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Source attribution of ozone in Southeast Texas before and after the Deepwater Horizon accident using satellite, sonde, surface monitor, and air mass trajectory data

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Abstract

Since the summer of 2004, over 300 ozonesondes have been launched from Rice University (29.7 N, 95.4 W) or the University of Houston (29.7 N, 95.3 W), each < 5 km from downtown Houston. The Texas Commission on Environmental Quality (TCEQ) maintains a large database of hourly surface ozone observations in Southeast Texas. In this study, we identify the contributions to surface ozone pollution levels from natural and anthropogenic sources, both local and remote in nature. This source identification is performed two ways: 1) through an analysis of sonde data, including ozone concentrations, wind speed and direction, and relative humidity data, and 2) through an analysis that combines trajectory calculations with surface monitor data. We also examine regional changes in Ozone Monitoring Instrument (OMI) measurements of nitrogen dioxide and formaldehyde from 2009 to 2010. In particular, we compare the 2010 sonde, surface monitor, and satellite data after the Deepwater Horizon accident **(20 April 2010)** with data from previous years to determine the impact, if any, of the large source of hydrocarbons in the Gulf of Mexico on air quality in Southeast Texas.

OMI Satellite Observations

NO_2 April – June

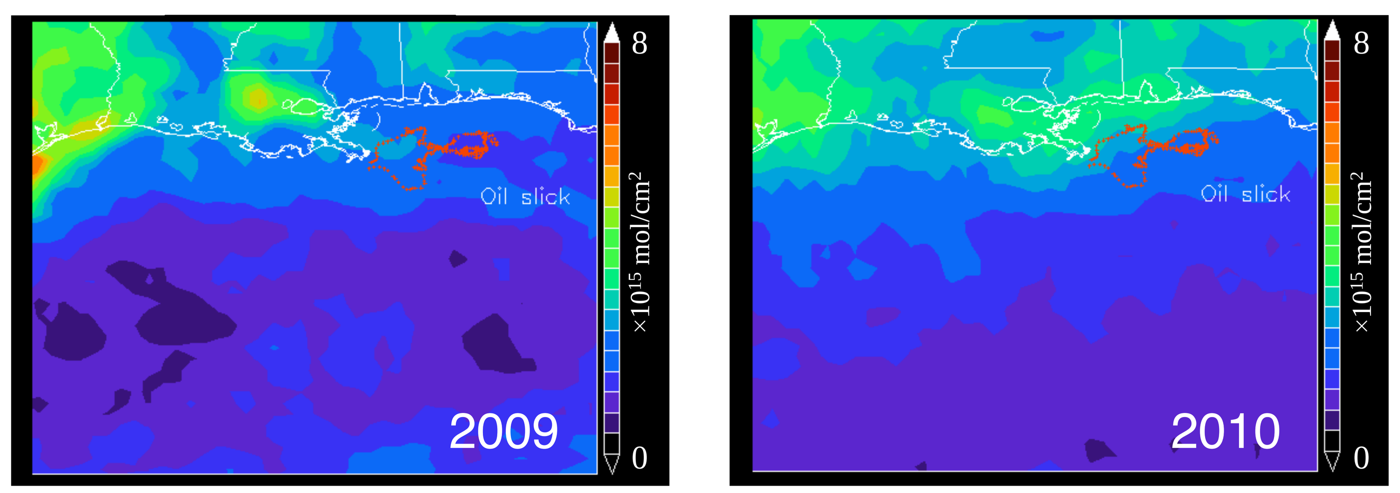


Figure 1. OMI Tropospheric Column NO_2 for the Gulf Coast of the USA in 2009 (left) and 2010 (right). The satellite data indicate no significant differences before and after the Deepwater Horizon accident.

HCHO April – June

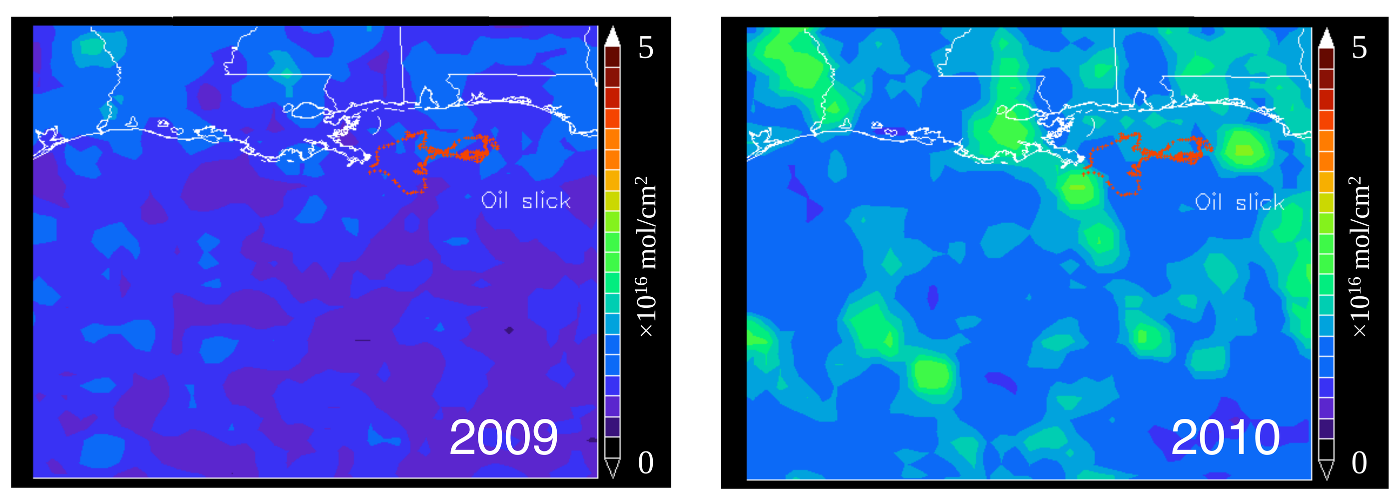


Figure 2. Same as Figure 1 but for HCHO, which seems generally elevated by 50 – 100% throughout the Gulf in 2010 compared to the same time period in 2009.

TCEQ Surface O_3 Observations

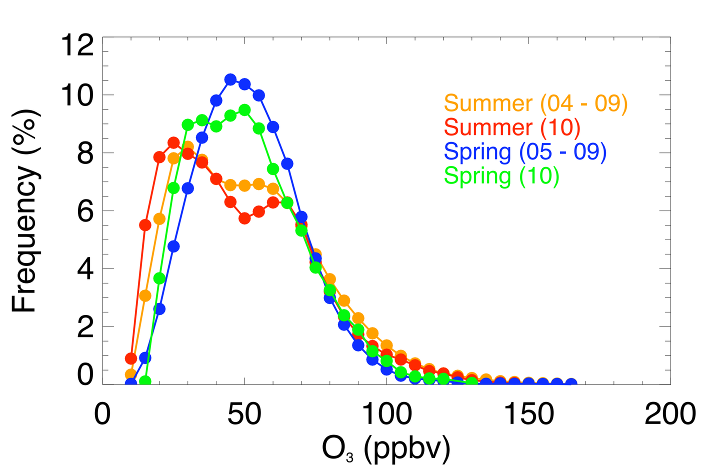


Figure 3. Histogram of daily 1-hr O_3 maxima from 54 CAMS sites in the Houston-Galveston-Brazoria County (HGB) non-attainment region. Summer data are for August & September 2004 – 2009 with 2010 data separated out. Spring data are for April & May 2005 – 2009 with 2010 separated out. The Summer 2010 data do not appear to be significantly different. The Spring 2010 data show somewhat higher frequencies at both low and high O_3 concentrations.

Houston Ozonesonde Observations

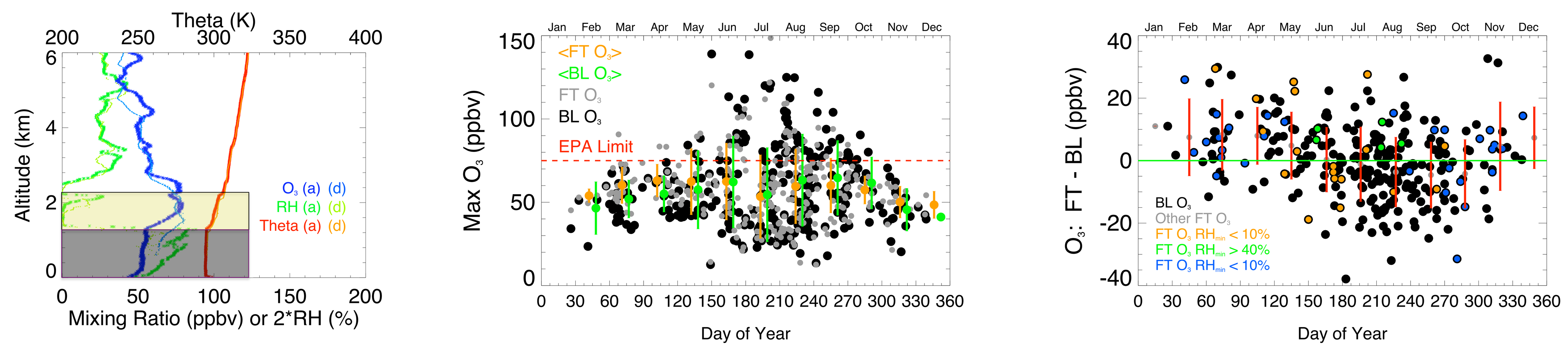


Figure 4. O_3, RH, and Theta profiles (left) can be helpful in defining the boundary layer (BL, shaded gray) and distinguishing local from remote, and natural from anthropogenic O_3. We subtract the max O_3 in the BL from the max O_3 in the next higher 1-km layer in the lower free troposphere (FT, shaded yellow). The max O_3 in the BL and FT are plotted as a function of season (center), with the monthly mean FT and BL values shown relative to the current EPA 8-hr O_3 standard. **O_3 in FT air near the BL frequently exceeds the EPA Limit, especially from May – Sept.** Finally, the difference between FT and BL O_3 is also plotted as a function of season (right). The color coded data in the right-hand figure identify different transport regimes: UT/LS air with O_3 > 75 ppb, UT/LS air with O_3 < 75 ppb, and transported pollution with O_3 > 75 ppb. **In March and April, FT O_3 > BL O_3, suggesting transport is more important. In Aug. and Sept., BL O_3 > FT O_3, suggesting local production is more important**. All error bars are 1σ.

Implications for the new EPA 8-hr Ozone Standard

Table 1. We compare the max O_3 in the 1-km layer above the BL (see Fig. 4) with the EPA 8-hr O_3 standard for the 282 afternoon Houston sonde profiles. The table lists the fraction that exceed the standard: the top row is for all soundings; the 2nd row is only those that also exceed the max BL O_3; the 3rd row is for those with a min RH in that layer < 10%; and the final row is for those with a min RH in that layer < 10% and for which the max FT O_3 > max BL O_3. The 3rd and 4th rows suggest an approximate frequency of UT/LS influences on BL O_3 in Houston. Data from the 2nd and 4th rows imply that under the current EPA O_3 standard during the Mar. – Sept. Houston O_3 season, 2.2 sampled days/year (on average) had an exceedance solely due to transported O_3, with 1.4 of those from natural, UT/LS sources; under the strictest proposed new standard, those number would increase to >7.5 days/year and 2.6 days/year respectively. Note: since 2006, we have more often launched on days forecast for high O_3; before 2006, however, launches were more randomly distributed, which means the estimates of exceedance days is a lower limit.

Case	Current O_3 Standard (75 ppb)	Future O_3 Standard? (60 ppb)
All	16%	44%
FT > BL	5%	17%
RH < 10%	6%	11%
RH < 10%, FT > BL	3%	6%

March – April – May

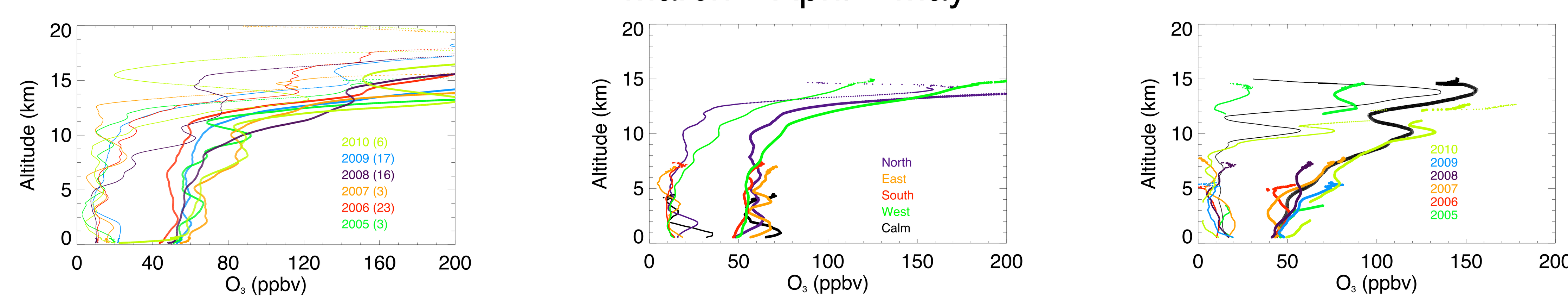


Figure 5. Mean (thick) and 1σ (thin) of O_3 profiles in Houston during Spring 2005 – 2010. Overall annual means are shown (left) with the number of soundings in parentheses. All profiles are taken after 1500 UTC, except Spring 2010 which includes all profiles. Means by wind direction are shown (center), 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.

July – Aug. – Sept.

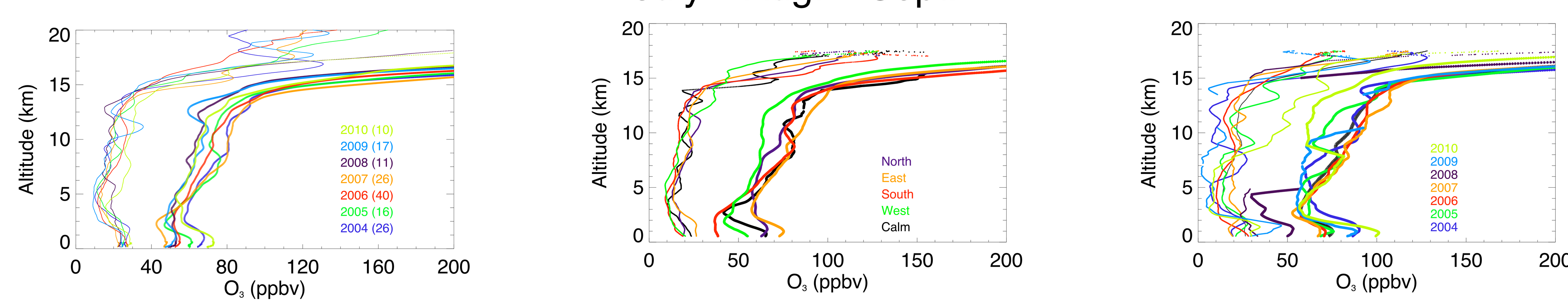


Figure 6. As in Figure 5 but for Summer 2004 – 2010. BL values in 2010 are the highest in our 7-year record (left), but launches were coordinated to coincide with frontal passages which result in higher surface O_3. South winds are associated with lower BL O_3 ,while East, North, and Calm winds have the highest BL O_3 (center). East winds in 2010 result in the highest O_3 in our record (right). Interannual variability in weather (especially rain events) must be investigated further.

Trajectory Analyses and Surface Data

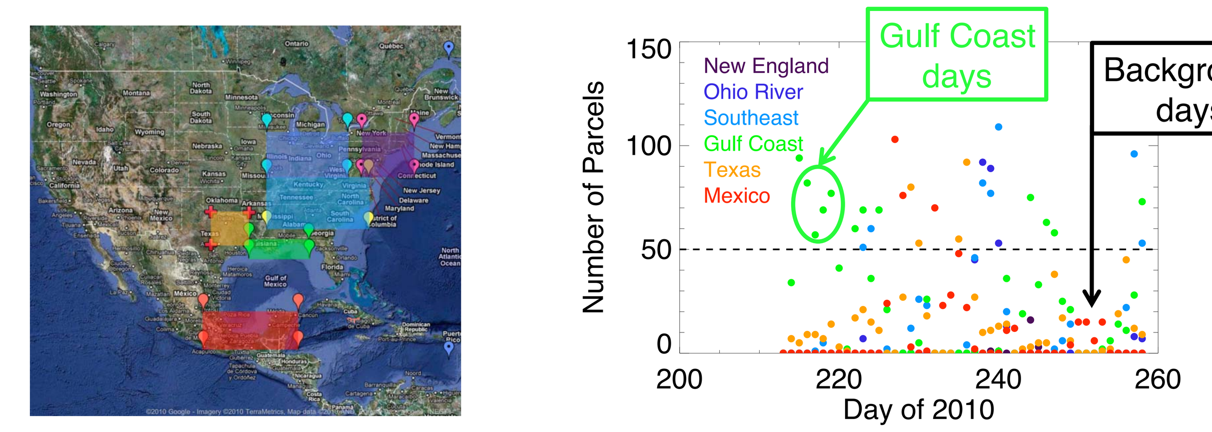
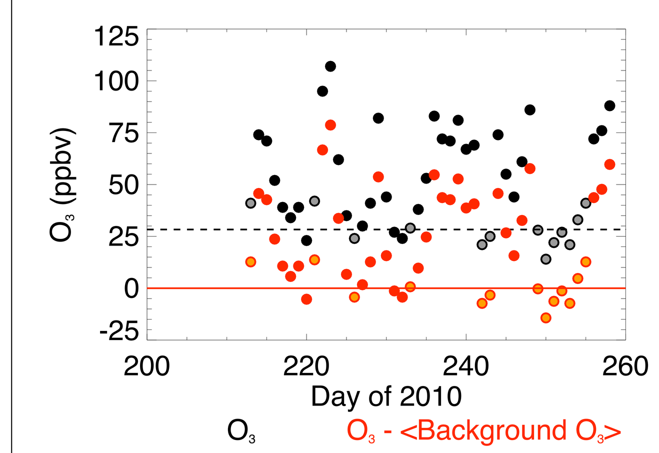


Figure 7. Using the NASA GSFC trajectory model with NCEP winds (1°×1°× 6 hr), we advect a grid (½°×½°) of air parcels stacked vertically at 0.5, 1.0, and 1.5 km from 6 source regions: New England, Ohio River, Southeast, Gulf Coast, Texas, and Mexico (left). We then count the number of parcels that arrive over Houston on each day (right). We consider days with at least 50 parcels from a given source region as days of influence, and days with < 50 parcels from all sources as "background days." We compare daily 1-hr O_3 maxima on days of influence with daily maxima on background days to diagnose the influence of these various source regions on Houston O_3.



<O_3 – Background O_3> (ppbv)

Source Region	Spring '05 – '10	Summer '04 – '09	Summer '10
Ohio River	N/A	31.1 ± 6.7	33.6 ± 3.0
Southeast	7 ± 13	22.7 ± 6.4	35.5 ± 4.0
Gulf Coast	8.4 ± 9.3	15.9 ± 6.0	26.0 ± 4.4
Texas	20.1 ± 6.1	24.5 ± 9.3	33.0 ± 3.6
Mexico	3.1 ± 3.1	-9.15 ± 0.92	11.5 ± 3.8

Figure 8 (left). Daily 1-hr O_3 maxima at CAMS 554 – West Houston. Black are original data. Gray are data on "background days" (see Fig. 7). Red are residuals, with the mean background O_3 (black dashed line) subtracted out; the orange dots show the data on "background days."

Table 2 (right). The analysis of Fig. 8 is repeated at all the CAMS sites in the HGB region, and a mean difference is computed with air from each identified source region. Summer source region contributions were generally higher in 2010 than the previous five years.

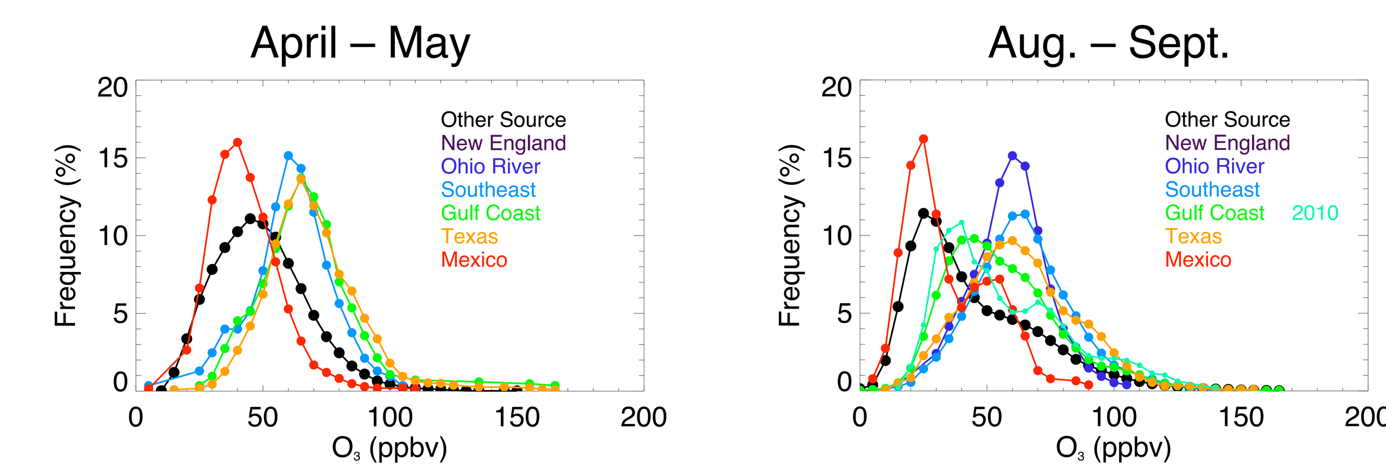


Figure 9. Histograms of daily 1-hr O_3 maxima at the 54 CAMS in the HGB Region, segregated by those days when at least 50 parcels were present < 1.5 km altitude over Houston starting in the lowest 1.5 km over each of the listed source areas. The "Other Source" curve shows the distribution on days when < 50 parcels were present from all source areas listed. Air from the Texas, Gulf Coast, Southeast, and Ohio River regions result in distributions with higher O_3. The Gulf Coast data in Aug. – Sept. 2010 show the highest fraction of elevated O_3 concentrations.

Conclusions

- OMI satellite data, TCEQ surface monitors in Houston, and Houston ozonesondes show no conclusive evidence of air quality impacts from the Deepwater Horizon accident.
- Ozonesonde data show higher O_3 from the South (Spring) and East (Summer) in 2010 than previous years; in general, East, North, and Calm winds result in the highest BL O_3 in Houston
- Transported FT O_3 > EPA 8-hr O_3 standard is found on 16% of ozonesonde profiles. This rate increases to 44% under the strictest new possible standard.
- Trajectory studies suggest continental transport of BL air results in +20 – 30 ppb O_3 in Houston.

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