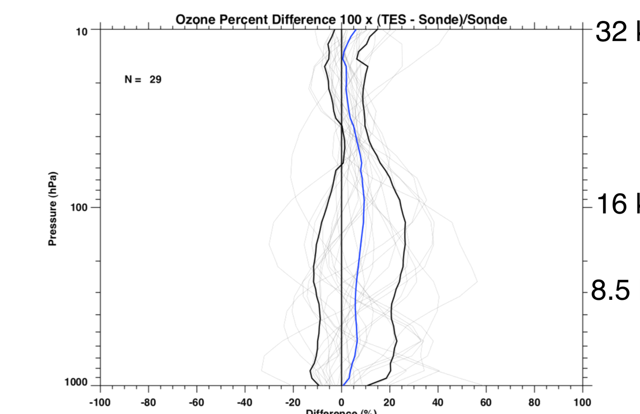

Figure 11. Mean (blue) and (mean ± 1σ) (black) % difference between TES and TOPP O_3 profiles from 2005 – 2010. On average, the two observations agree to within ~5%. Differences with individual observation are shown in light gray.

	SPRING (March - May)				SUMMER (July - September)			
	MOZAIC		Ozonesonde		MOZAIC		Ozonesonde	
Year	all days	flt days	all days	flt days	all days	flt days	all days	flt days
1994	60 ± 23	N/A			72 ± 26	24 ± N/A		
1995	55 ± 20	61 ± 22			79 ± 31	116 ± 2		
1996	65 ± 26	50 ± 14			81 ± 45	100 ± 54		
1997	59 ± 22	53 ± 18			75 ± 38	66 ± 24		
1998	72 ± 26	67 ± 19			69 ± 32	63 ± 34		
1999	62 ± 23	65 ± 24			82 ± 29	79 ± 30		
2000	58 ± 21	49 ± 11			91 ± 41	100 ± 46	74 ± 38*	87 ± 40*
2001	57 ± 22	57 ± 20			70 ± 29	59 ± 4		
2002	53 ± 18	47 ± N/A			56 ± 23	72 ± 32		
2003	58 ± 24	66 ± 17			61 ± 24	37 ± 11		
2004	53 ± 16	70 ± 29			64 ± 21	N/A	52 ± 27	55 ± 21
2005			56 ± 16	48 ± 16			59 ± 28	70 ± 30
2006			46 ± 16	44 ± 11			51 ± 27	60 ± 31
2007			43 ± 15	48 ± 20			38 ± 20	44 ± 24
2008			44 ± 14	42 ± 11			45 ± 22	45 ± 23
2009			44 ± 16	53 ± 22			44 ± 22	44 ± 23
2010			44 ± 16	69.5 ± 9.7			40 ± 22	67 ± 22
Overall	57 ± 20	59 ± 20	47 ± 16	48 ± 16	66 ± 31	77 ± 40	46 ± 25	53 ± 28

Table 1. Mean daily 1-hour ozone maxima on all days within a season and on flight ("flt") days only. MOZAIC data are compared with CAMS 8. Ozonesonde data are compared with CAMS 81 except in 2000, when NOAA launches are compared with CAMS 35 (Deer Park: 29.67⁰N, 95.13⁰W) near Ellington Field. "SPRING" includes March – May each year while "SUMMER" includes July – September.

Conclusions

- CAMS data show a decreasing number of days of peak O_3 > EPA standard since 1997.
- We find good agreement between near surface sonde/MOZAIC O_3 and nearby CAMS monitors, and good profile agreement between MOZAIC and the NOAA sondes (2000) and the TOPP sondes (2004).
- Spring profiles < 2 km show their highest means for the 2004 – 2007 period, while Summer profiles < 2 km show their highest means in 2000.
- The largest O_3 amounts < 2 km are associated with Calm, Easterly, and Northerly winds.
- Trend analyses must examine interannual meteorological variability and sampling differences.

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