Recent Findings on Ozone and Precursors in the Houston-Galveston-Brazoria Area

Data and Trend Analysis Supporting the 2010 HGB Eight-Hour Ozone State Implementation Plan

Kasey Savanich, David Westenbarger,

Fernando Mercado, John Jolly, Jonathan Steets,

Mark Estes, and Zhaohua Fang

CEO/Air Quality Division

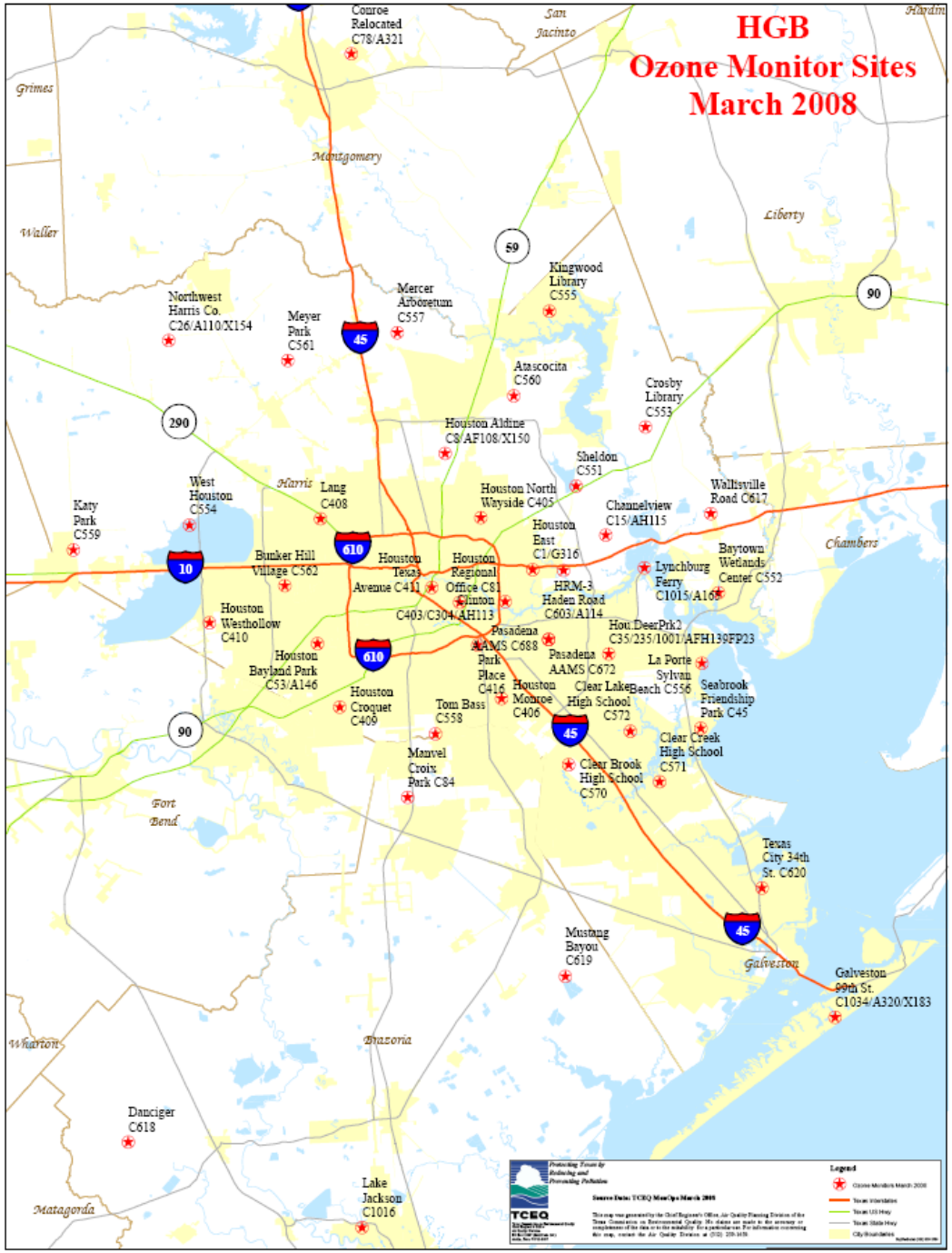
PURPOSE

- The following slides present recent TCEQ findings on temporal and spatial trends in ozone and precursors in the Houston-Galveston-Brazoria area, currently classified as a severe eight-hour ozone non-attainment area.
- These findings support the 2010 HGB 8-hour ozone State Implementation Plan, providing further evidence, in addition to photochemical modeling, that the HGB area is on pace to attain Federal ozone NAAQS by the 2018 attainment date.
- This evidence is officially referred to as “Weight of Evidence” in the SIP (Chapter 5) available here: www.tceq.state.tx.us/implementation/air/sip/hgb.html.

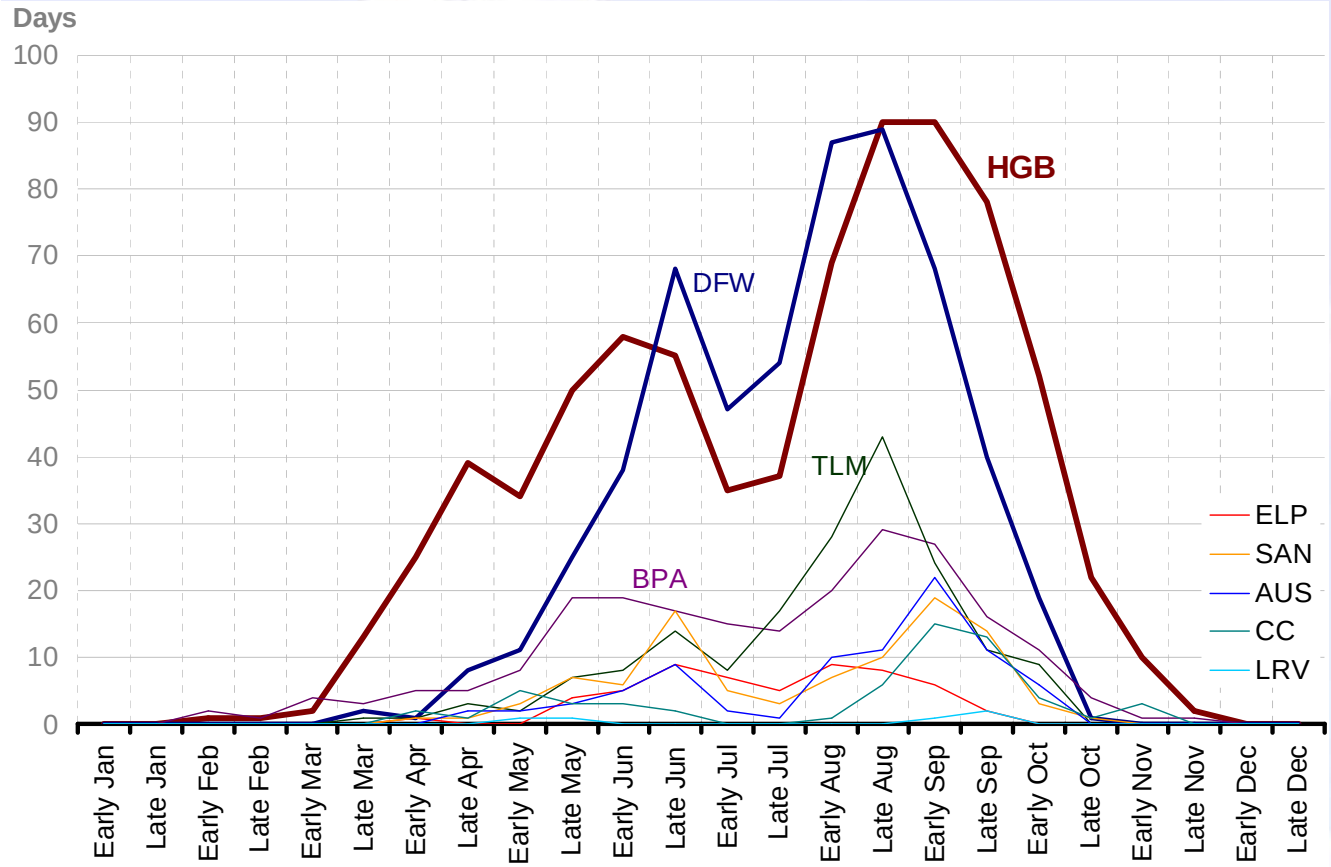
OUTLINE

- Trends in Ozone
- Trends in Ozone Precursors
  - Nitrogen Oxides (NO_X)
  - Volatile Organic Compounds (VOC)
- Analysis of Meteorology and Transport
- Analysis of Background Ozone

MONITOR LOCATIONS in HGB



OZONE SEASONS in TEXAS – EXCEEDANCE DAYS (1991-2008)



The number of days that ozone exceeds the NAAQS peaks in early June, followed by a higher, longer peak in late August and early September.

July tends to observe fewer exceedance days compared to the two peaks.

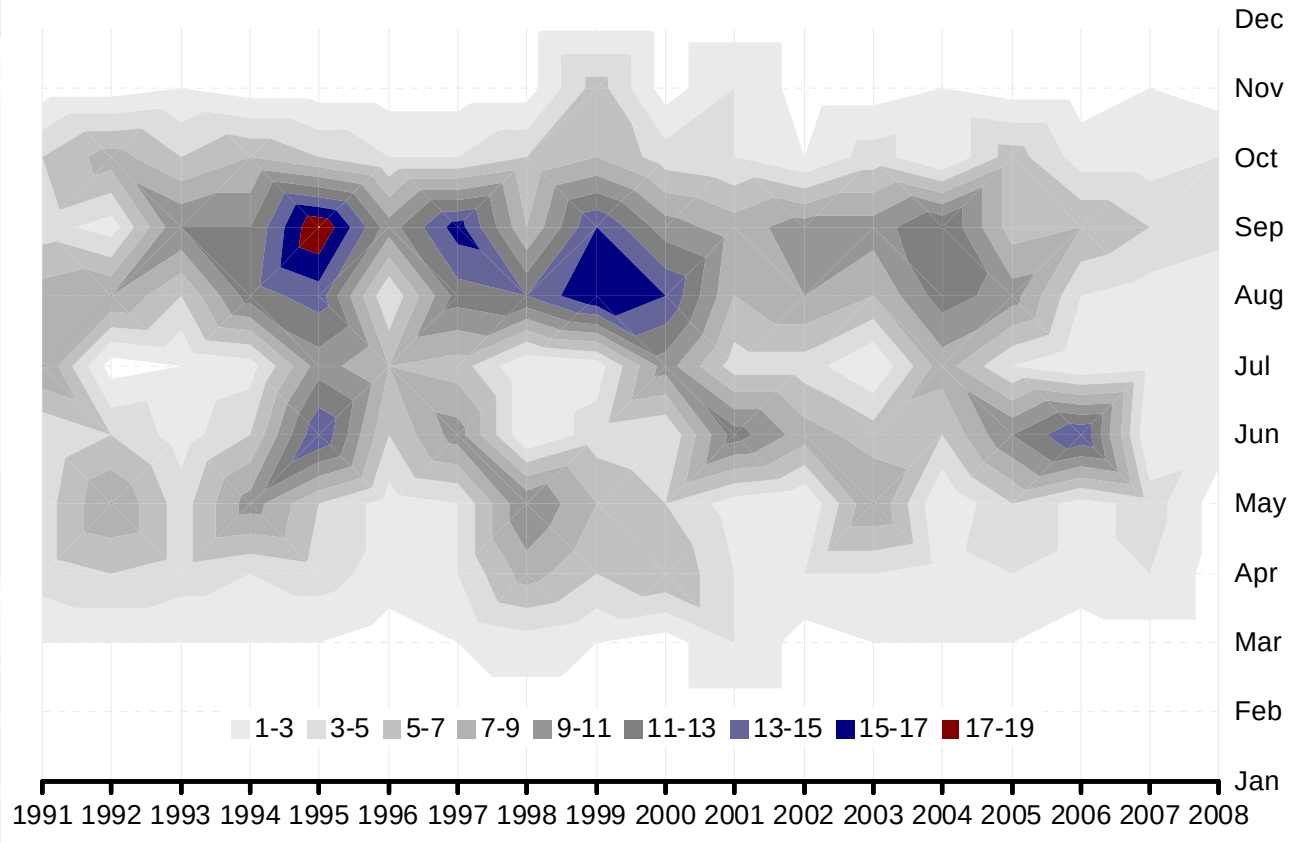
Other areas follow similar patterns, but with fewer exceedances.

OZONE SEASON in HGB

The number of days that ozone exceeds the NAAQS peaks in early June, followed by a higher, longer peak in late August and early September.

Before 2000, the ozone season exhibited many exceedance days and lasted most of the year.

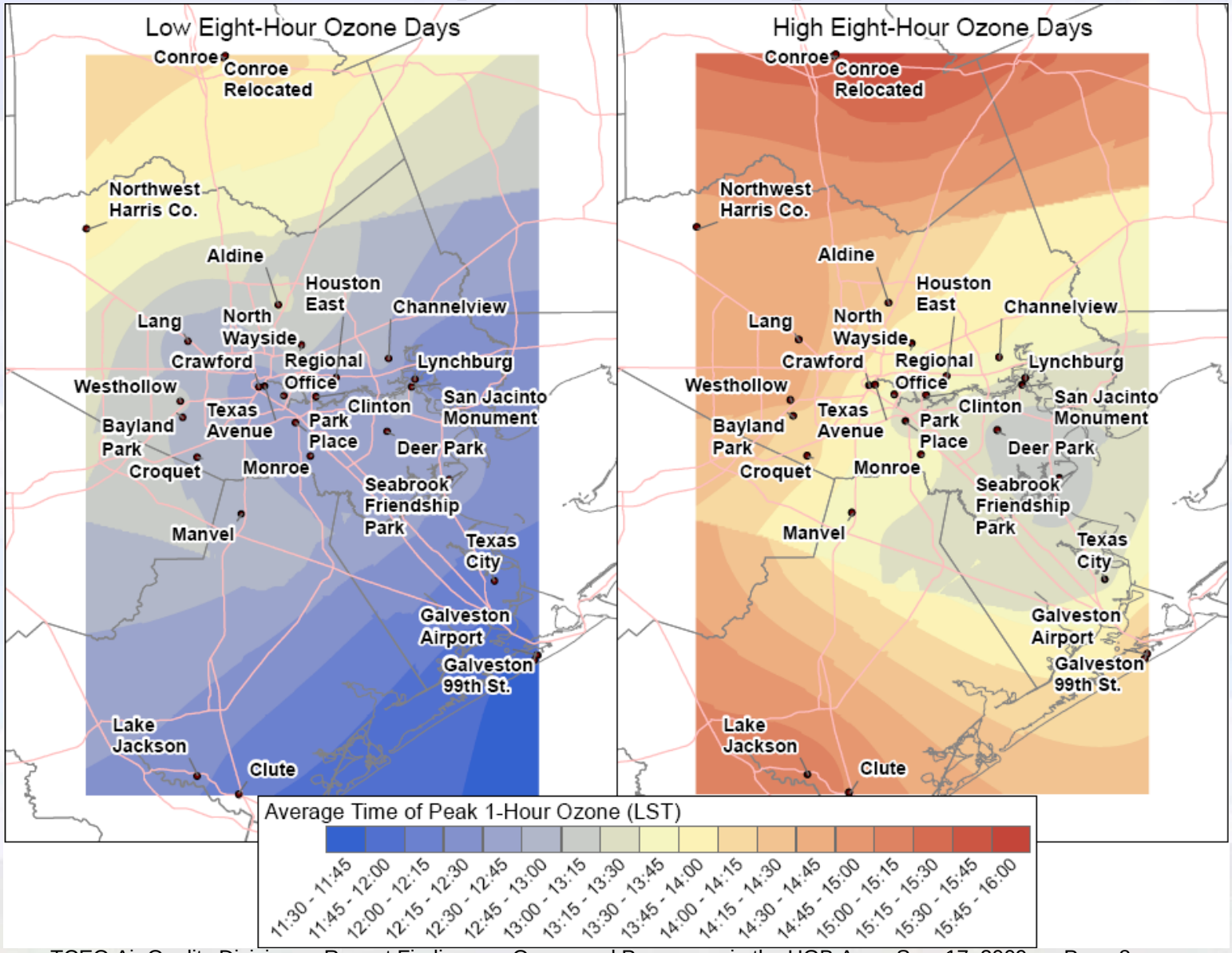
Recently, the ozone season exhibits far fewer exceedances, especially in the peak months



TIME of DAY of PEAK OZONE

- The time of day when ozone peaks at different locations suggests when and where ozone forms. Knowing when and where ozone forms informs our understanding of how and why it forms.
- On **LOW** ozone days: Monitors near the coast peak early, while inland monitors peak successively later and further north, indicating sea/bay breezes dominate.
- On **HIGH** ozone days: Peaks occur later, first in the Houston Ship Channel, later over downtown, west, and northwest, indicating high ozone is formed in the Houston Ship Channel, then transported to other areas of the city.

AVERAGE TIME of PEAK OZONE (1998-2008)



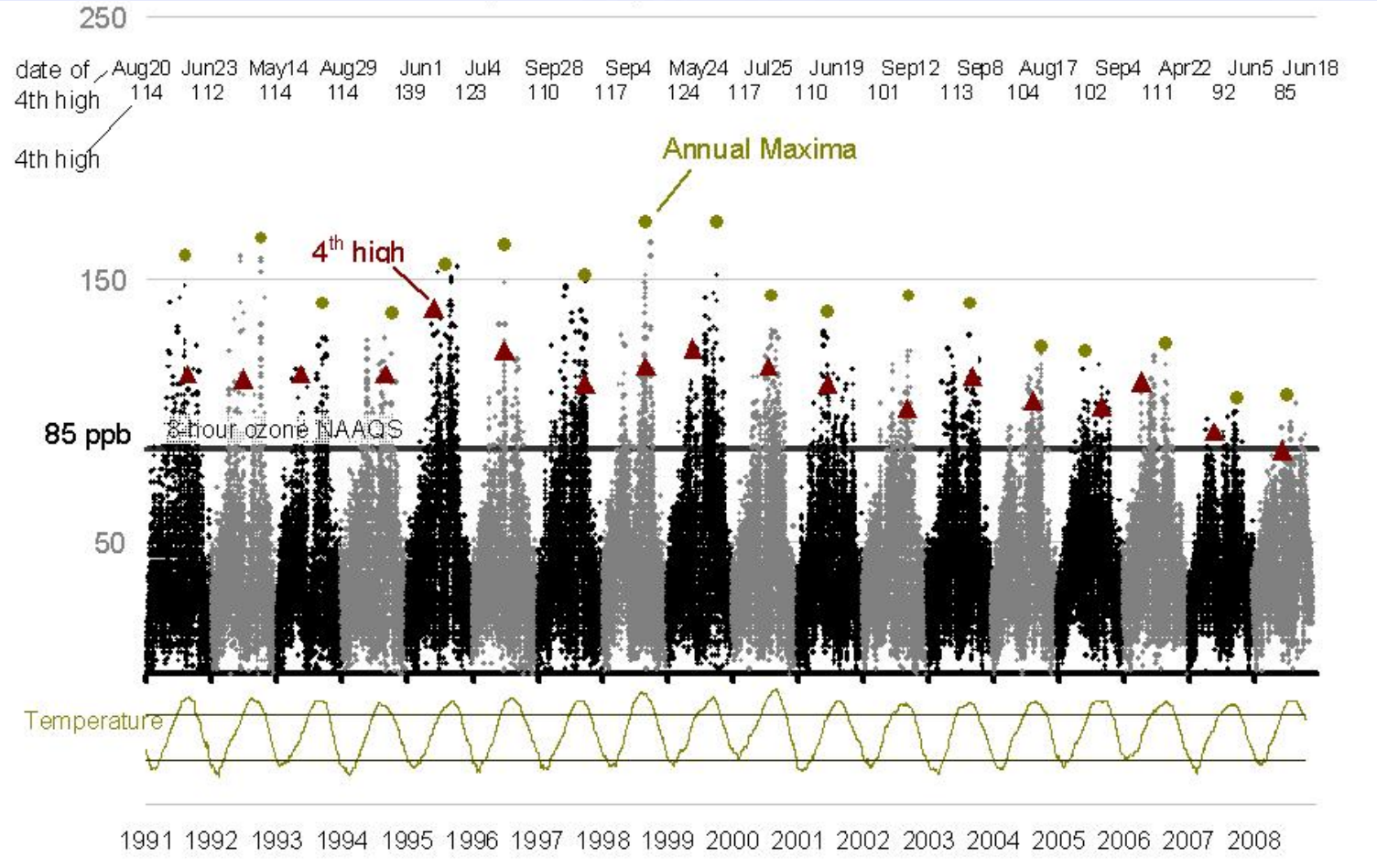
OZONE TRENDS

- Daily peak ozone. First, we look at all the daily peak data.
- Design Values. Next, we inspect DVs, which are used to compare monitored ozone to the National Ambient Air Quality Standards (NAAQS).
  - A DV is computed as the 3-year average of the 4th highest daily maximum 8-hour averaged ozone.
  - A DV is computed for each monitor.
  - The maximum from all monitors represents the area's design value.
- Exceedance days. An "exceedance day" is any day that measures an ozone concentration above the NAAQS (0.08 ppm). Trends in exceedance days provide additional insight.
- Transient High Ozone Events. Finally, we examine these rapid increases in ozone to identify causes.

DAILY PEAK EIGHT-HOUR OZONE

- The next slide plots daily peak ozone concentrations from all monitors in the HGB area for 1991-2008.
- This plot shows the seasonal cycle of ozone formation, which occurs year-round, but peaks during warmer and sunnier summer months.
- Annual maxima and fourth high values are noted.
- Though there is considerable variability, a clear downward trend since about 1999 is evident.
- Downward trends in maximum and fourth highest ozone concentrations are also apparent.

DAILY PEAK EIGHT-HOUR OZONE

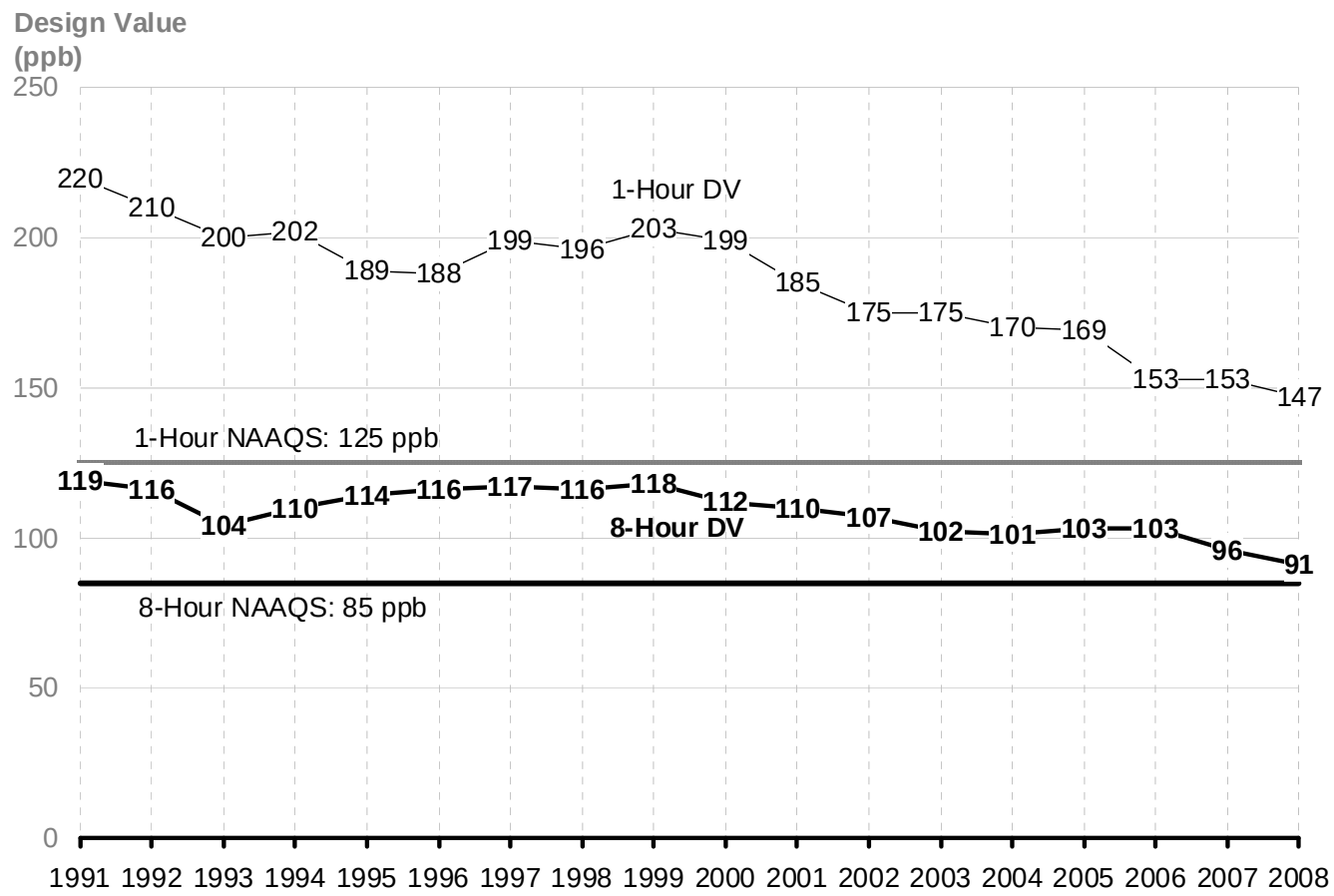


All HGB area monitors.

Note annual cycle, with highest values in summer.

Both max and 4th highs have been steadily dropping since 1999.

OZONE DESIGN VALUES



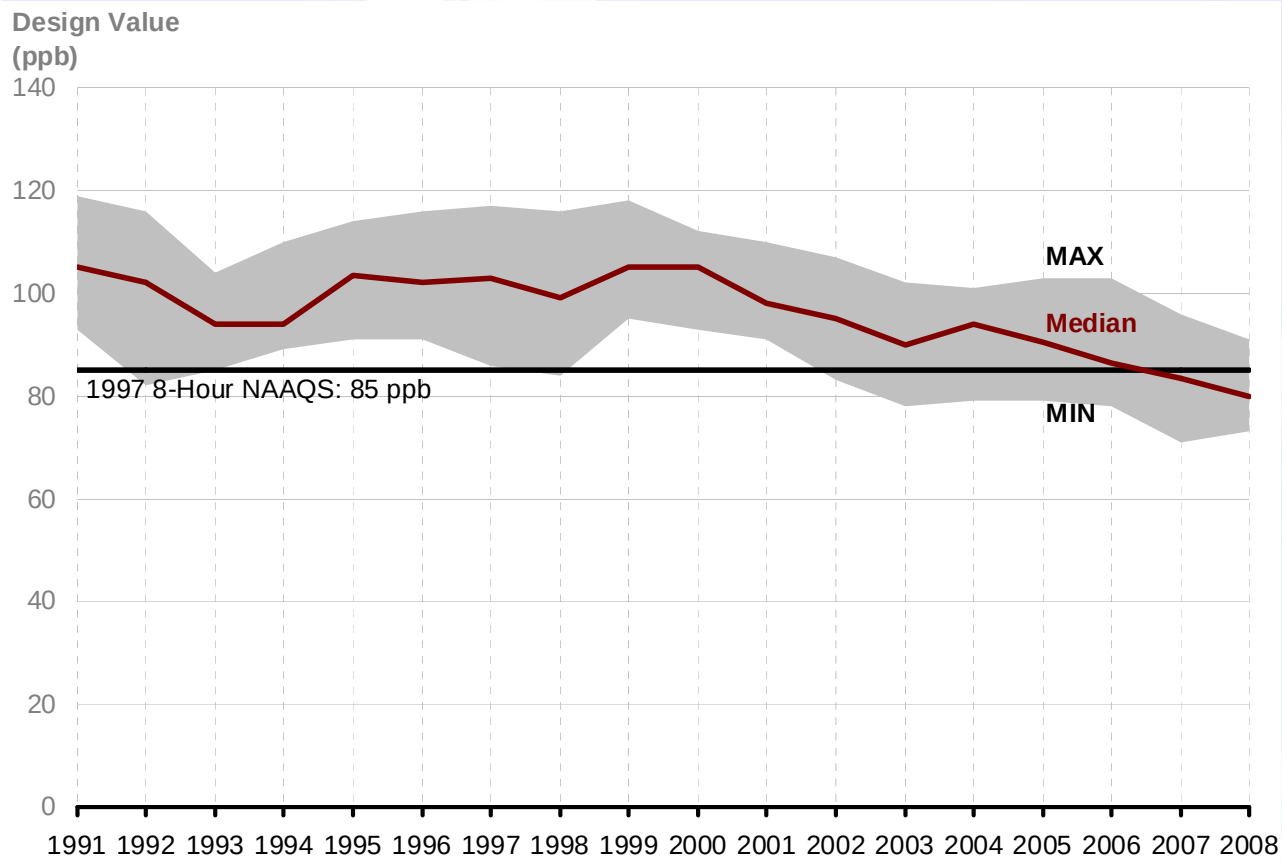
Both one-hour and eight-hour DVs are decreasing, with these decreases being more pronounced since 1999.

Decrease since:	1991	1999
…in the one-hour DV	-33%	-28%
…in the eight-hour DV	-24%	-23%

OZONE DESIGN VALUES

- While the maximum design value in an area is important from a regulatory viewpoint, we are also interested in whether decreases are occuring at only a few monitors, or at all monitors, indicating a region-wide phenomenon.
- Trends in the distribution of design values, e.g., maxima, medians, and minima, summarize the behavior of all monitors in the region over time.
- This is useful for measuring progress, provides a range for design values in the area, and helps identify anomalies.

EIGHT-HOUR OZONE DESIGN VALUES



Maximum, median, and minimum design values are all decreasing since 1999.

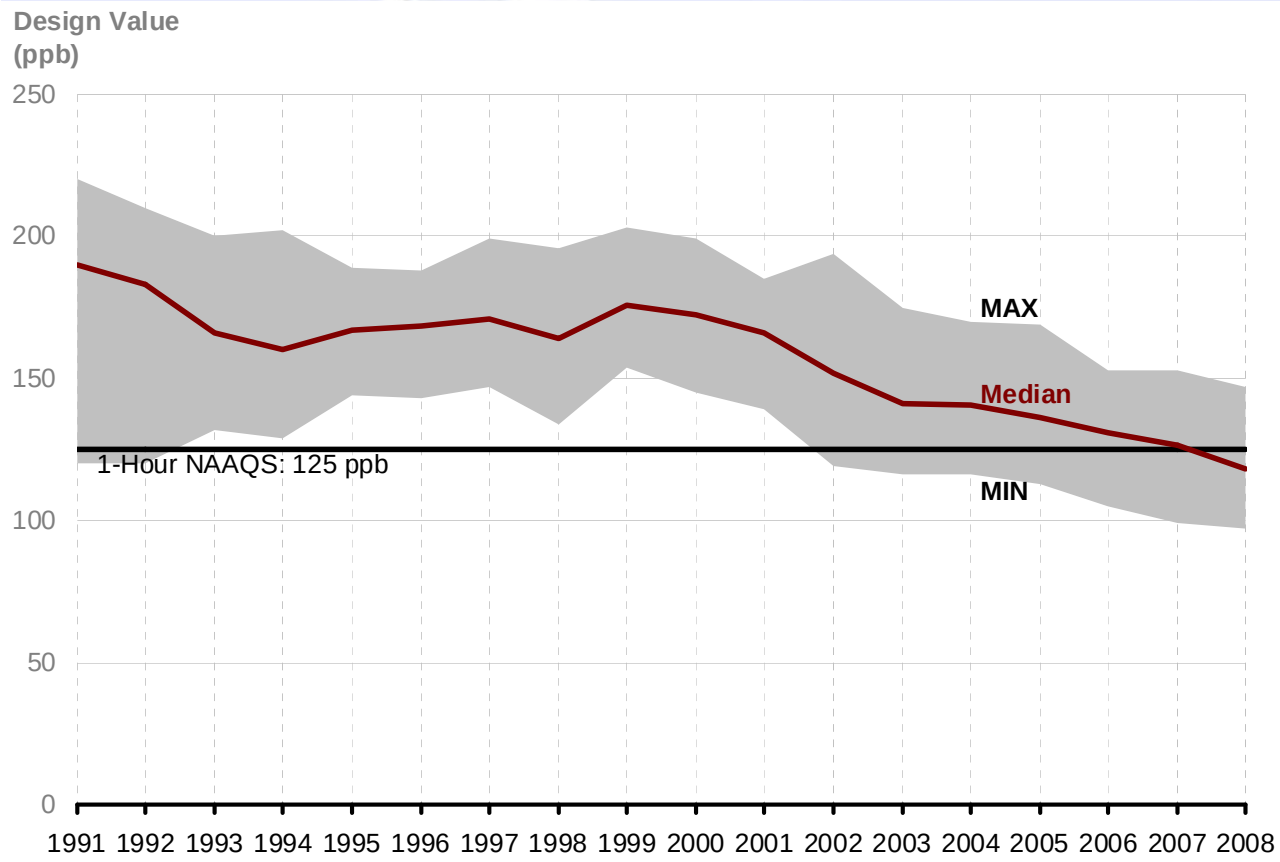
As of 2007, the median design value is below the NAAQS, indicating over half the monitors attain the standard.

By contrast, note that as recent as 2002, none of the monitors was below the NAAQS.

EIGHT-HOUR OZONE DESIGN VALUES

Monitor/CAMS #	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Houston Bayland Park C53										111	110	100	102	101	103	103	96	91
Houston Westhollow C410						95	101	95	102	102	104	95	87	87	89	96	92	89
Park Place C416																		89
Houston Deer Park 2 C35/139									108	112	108	103	102	101	100	96	93	87
Manvel Croix Park C84													91	97	97	96	91	85
Northwest Harris Co. C26	98	101	100	110	113	110	106	106	109	108	105	101	100	94	93	91	91	85
Houston Aldine C8/C108/C150	119	116	104	102	103	114	116	116	108	111	108	107	100	95	92	88	84	83
Houston Monroe C406	105	102	96	93	97	102	109	112	113	106	93	90	90	95	97	99	91	81
Houston Croquet C409	117	112	103	96	104	104	117	115	118	110	104	102	99	99	98	94	87	80
Conroe Relocated C78														85	86	85	84	80
Channelview C15/C115													87	90	89	85	83	80
Houston East C1	104	103	88				86	108	106	102	103	101	100	95	87	83	78	80
Seabrook Friendship Park C45													85	94	92	90	86	79
Houston Texas Avenue C411													88	89	88	84	78	76
Lang C408	105	103	93	95	98	99	100	96	96	96	91	83	78	79	79	80	77	76
Lake Jackson C1016															79	79	76	76
Houston North Wayside C405	114	102	94	91	91	91	96	99	104	105	98	89	86	85	82	78	76	75
Lynchburg Ferry C1015															96	89	82	74
Houston Regional Office C81												95	94	88	88	84	81	74
Clinton C403/C113/C304	115	109	100	100	106	106	107	100	103	101	97	93	96	96	95	85	79	73
Galveston Airport C34/C109/C154								90	112	108	98	89	89	91	87	83	71	
Clute C11		96	93	91	96	92	92	84	95	93	91	86	87					
Texas City C10	93	82	90	89	114	102	105	91	100	98	91	83	80					
Conroe C65											91							
Houston Crawford C407	105	98	89	89	95	91	97	96	100	100								
Houston Manchester C22	103	104	104	103	106	102	103											
Houston Deer Park C18	107	96	85	89	107	116												

One-Hour Ozone Design Values at All Monitors



Similar to eight-hour, one-hour ozone design values exhibit decreases in maxima, medians, and minima since about 1999.

As of 2007, the median one-hour ozone design value is below the NAAQS, indicating over half the monitors attain the one-hour standard (0.12 ppm).

As with eight-hour ozone, prior to 2002, few, if any, monitors in the HGB area were below the one-hour ozone NAAQS.

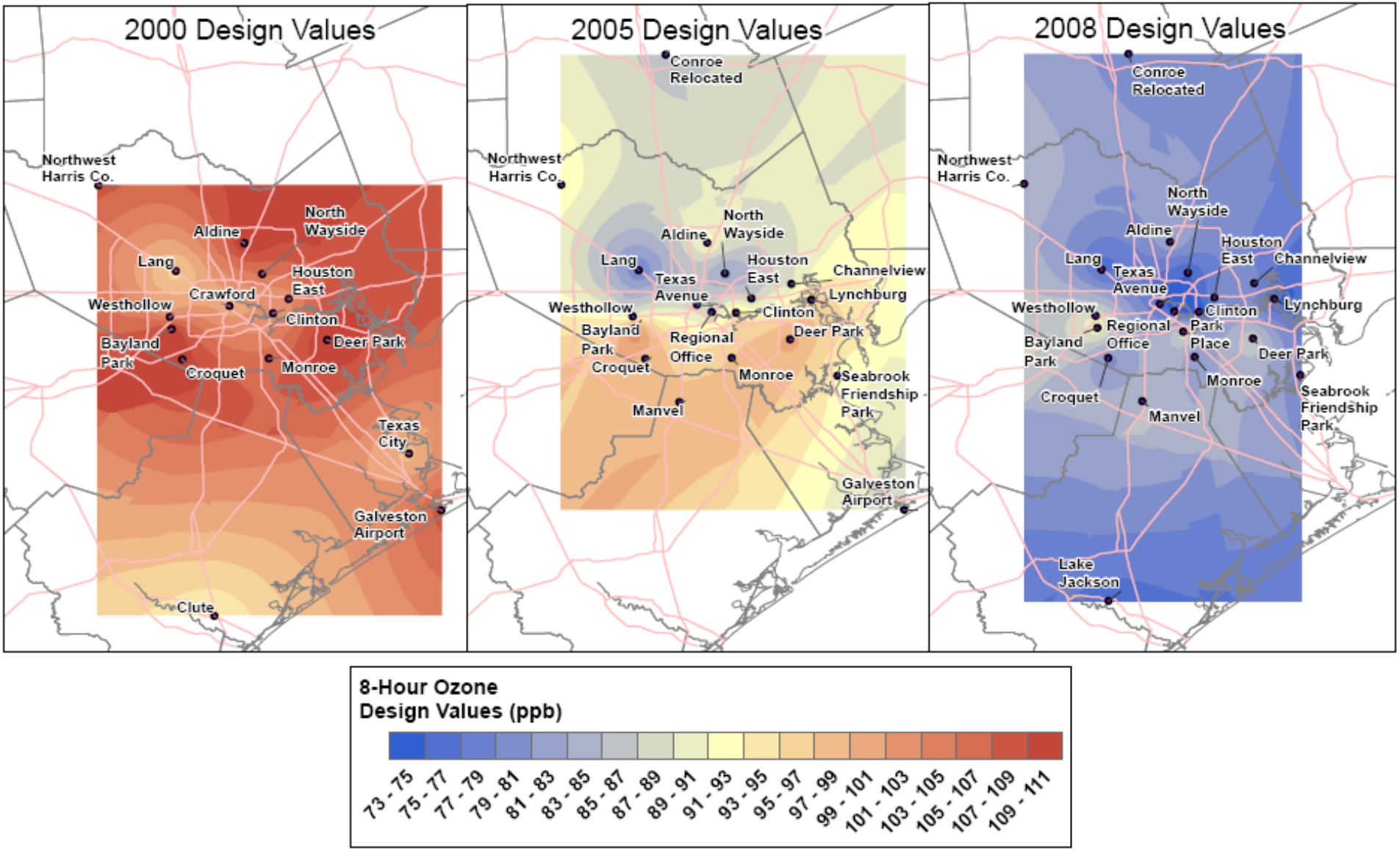
One-Hour Ozone Design Values

Monitor/CAMS #	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Houston Deer Park 2 C35/139							147	164	203	185	182	168	161	157	153	150	150	147
Houston Bayland Park C53									189	185	173	154	163	148	148	143	142	139
Park Place C416																	136	132
Manvel Croix Park C84												143	132	142	134	138	128	128
Houston Westhollow C410					164	155	164	155	165	150	150	141	141	128	126	131	127	126
Northwest Harris Co. C26	160	160	166	173	172	172	165	164	163	161	157	154	156	148	131	127	127	126
Houston Aldine C8/C108/C150	220	190	197	197	189	173	189	187	187	180	166	166	143	136	139	125	122	122
Channelview C15/C115												154	141	140	135	134	128	120
Seabrook Friendship Park C45												132	135	135	153	153	153	119
Houston Regional Office C81											185	178	175	170	169	135	131	119
Houston East C1	210	200	200	202		177	182	182	198	180	180	171	171	165	154	137	119	119
Lynchburg Ferry C1015														157	157	152	149	117
Houston Monroe C406	170	170	155	147	154	161	174	196	196	170	143	151	141	141	131	133	131	117
Houston Croquet C409	200	200	178	152	167	167	168	168	167	167	160	157	150	141	136	131	126	117
Conroe Relocated C78												119	137	128	128	128	124	116
Galveston 99th St. C1034																	115	115
Clinton C403/C113/C304	210	210	176	158	173	173	173	161	183	199	176	157	175	158	158	124	121	111
Houston Texas Avenue C411												146	172	157	157	127	110	110
Lang C408	200	183	158	159	159	159	158	155	155	175	175	149	128	128	127	126	108	108
Houston North Wayside C405	210	190	173	173	155	143	155	158	189	190	168	153	131	138	138	118	100	102
Lake Jackson C1016														119	113	105	99	101
Galveston Airport C34/C109/C154							170	170	176	168	164	133	123	129	129	117	103	97
Texas City C10	150	150	163	163	184	182	182	146	175	172	139	121	116	116	124			
Clute C11	150	150	132	129	144	144	148	134	154	161	154	136	133	136				
Houston Crawford C407	220	190	165	165	165	166	172	172	164	173	173	194						
Conroe C65										145	145	140						
Houston Manchester C22	190	190	180	160	172	170	175	173	176									
Houston Deer Park C18	160	160	150	157	188	188	199	163										
Rosenberg C88	150	150																
Hempstead C89	120	120																

SPATIAL TRENDS in EIGHT-HOUR OZONE DESIGN VALUES

- Examination of where high ozone occurs lends insight into how it is formed.
- Eight-hour ozone design values are highest at Deer Park and Bayland Park Monitors.
- Design values are the lowest near Lang, North Wayside, and Lake Jackson.
- The location of the peak design values does not appear to be changing over time; however, the levels of ozone have clearly decreased throughout the entire HGB area.

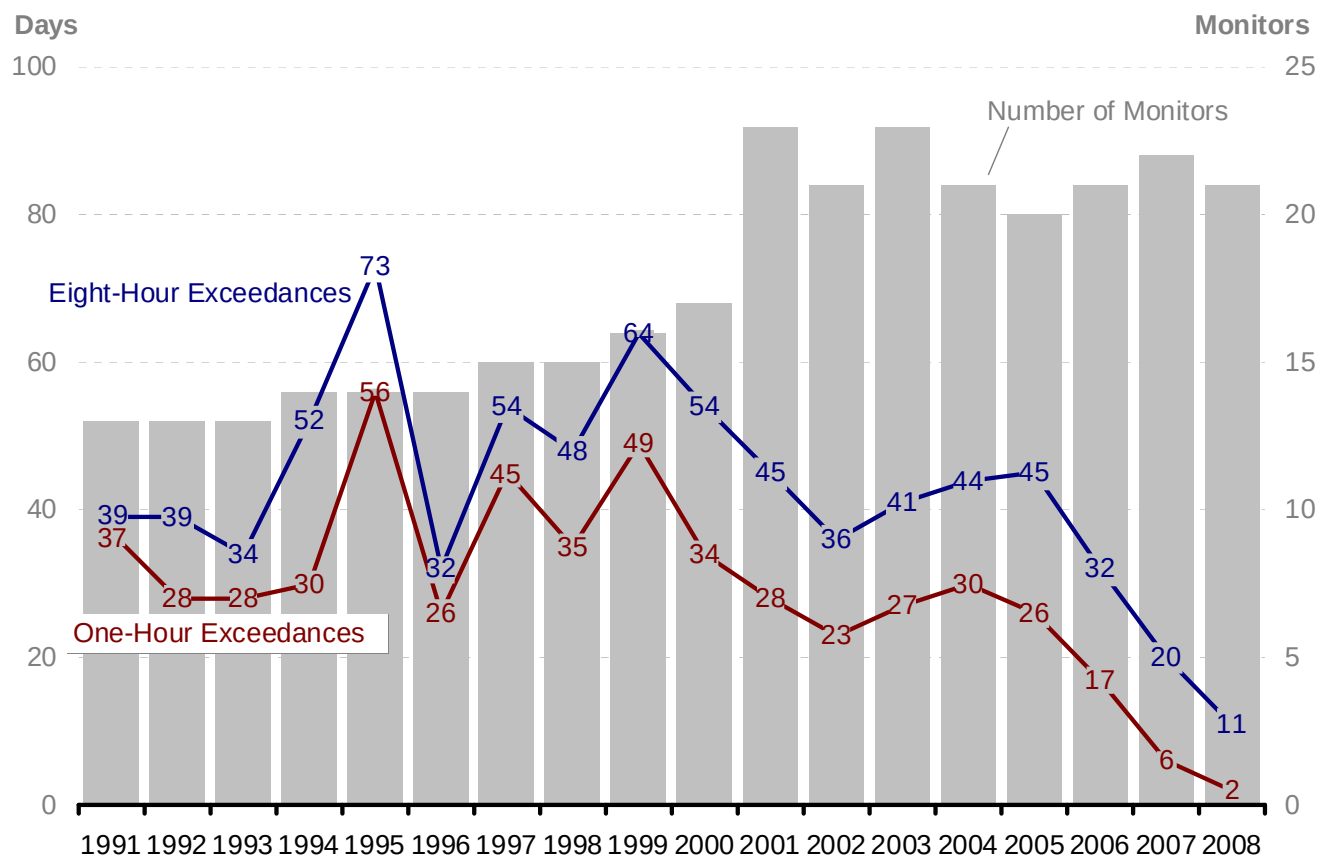
SPATIAL TRENDS in EIGHT-HOUR OZONE DESIGN VALUES



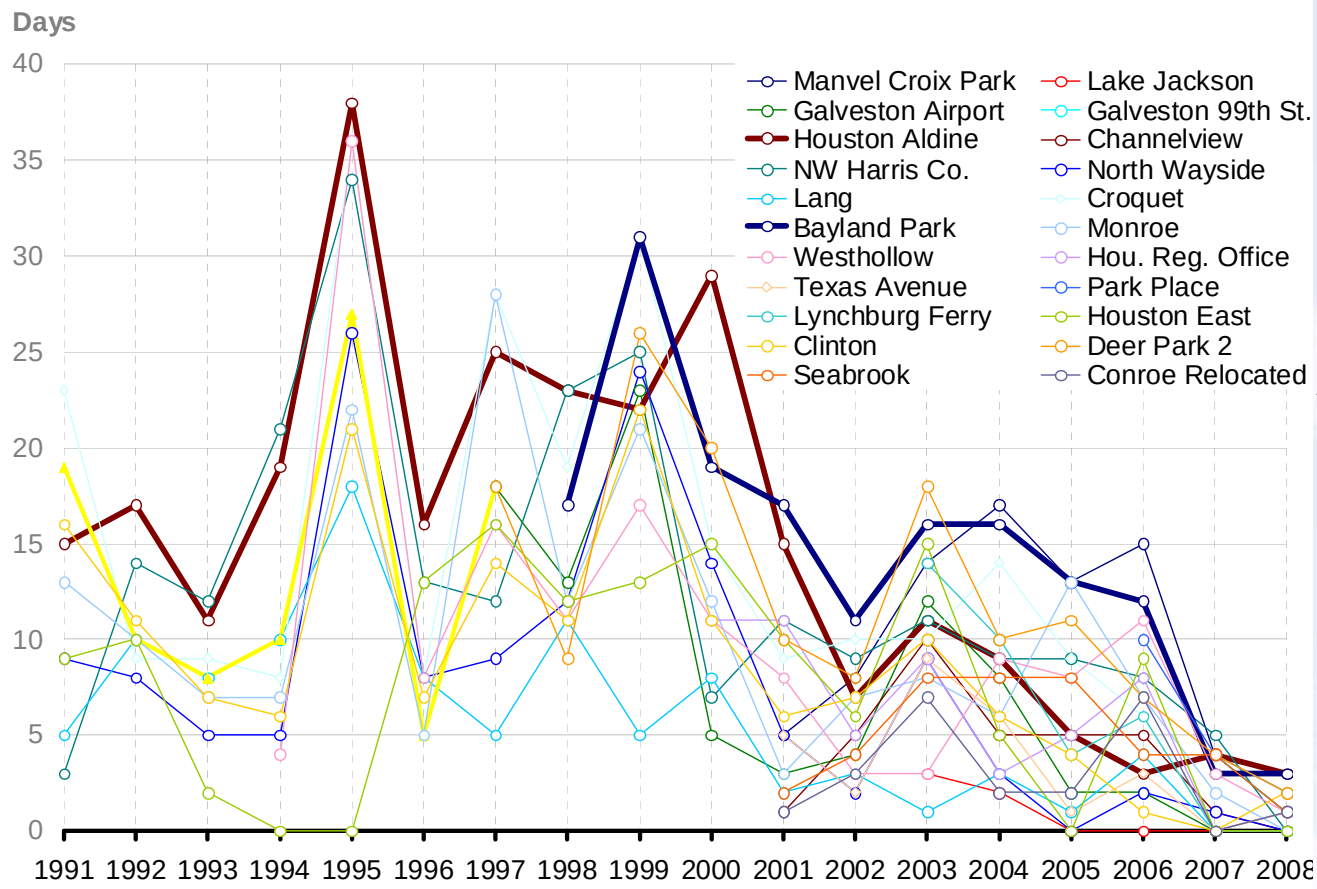
OZONE EXCEEDANCE DAYS

While the number of exceedance days is not as reliable an indicator of air quality due to its correlation with the number of monitors in an area, it is useful as long as the number of monitors is taken into account.

Despite an increase in the number of monitors, the number of both eight-hour and one-hour exceedance days has decreased since 1999.



EIGHT-HOUR OZONE EXCEEDANCE DAYS by MONITOR



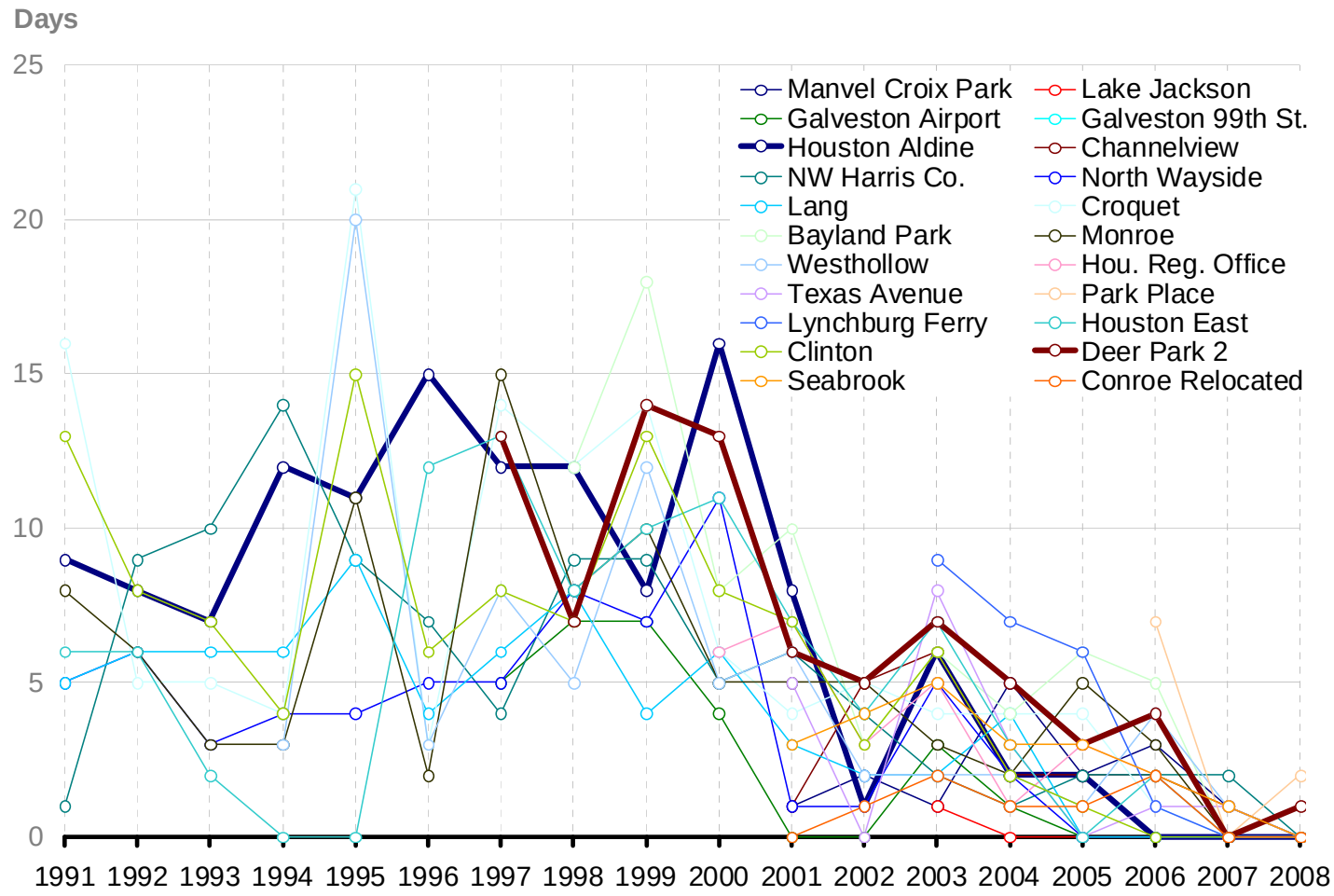
Looking at exceedance days by monitor removes the influence of the number of monitors on exceedance days.

Although it changes from monitor to monitor, the general trend in eight-hour ozone exceedance days is decreasing.

EIGHT-HOUR OZONE EXCEEDANCE DAYS

Monitor	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Bayland Park C53								17	31	19	17	11	16	16	13	12	3	3
Houston Aldine C8	15	17	11	19	38	16	25	23	22	29	15	7	11	9	5	3	4	3
Clinton C403/C113/C304	16	11	7	6	21	7	14	11	22	11	6	7	10	6	4	1	0	2
Deer Park 2 C35/139							18	9	26	20	10	8	18	10	11	7	4	2
Park Place C416																10	4	2
Lake Jackson C1016													3	2	0	0	0	1
Houston Croquet C409	23	9	9	8	36	8	28	19	31	15	9	10	10	14	9	6	0	1
Conroe Relocated C78											1	3	7	2	2	7	0	1
Houston Westhollow C410				4	36	8	16	11	17	11	8	3	3	9	8	11	3	1
Seabrook Friendship Park C45											2	4	8	8	8	4	4	1
Manvel Croix Park C84											5	8	14	17	13	15	4	1
Galveston 99th St. C1034																	4	1
Houston Texas Avenue C411											5	2	9	6	1	3	0	0
Lang C408	5	10	8	10	18	8	5	11	5	8	2	3	1	3	1	4	0	0
Lynchburg Ferry C1015													14	10	4	6	0	0
Houston Regional Office C81										11	11	5	9	3	5	8	0	0
Houston East C1	9	10	2	0	0	13	16	12	13	15	10	6	15	5	0	9	0	0
Houston North Wayside C405	9	8	5	5	26	8	9	12	24	14	5	2	9	3	0	2	1	0
Channelview C15/C115											1	5	10	5	5	5	1	0
Houston Monroe C406	13	10	7	7	22	5	28	12	21	12	3	7	8	6	13	7	2	0
Northwest Harris Co. C26	3	14	12	21	34	13	12	23	25	7	11	9	11	9	9	8	5	0
Galveston Airport C34/C109/C154							18	13	23	5	3	4	12	8	2	2	0	
Clute C11	8	10	6	5	15	3	4	5	9	2	3	6	3					
Texas City C10	6	1	9	7	25	1	10	10	11	6	1	3	3	0				
Manchester	19	10	8	10	27	5	18											
Deer Park C18	8	4	3	18	27	12												
Crawford	5	6	7	4	15	3	16	10	11	8	0							
San Jacinto Monument											0	5	1					
Conroe C65									4	17	6							
Number of Monitors in Operation	13	13	13	14	14	14	15	15	16	17	23	21	23	21	20	21	22	21

ONE-HOUR OZONE EXCEEDANCE DAYS by MONITOR



Similar to eight-hour ozone exceedance days, the general trend in one-hour ozone exceedance days is decreasing.

ONE-HOUR OZONE EXCEEDANCE DAYS

Monitor	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Park Place C416																7	0	2
Deer Park 2 C35/139							13	7	14	13	6	5	7	5	3	4	0	1
Northwest Harris Co. C26	1	9	10	14	9	7	4	9	9	5	6	4	2	1	2	2	2	0
Houston Westhollow C410				3	20	3	8	5	12	5	6	2	2	2	1	4	1	0
Manvel Croix Park C84											1	2	1	5	2	3	1	0
Seabrook Friendship Park C45											3	4	5	3	3	2	1	0
Channelview C15/C115											1	5	6	2	2	2	1	0
Houston Texas Avenue C411											5	0	8	3	0	1	1	0
Bayland Park C53								12	18	8	10	3	6	4	6	5	0	0
Houston Monroe C406	8	6	3	3	11	2	15	8	10	5	5	5	3	2	5	3	0	0
Houston Regional Office C81										6	7	3	5	1	3	2	0	0
Conroe Relocated C78											0	1	2	1	1	2	0	0
Houston East C1	6	6	2	0	0	12	13	8	10	11	7	4	7	3	0	2	0	0
Lynchburg Ferry C1015													9	7	6	1	0	0
Houston Croquet C409	16	5	5	4	21	3	14	12	14	6	4	5	4	4	4	1	0	0
Houston Aldine C8	9	8	7	12	11	15	12	12	8	16	8	1	6	2	2	0	0	0
Clinton C403/C113/C304	13	8	7	4	15	6	8	7	13	8	7	3	6	2	1	0	0	0
Lang C408	5	6	6	6	9	4	6	8	4	6	3	2	2	4	0	0	0	0
Houston North Wayside C405	5	6	3	4	4	5	5	8	7	11	1	1	5	2	0	0	0	0
Lake Jackson C1016													1	0	0	0	0	0
Galveston 99th St. C1034																	0	0
Galveston Airport C34/C109/C154							5	7	7	4	0	0	3	1	0	0	0	
Clute C11	3	3	2	0	6	1	3	1	4	2	0	2	1					
Texas City C10	4	1	7	2	14	0	3	3	7	3	0	0	1	0				
San Jacinto Monument											0	2	0					
Conroe C65									1	5	2							
Houston Crawford C407	5	4	5	3	9	4	11	12	5	8	0							
Manchester C1029	11	7	7	7	18	4	10											
Deer Park C18	6	2	1	6	18	4												
Number of Monitors in Operation	13	13	13	14	14	14	15	15	16	17	23	21	23	21	20	21	22	21

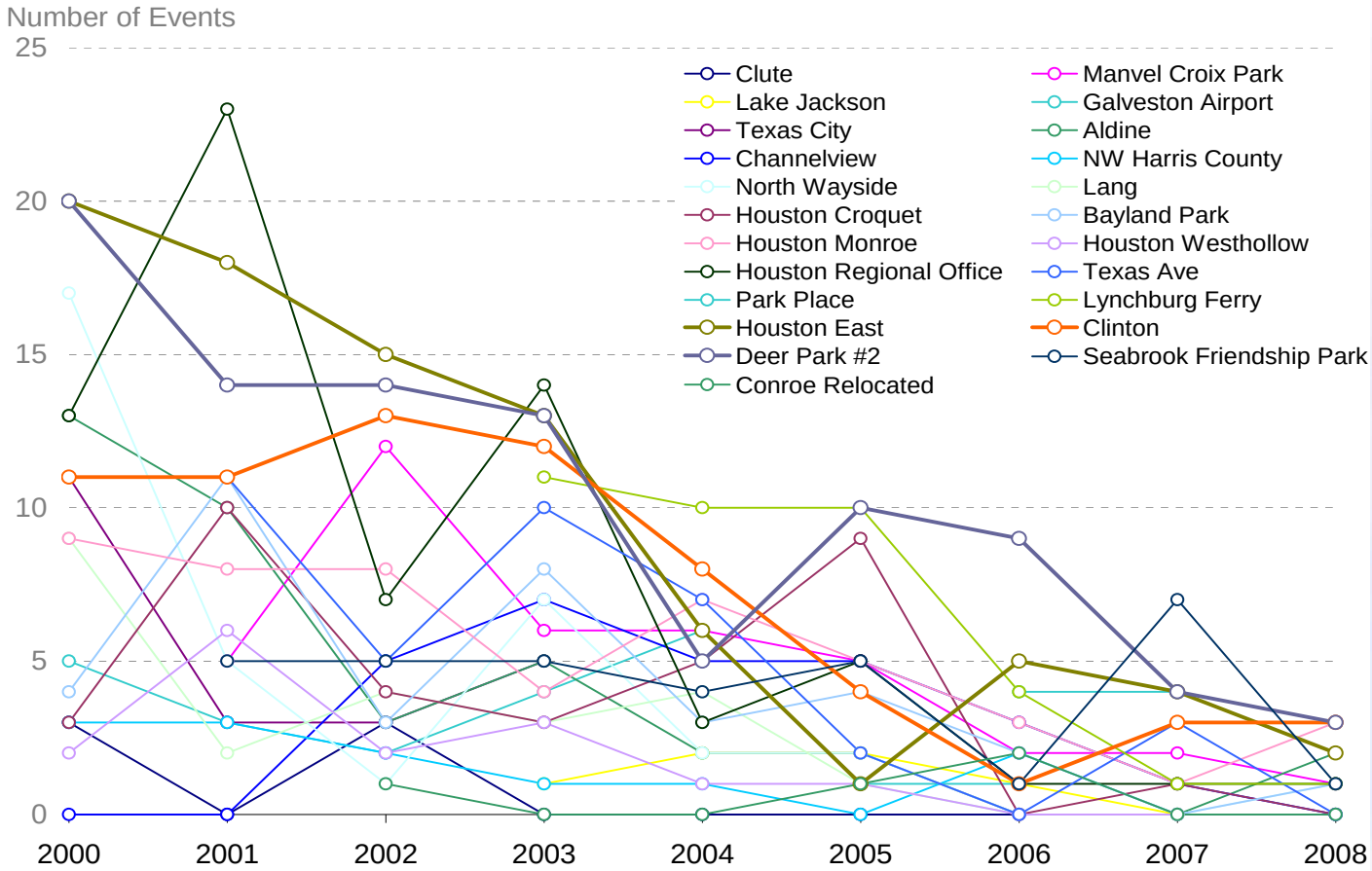
TRANSIENT HIGH OZONE EVENTS

A "THOE" is defined as an increase in one-hour ozone of **40 ppb or more in one hour**.

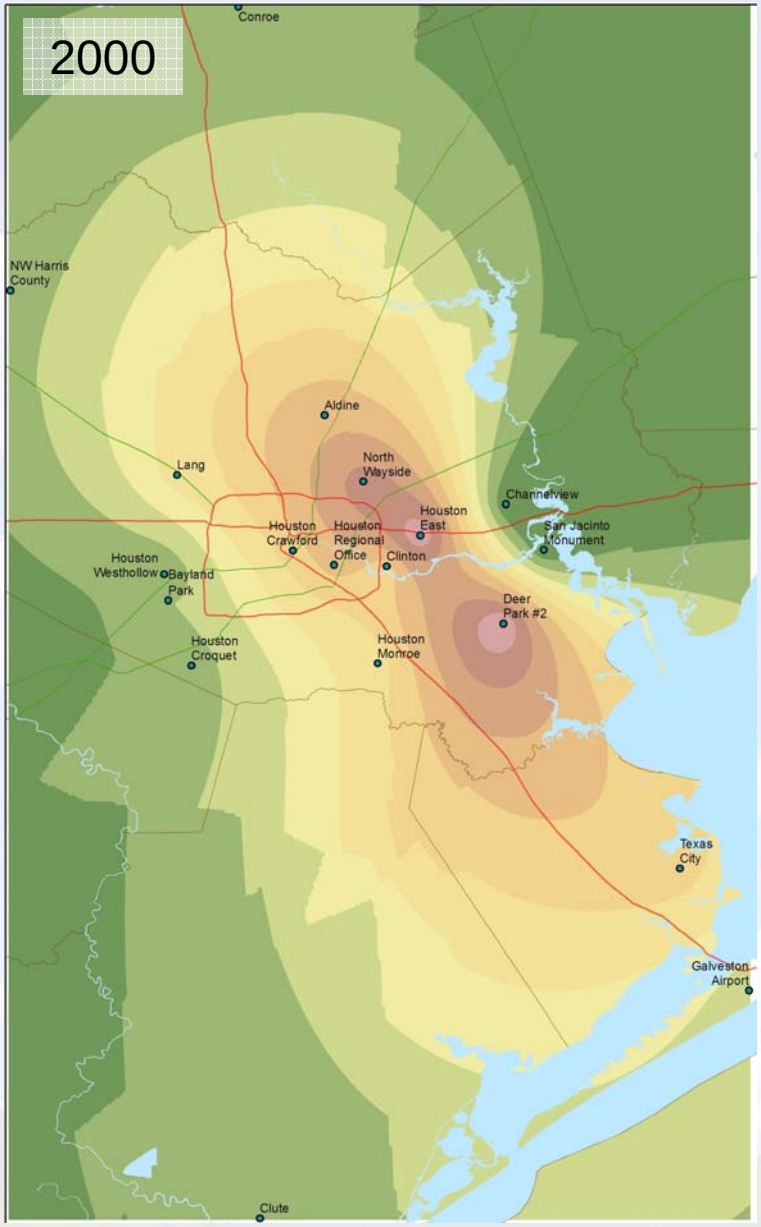
Multiple THOEs can occur in one day.

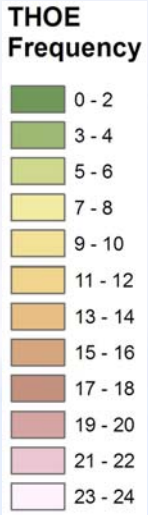
THOEs typically are observed in the more industrial areas of HGB.

The frequency of these events has decreased dramatically from 2000 to 2008.



TRANSIENT HIGH OZONE EVENTS





OZONE PRECURSOR TRENDS

- NO_X Trends
  - Daily Peak NO_X
  - Median NO_X
  - NO_X by Source Type
- VOC Trends
  - Total Non-Methane Hydrocarbon (TNMHC)
  - Highly Reactive VOC (HRVOC)
  - HRVOC by Wind Direction

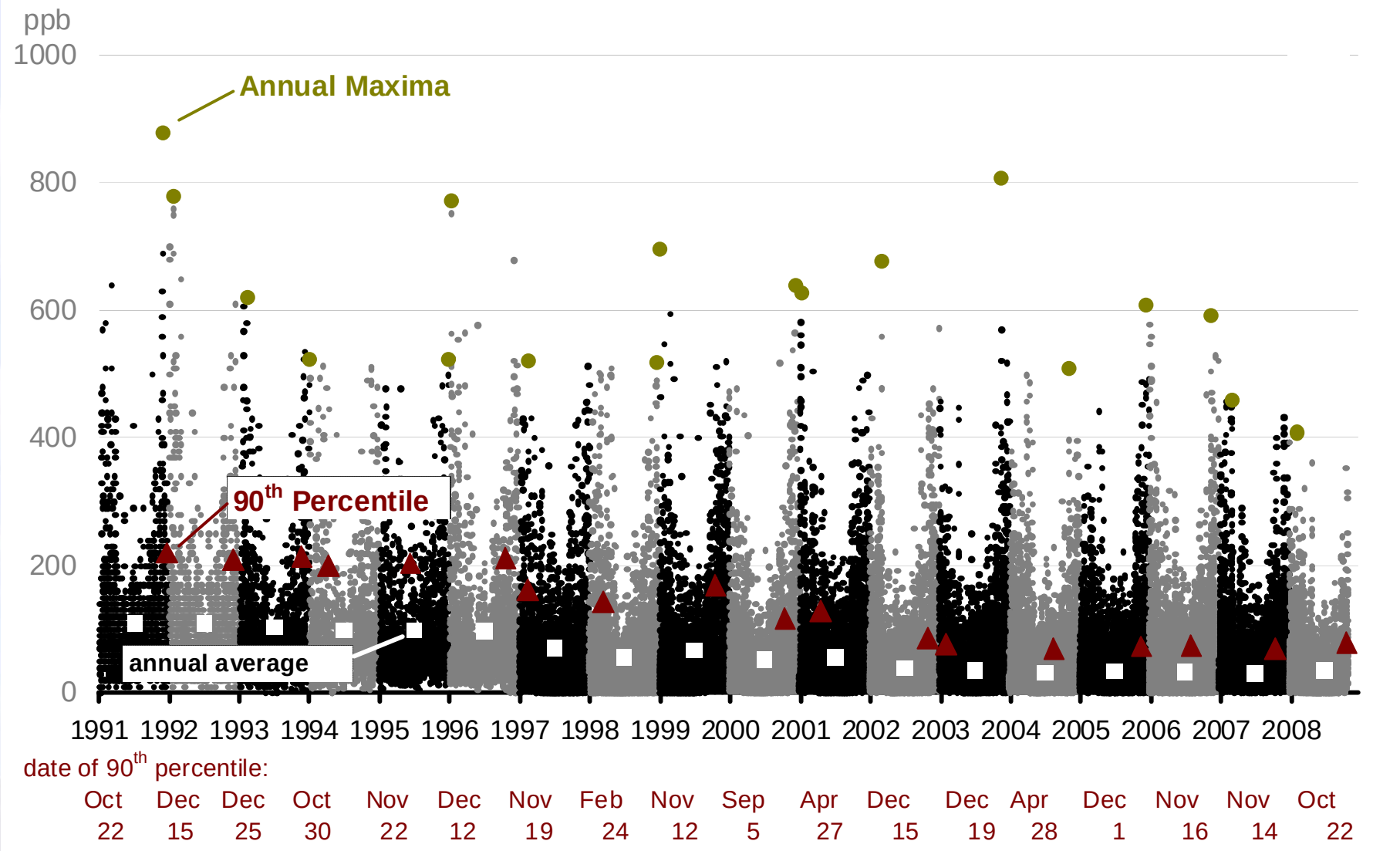
NO_X TRENDS

- NO_X is a combination of nitric oxide (NO) and nitrogen dioxide (NO_2).
- It is emitted by many combustion sources, some of which include:
  - Mobile sources (cars, trucks, ships, trains, heavy machinery, airplanes, etc…)
  - Fossil fuel-burning electric generating units
  - Industrial equipment (boilers, process heaters, duct burners, furnaces, etc…)
  - Diesel generators

DAILY PEAK NO_X

- The next slide plots daily peak NO_X concentrations for all monitors in the HGB area for 1991-2008.
- This plot shows the seasonal cycle of NO_X, which peaks during winter, but is abundant year-round. Annual maxima, 90th percentile and average values are noted.
- Though there is considerable variability, a clear downward trend since about 1999 is evident in the overall scatter plots, including the maxima and other higher values.
- The maximum, 90th percentile, and mean peak daily NO_X also show decreasing trends.

DAILY PEAK NO_X



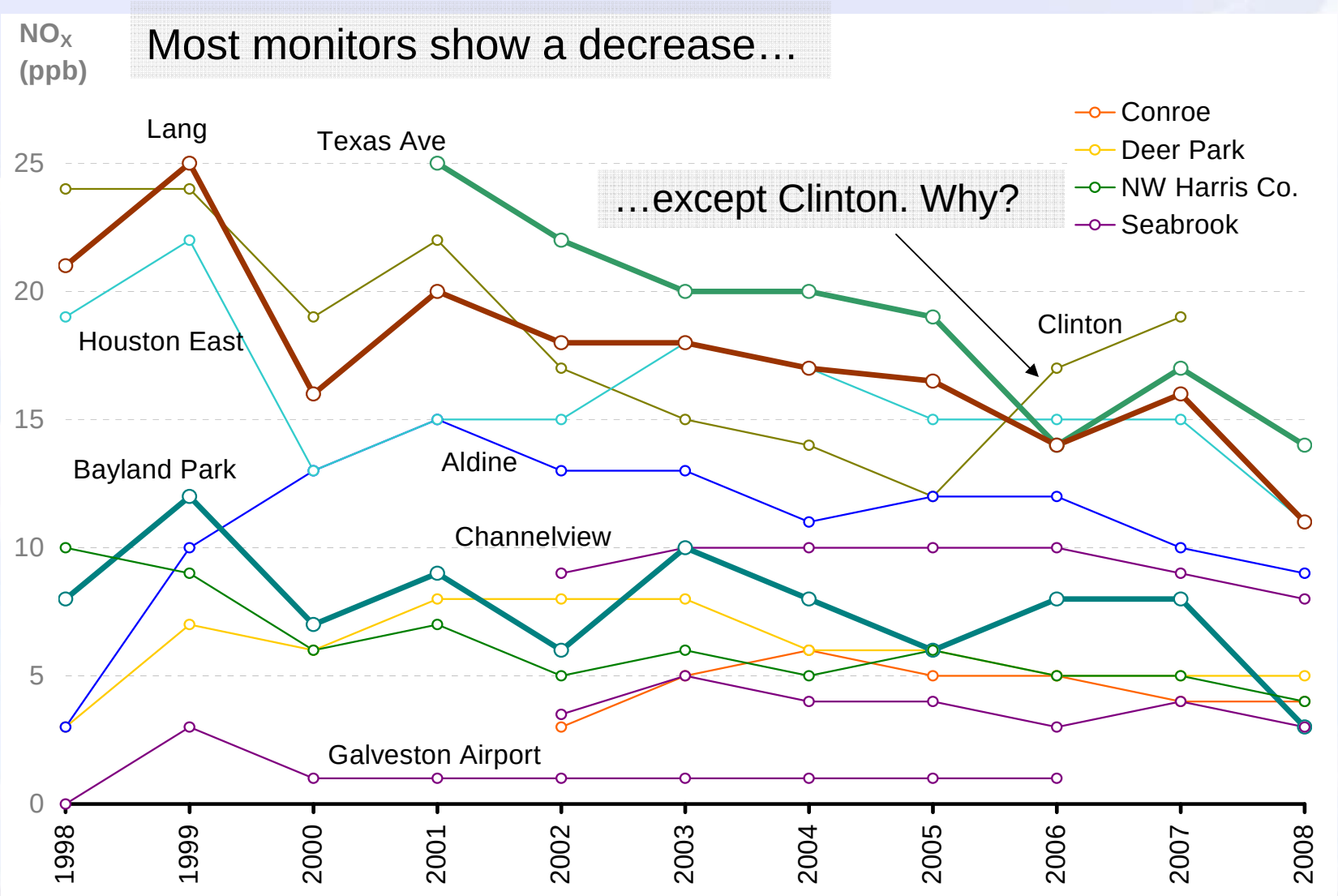
NO_X TRENDS

While NO_X has been decreasing over the last two decades, most of the decrease has occurred recently.

Decrease since:	1991	1999
…in the maximum	-54%	-41%
…in the average	-68%	-53%

	NO_X Concentrations	
	Annual Maximum	Annual Average
Year	NO_X *ppb*	NO_X *ppb*
1991	880	110
1992	780	110
1993	622	103
1994	523	99
1995	524	99
1996	773	98
1997	521	75
1998	520	67
1999	696	75
2000	641	57
2001	629	66
2002	678	52
2003	809	53
2004	509	49
2005	609	49
2006	593	49
2007	461	48
2008	509	35

MEDIAN NO_X CONCENTRATIONS



Trends are from May through October (peak ozone season)

ANNUAL AVERAGE PEAK NO_X TRENDS

- The following table shows annual average peak NO_X trends at selected monitors, along with the predominate type of NO_X source associated with each monitor.

- Statistically significant decreasing trends were observed at most monitors. The largest decreases were observed at monitors primarily located near mobile sources. Caution is warranted, however, as all monitors in HGB are influenced, to a greater or lesser degree, by both mobile and industrial sources.

- Channelview is the only monitor which shows an increase. The cause for this increase in still under investigation.

ANNUAL AVERAGE DAILY PEAK NO_X TRENDS

Trend* (ppb/yr)	Primary Source Type	Site Name	2002 Average Peak NO_X *ppb*	2007 Average Peak NO_X *ppb*
-3.1	Mobile	Texas Avenue	99	82
-2.6	Mobile	Lang	97	84
-2.4	Mobile	Bayland Park	63	53
-2.0	Mobile	Aldine	69	55
-1.9	Industry	Deer Park	41	32
-1.1	Other	Manvel Croix	34	30
-1.0	Other	Seabrook Friendship Park	25	21
-0.9	Other	Northwest Harris Co.	23	19
+2.3	Industry	Channelview	42	50

*Only statistically significant trends at the five percent level are displayed here. The trends are displayed in ascending order.

VOC TRENDS

- TNMHC

  We chose total non-methane hydrocarbons (TNMHC) to investigate trends in total VOC concentrations. The next slide shows all TNMHC measured in HGB since 1997.

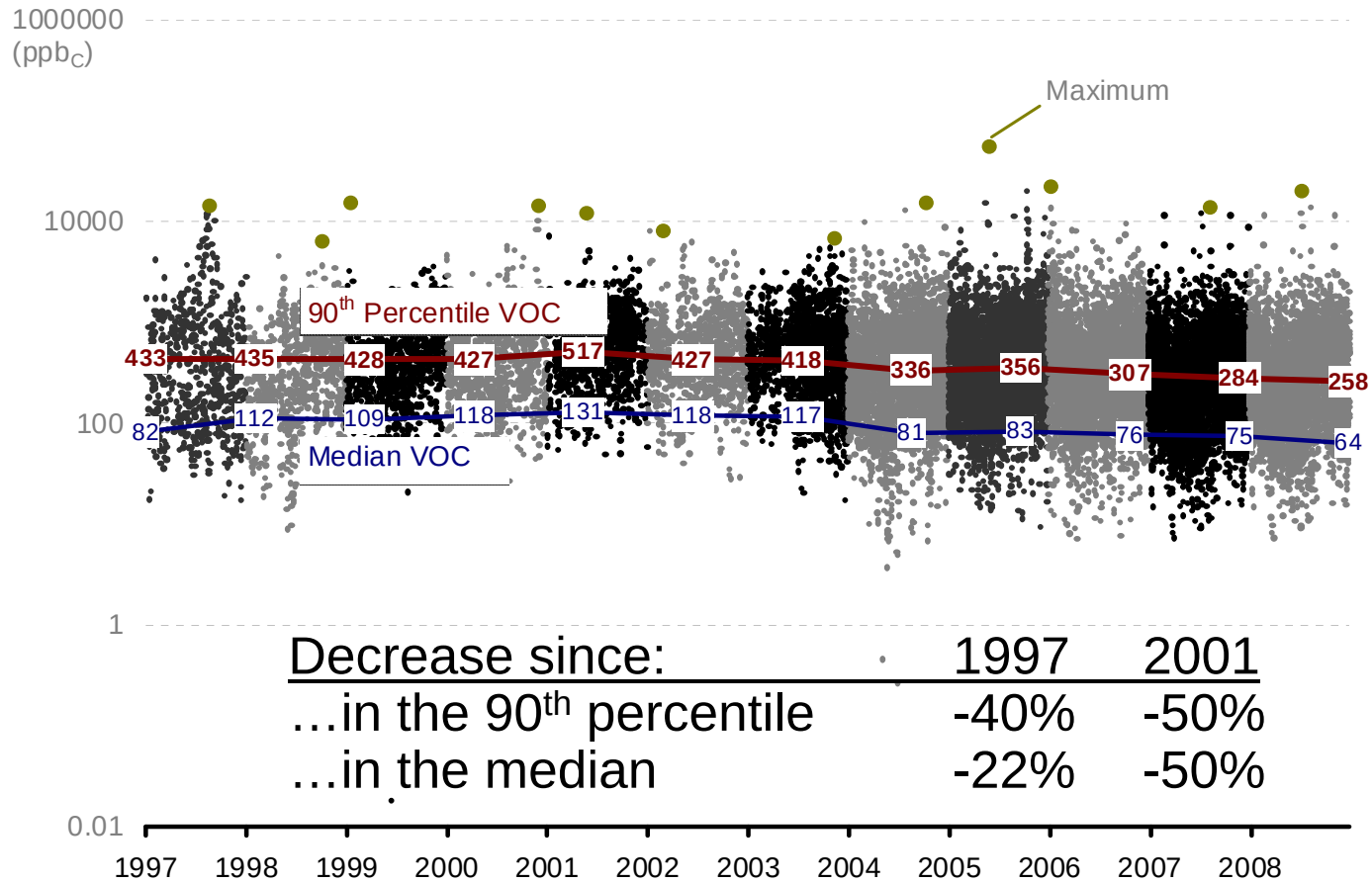
- HRVOC

  We also look at highly reactive VOC (HRVOC) species, which include:

  – ethylene
  – propylene
  – 1,3-butadiene
  – butene complex

TNMHC TRENDS

Daily peak TNMHC for all HGB auto-GC monitors



Decrease since:	1997	2001
…in the 90th percentile	-40%	-50%
…in the median	-22%	-50%

TNMHC is quite variable and skewed (note logarithmic y-axis).

While the max does not appear to exhibit a trend, both 90th percentile and median fell from 1997 to 2008.

In fact, both fell by **half** (50%) or more since peaking in 2001.

Auto-GC = automated gas chromatograph
Note that a logarithmic scale is used due to the assymetric nature of VOC measurements.

HIGHLY-REACTIVE VOC

- HRVOC are emitted mostly by petrochemical facilities.

  TexAQS 2000 and other studies have found HRVOC contributes enormously to ozone production.

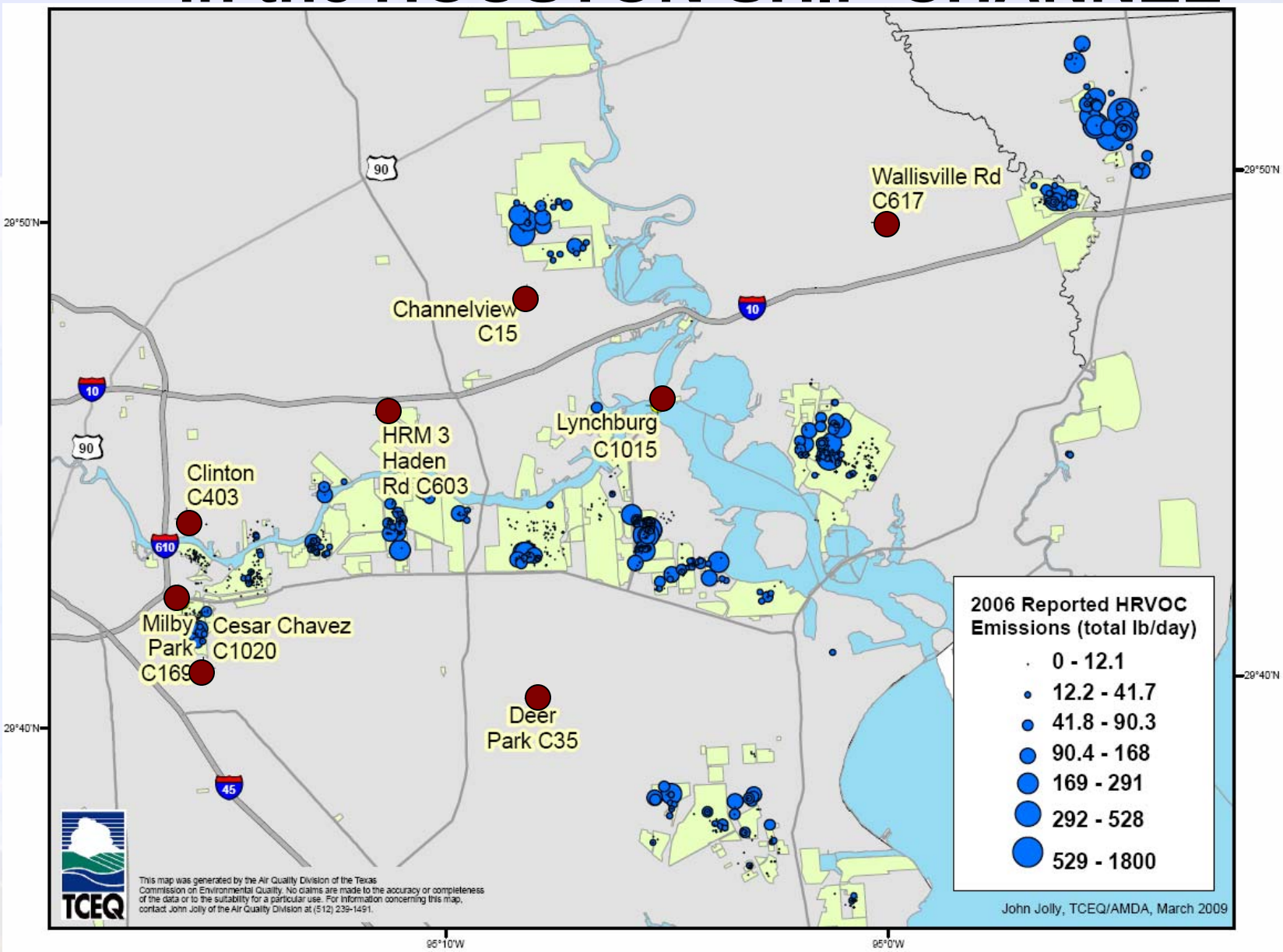
- HRVOC in ambient air is dropping.

  This is likely due to decreasing HRVOC emissions at major sources in and around the Houston Ship Channel have generally dropped since 2003.

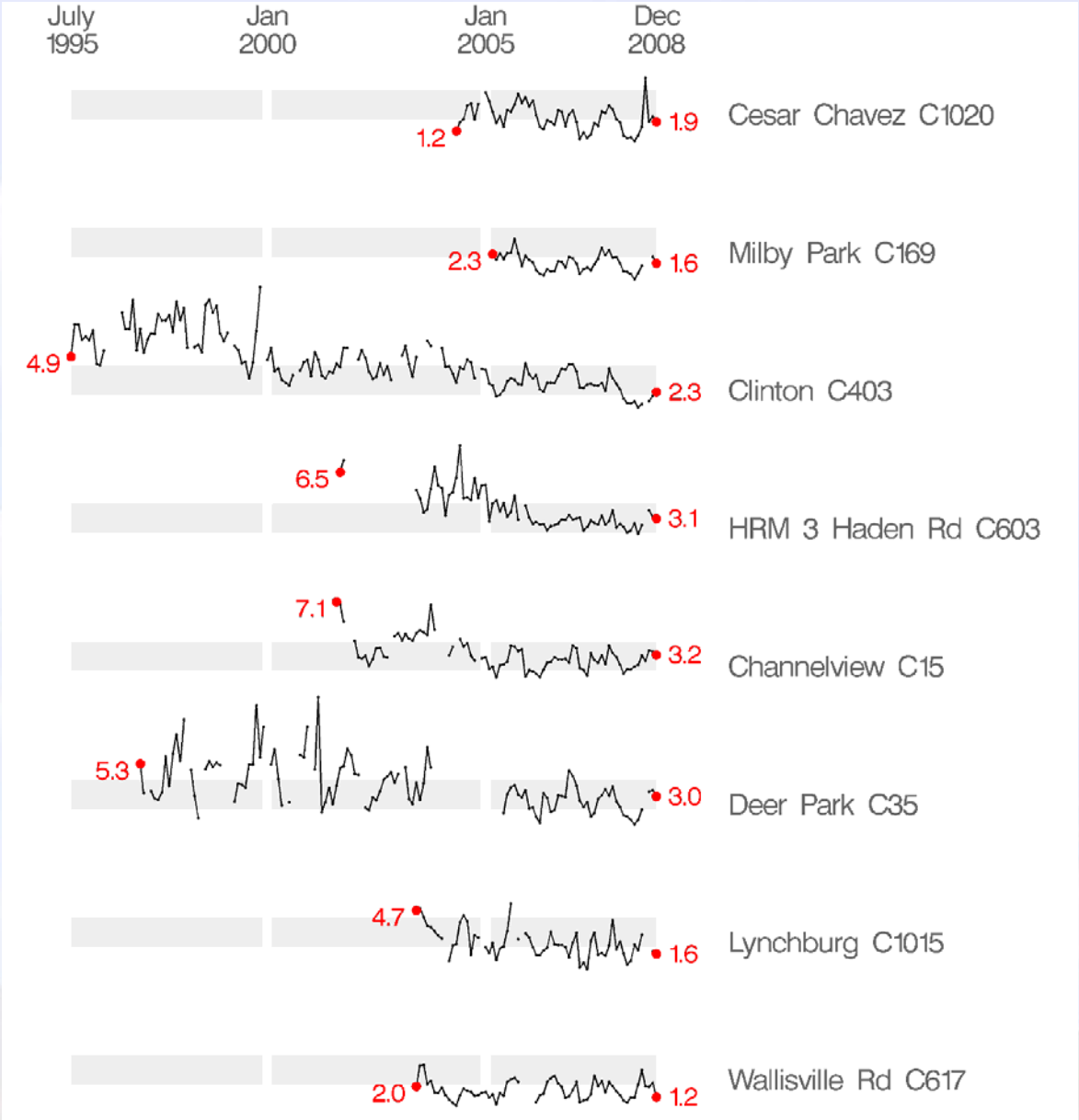
- Decreases correlate with lower ozone downwind.

  Measured decreases in HRVOC correlate with lower ozone concentrations at downwind monitors. Further HRVOC emissions reductions may be expected in the future as the HECT program expands.

AUTO-GCs and HRVOC SOURCES in the HOUSTON SHIP CHANNEL



ETHYLENE

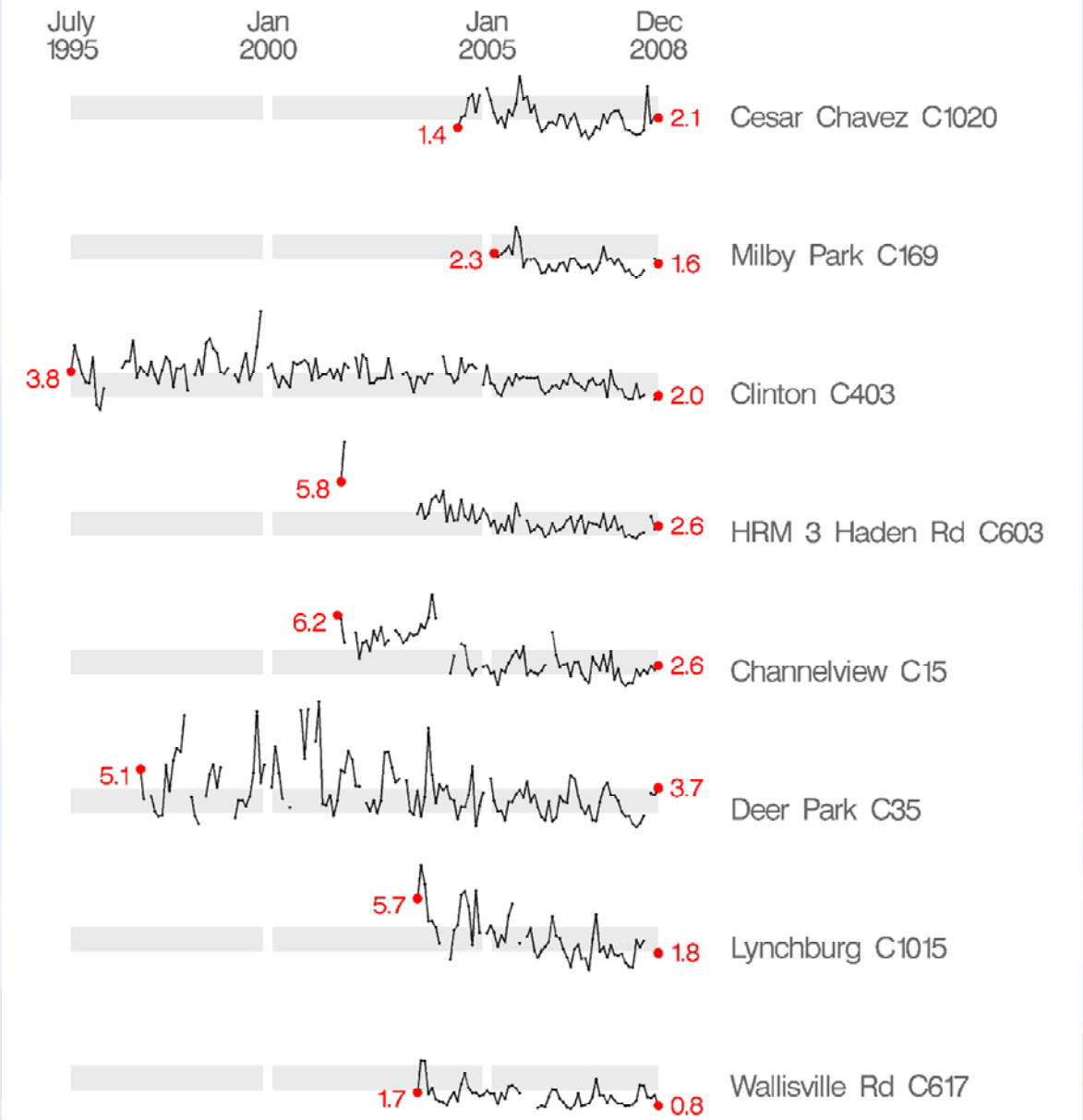


These spark lines plot monthly geometric mean ethylene collected with auto-GCs.

While the data is quite variable, most auto-GCs show decreases in recent years.

Beginning and ending values are highlighted in red.
Grey bars denote 25th and 75th percentile bounds.
Gaps indicate incomplete data (<75% complete for a month).

PROPYLENE



These spark lines plot monthly geometric mean propylene collected with auto-GCs.

While the data is quite variable, most auto-GCs show decreases in recent years.

Beginning and ending values are highlighted in red.
Grey bars denote 25th and 75th percentile bounds.
Gaps indicate incomplete data (<75% complete for a month).

HRVOC TRENDS by WIND DIRECTION

Parameter Estimates of Monthly Geometric Mean Concentrations

	ethylene				propylene			
monitoring site	N	slope	inter-cept	R^2	N	slope	inter-cept	R^2
Houston Ship Channel-area auto-GC monitors:								
Cesar Chavez C1020/175	52	-0.019*	2.74	0.09	52	-0.025*	2.86	0.16
Channelview C15/C115	62	-0.017*	3.85	0.22	62	-0.039*	4.64	0.49
Clinton C403/C113/C304	60	-0.032*	4.75	0.44	62	-0.018*	3.85	0.36
Deer Park C35/139	54	-0.033*	4.12	0.25	65	-0.026*	4.09	0.22
HRM-3 Haden Road C603	56	-0.051*	5.37	0.55	55	-0.026*	3.82	0.42
Houston Milby Park A169	39	-0.011	1.88	0.06	39	-0.021*	2.05	0.20
Lynchburg Ferry C1015	56	-0.029*	3.41	0.24	56	-0.059*	4.89	0.42
Wallisville Road C617	55	-0.002	1.79	0.00	55	-0.017*	2.08	0.17
Non-Houston Ship Channel-area auto-GC monitors:								
Mustang Bayou C619	53	-0.008*	0.72	0.20	53	-0.006*	0.83	0.13
Danciger C618	56	-0.003	0.57	0.05	56	-0.006*	0.78	0.16
Lake Jackson C1016	50	-0.006	1.00	0.05	50	-0.007*	0.77	0.18
Texas City 34th St. C620	59	-0.027*	2.43	0.50	59	-0.020*	2.19	0.37

*Significant at the 5 percent (0.05) level. Significance levels for intercepts are not reported.

Parameter estimates from ordinary least squares fits of monthly geometric mean concentrations of ethylene and propylene on an index of month, by monitoring site and compound.

HRVOC TRENDS by WIND DIRECTION

- HRVOC by wind directions

  Examining HRVOC trends by wind direction helps determine specific sources of observed (monitored) decreases.

- Ethylene and Propylene are decreasing…

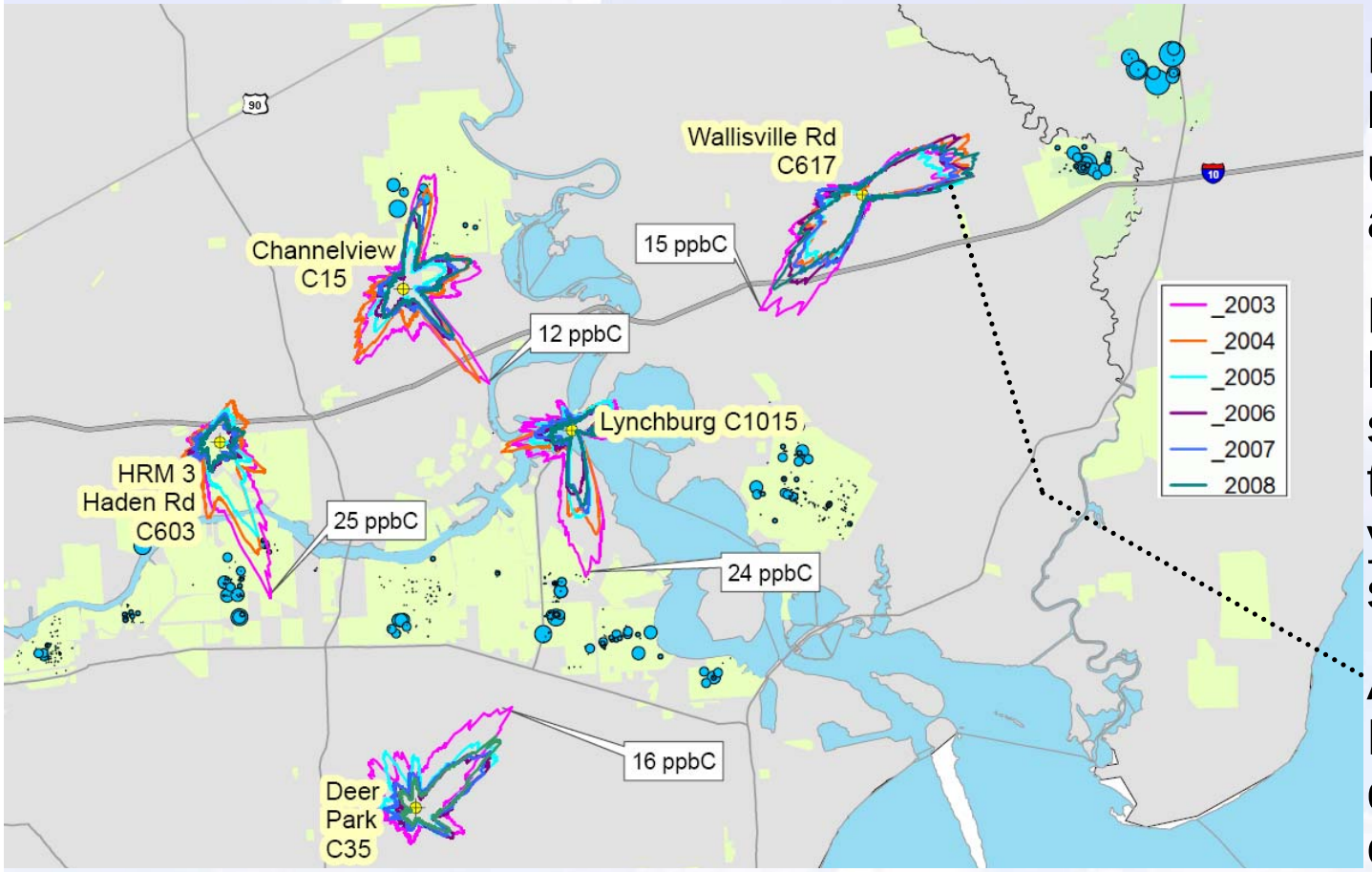
  Most auto-GC monitors have measured decreases in ethylene and propylene from all directions.

- …except at Wallisville Rd.

  Wallisville Rd. shows decreases in ethylene and propylene in the direction of the Ship Channel, but not in the direction of Mont Belvieu.

ETHYLENE TRENDS by WIND DIRECTION

EASTERN SHIP CHANNEL MONITORS



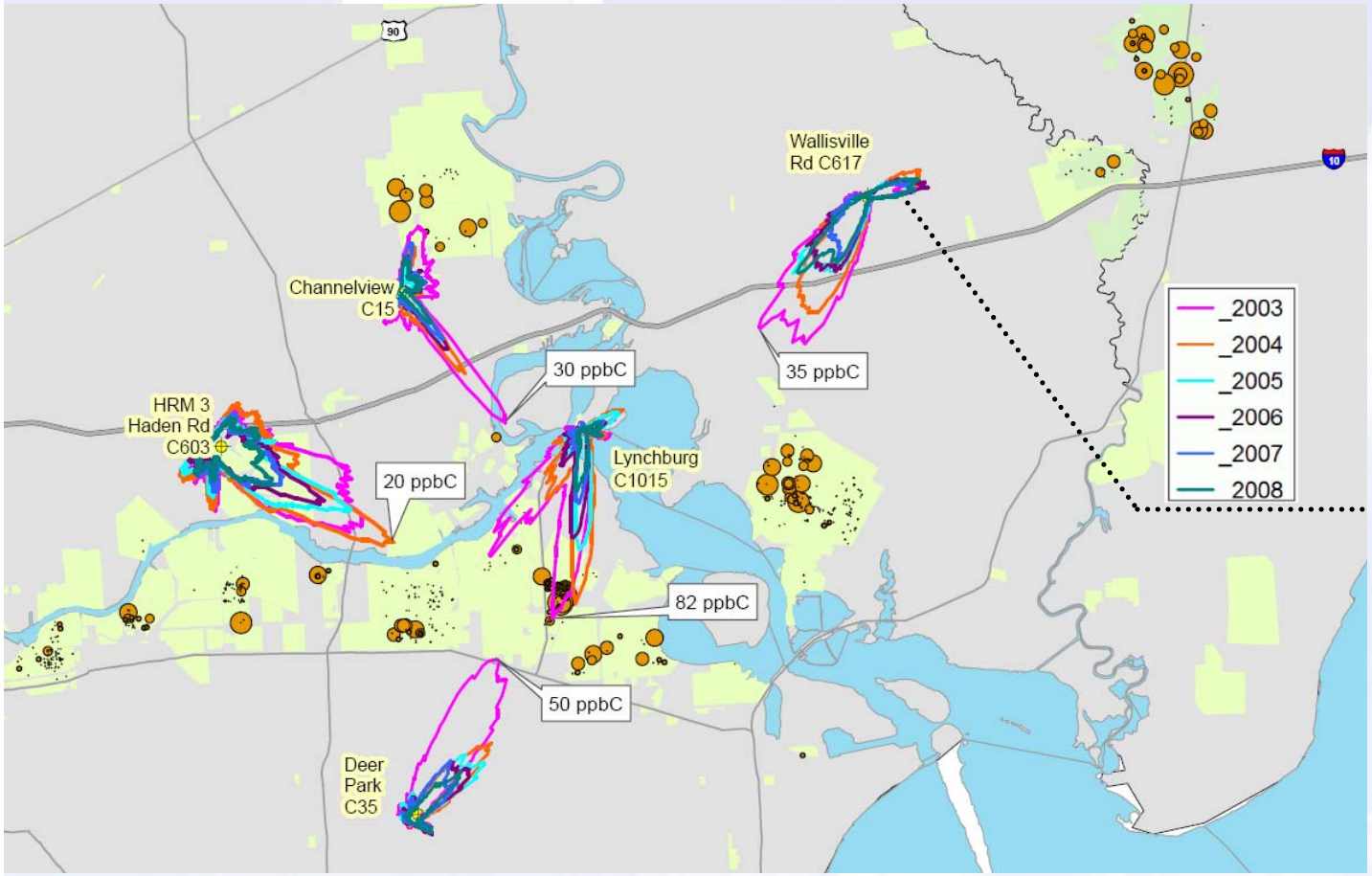
Examining HRVOC by wind direction is used for source attribution.

Notice the 2003 lobes (pink) are substantially longer than subsequent years, which shrink over time.

All but Wallisville Rd. observe decreases, both over time and in all directions.

PROPYLENE TRENDS by WIND DIRECTION

EASTERN SHIP CHANNEL MONITORS

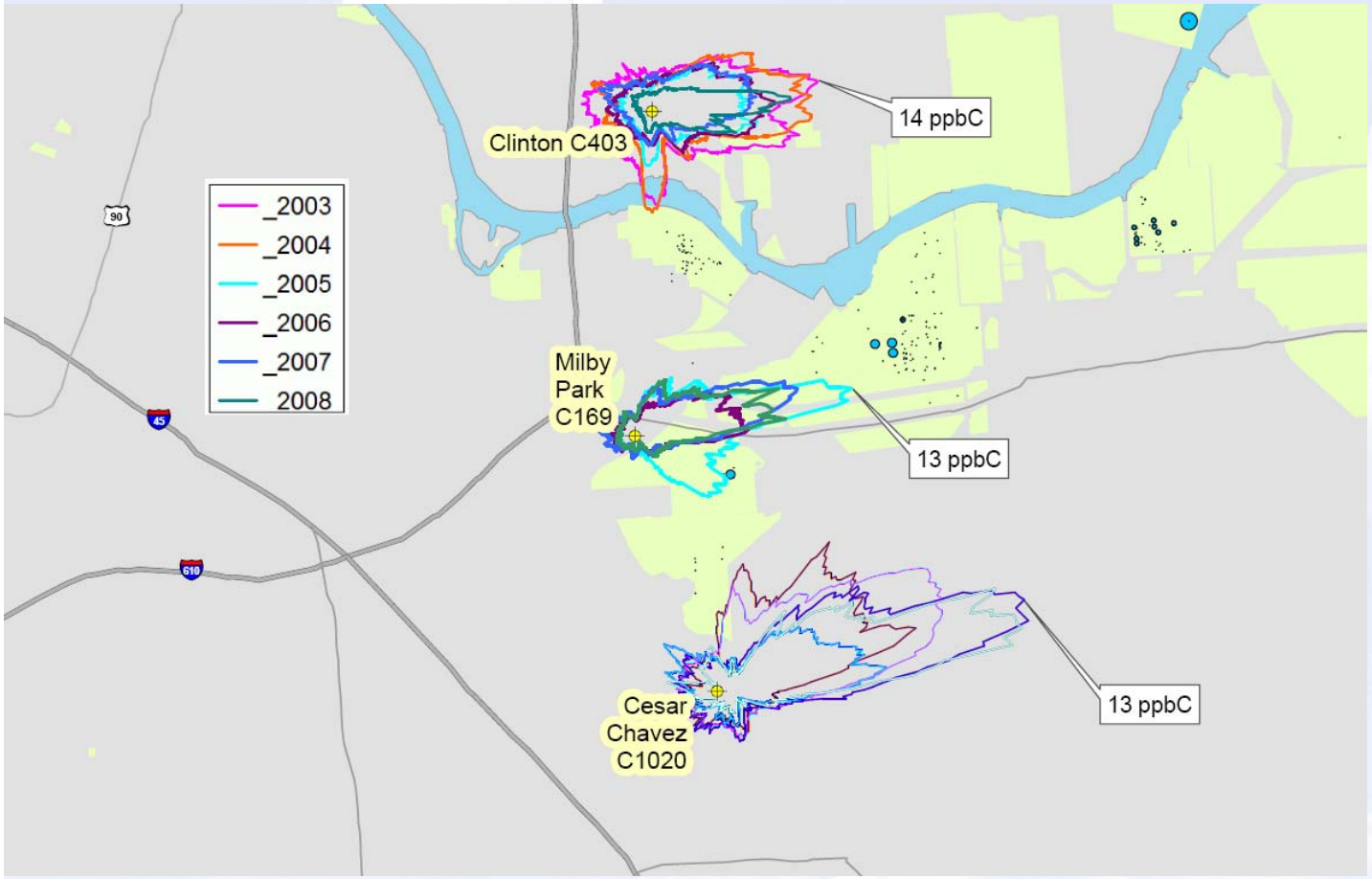


Propylene sources differ somewhat, but the decreases over time are similar...

…including lack of trend from Mont Belvieu.

ETHYLENE TRENDS by WIND DIRECTION

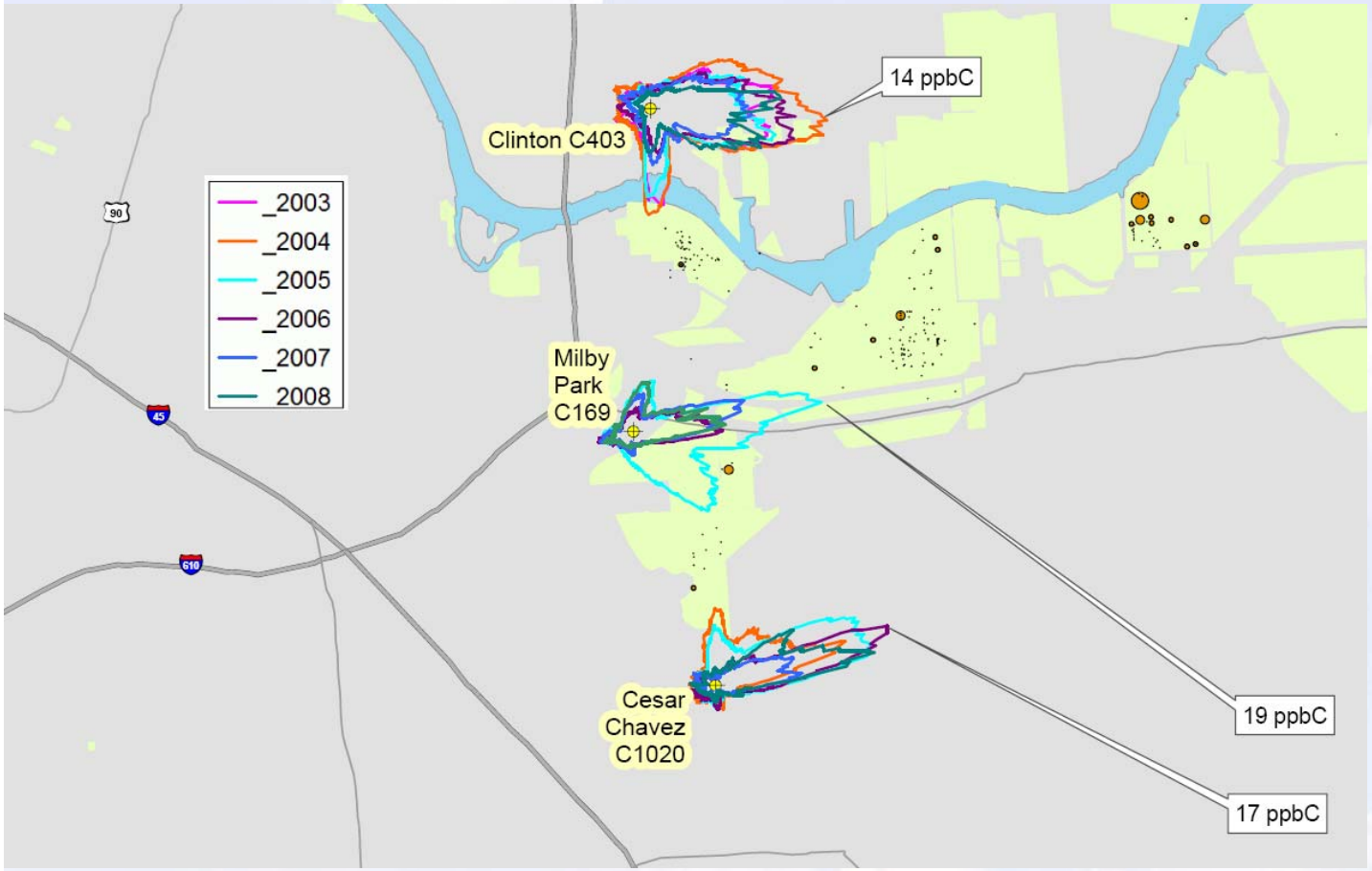
WESTERN SHIP CHANNEL MONITORS



A similar pattern is evident at AGC monitors in the western portion of the Ship Channel.

PROPYLENE TRENDS by WIND DIRECTION

WESTERN SHIP CHANNEL MONITORS



A similar pattern is evident at AGC monitors in the western portion of the Ship Channel.

ANALYSIS of METEOROLOGY

- Meteorological adjustment of ozone trends

  Are recent observed decreases in ozone concentrations due to NO_X and VOC control strategies or merely due to natural variability in meteorology? By adjusting ozone trends for meteorology, we will demonstrate that ozone would be dropping even without favorable meteorology.

- Regional wind flow patterns

  Are unusual synoptic (large-scale) weather systems influencing ozone formation dynamics in the HGB area in ways they have not in the past? We do not see evidence of this.

- Trends in backward trajectories

  No deviations from typical meteorology are evident from analysis of backward trajectories across years.

METEOROLOGICAL ADJUSTMENT of OZONE TRENDS

- Meteorology is highly variable.

  Wind speeds and directions, humidity, and solar radiation, among other factors, all affect ozone formation. These factors vary considerably from year to year, even day to day But, in the aggregate, is it enough to affect ozone trends?

- Removing meteorological influences from ozone trends reveals whether observed ozone decreases result from:

  (1) variation in meteorology or

  (2) reductions in precursors.

- Based on meteorology alone, ozone in 2007 should have been higher than was actually measured, suggesting that **factors unrelated to meteorology** are likely responsible for observed downward trends.

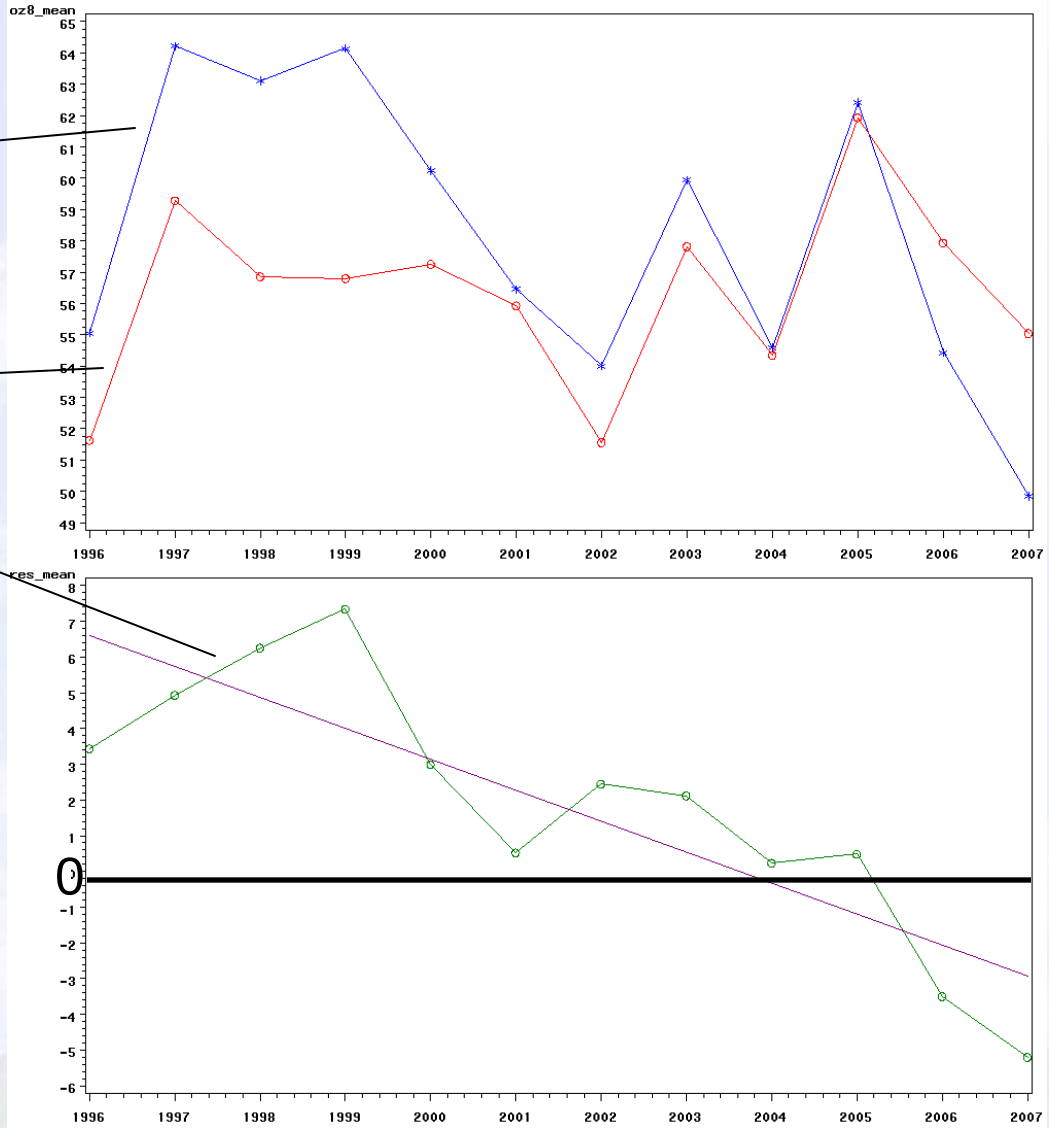
METEOROLOGY-ADJUSTED OZONE

Since 1999, met-corrected ozone has dropped considerably.

Average peak daily ozone **(MEASURED)**

Average peak daily ozone attributable to meteorology alone **(PREDICTED)**

Meteorology-corrected ozone trend **(DIFFERENCE)**



Parameter estimates for meteorologically-adjusted ozone trends, 1996-2007

Parameter	Value	t-stat
Intercept	6.438	
Slope	-0.86*	-4.20
p-value	0.00	
lag 1 coefficient	-0.20	-0.63

* Value is statistically significant. (Sullivan et al., 2009)

REGIONAL WIND FLOW PATTERNS

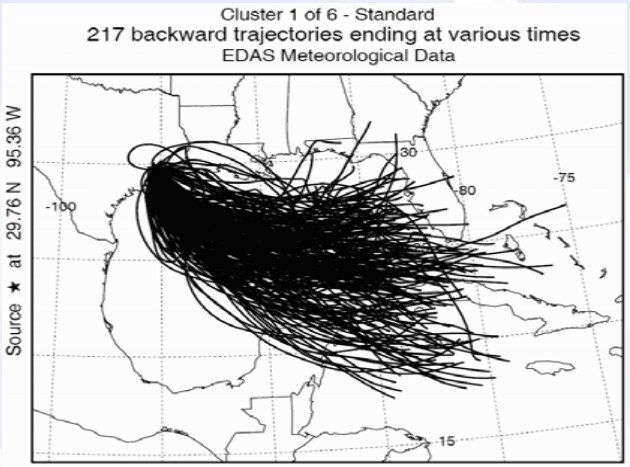
PROCESS

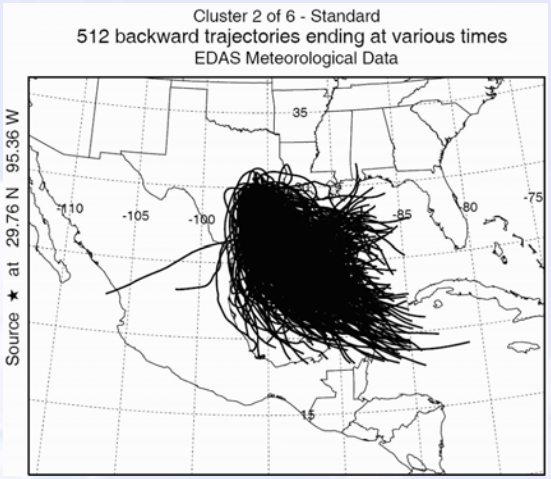
- Backward trajectories were run for each day from May-October, 2000-2007, and grouped into clusters.
- Six ‘regional scale’ clusters were identified.
- Background ozone concentrations were computed for each cluster.

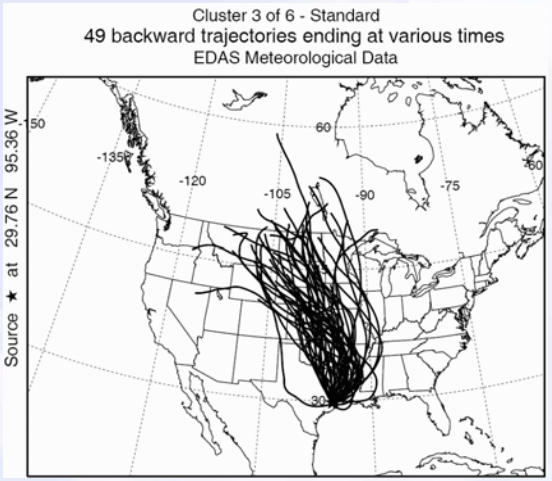
RESULTS

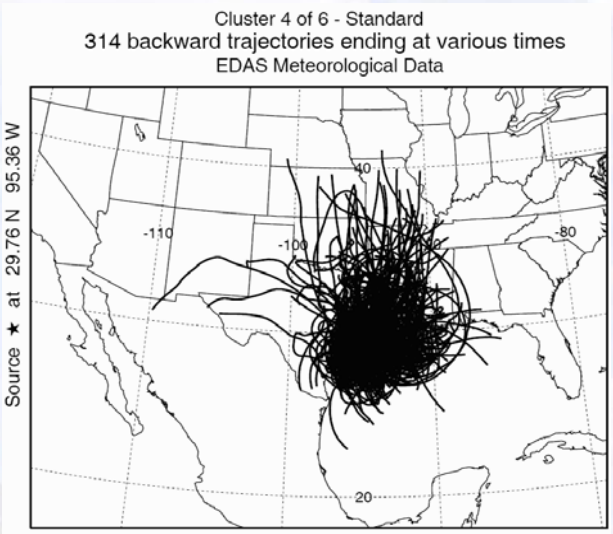
- 3 regional-scale **northerly** wind clusters were observed bringing relatively high background ozone into southeast Texas.
- 2 regional-scale **southerly** wind clusters were observed bringing low background ozone into southeast Texas.
- One cluster (#4:cyan) has a very short trajectory, representing stagnant conditions. Its “background” ozone value probably includes some locally-generated ozone.

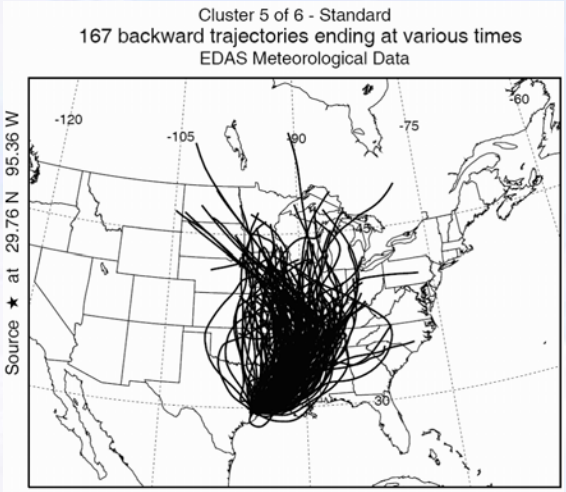
CLUSTER ANALYSIS of WIND FLOW

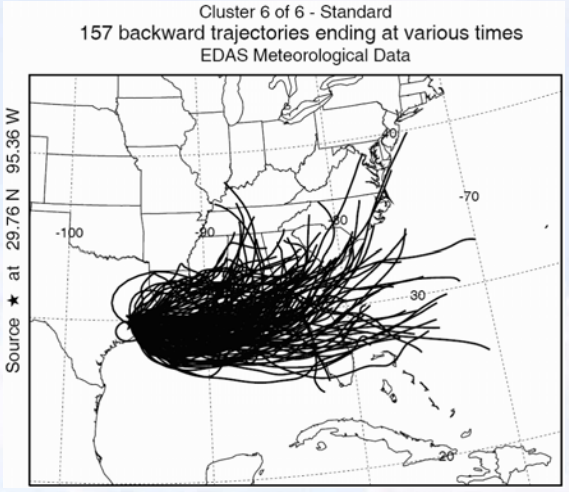






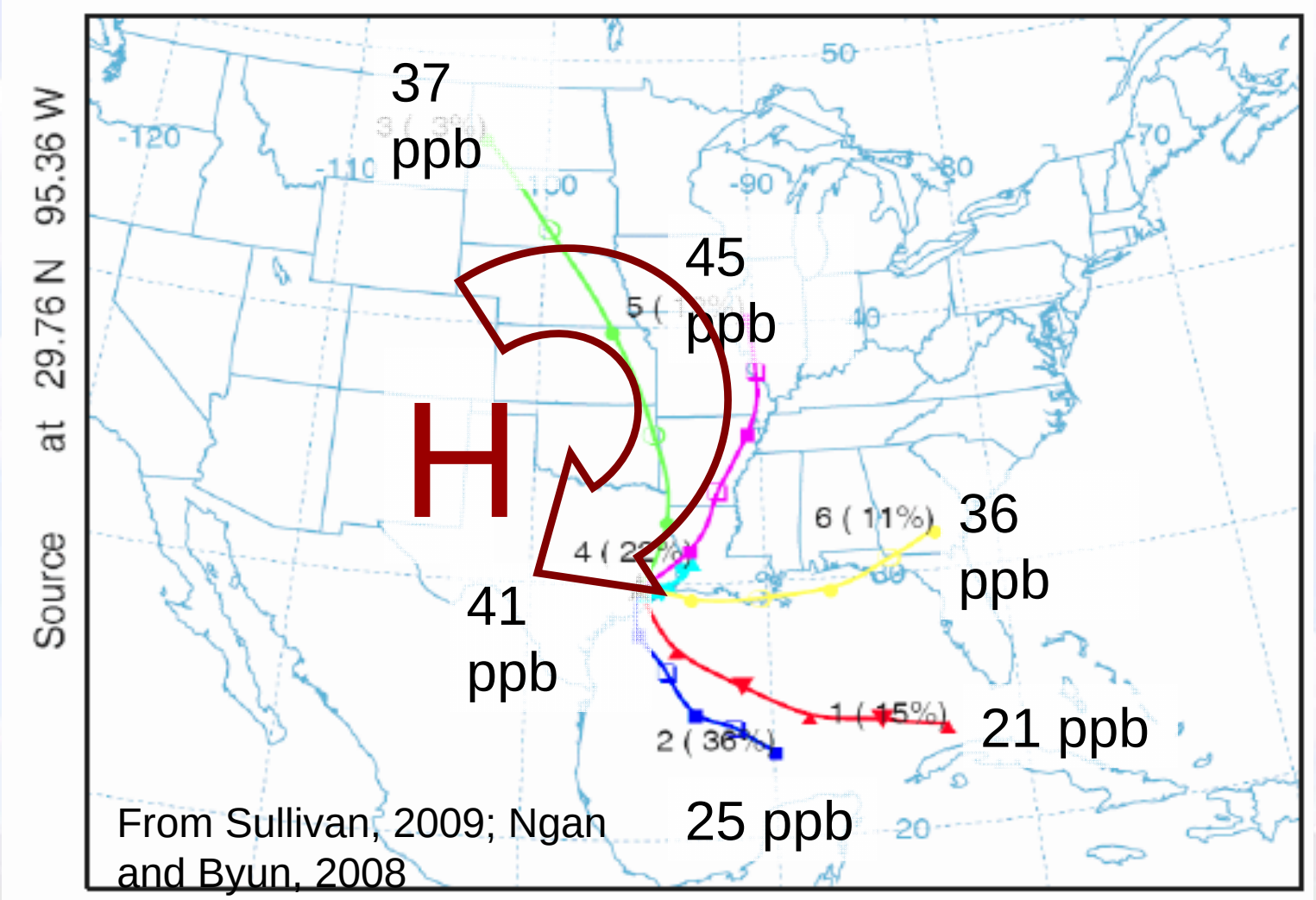






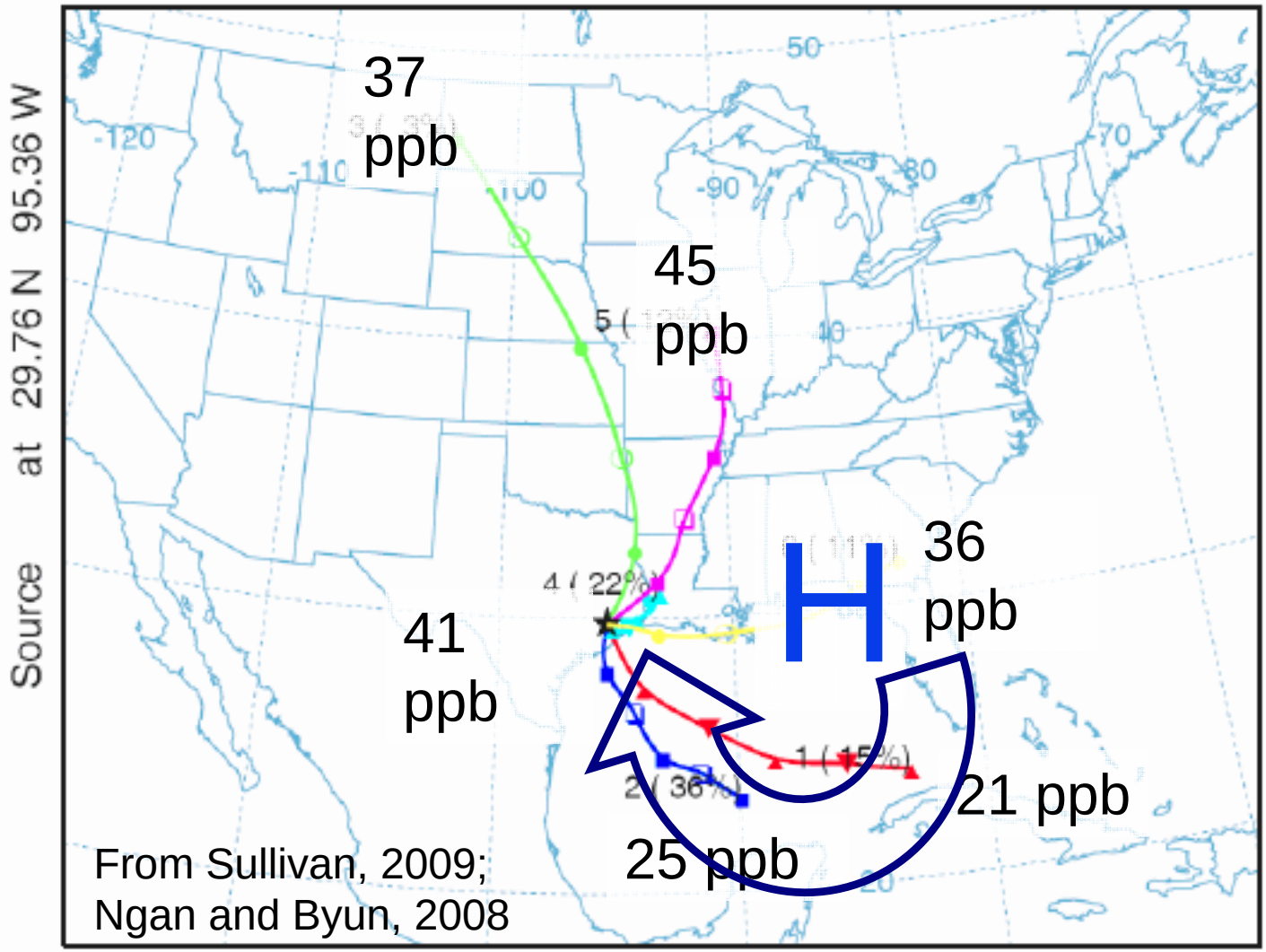
TRAJECTORY CLUSTERS – HIGH OZONE REGIMES

Means of Six 60-Hour Backward Trajectory Clusters



TRAJECTORY CLUSTERS – LOW OZONE REGIMES

Means of Six 60-Hour Backward Trajectory Clusters



LOCAL / REGIONAL FLOW REGIMES

- GULF BREEZE.

  Bay breezes and Gulf breezes occur regularly in Houston during summer, due to the contrast between cooler ocean and warmer land, which is common in coastal areas around the globe.

  This land-sea breeze effect is particularly strong near 30° N latitude. Downtown Houston is at roughly 29.75° N.

- FLOW REVERSAL.

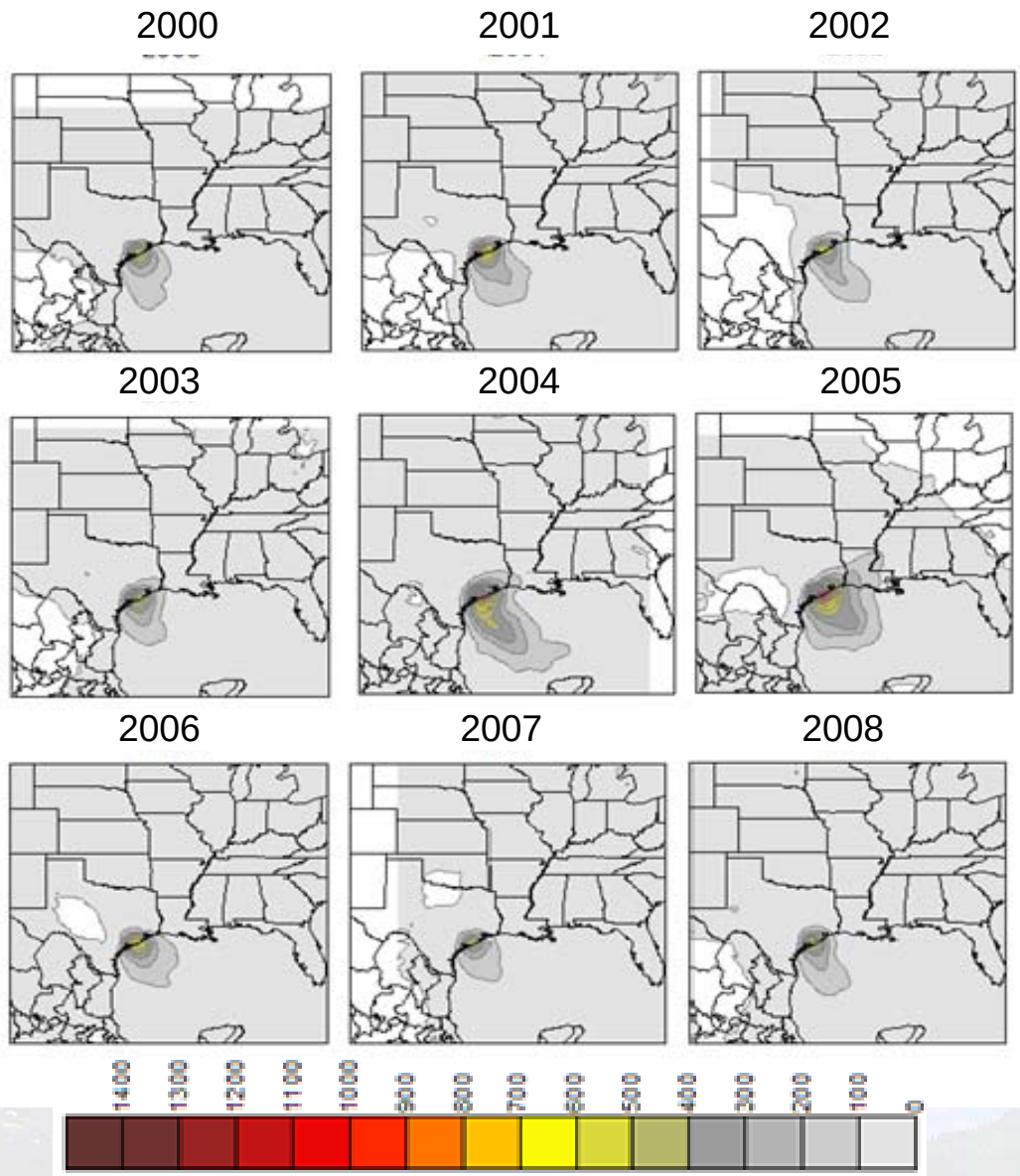
  If the regional flow is strong enough to oppose the bay breeze and/or Gulf breeze, stagnation and flow reversal result.

- TWO RESULTING EPISODE TYPES.

  Two major episode types result from interacting regional flow and local flow:

  – **typical veering**
  – **flow reversal.**

WIND TRAJECTORIES



Further evidence of the influence, or lack of influence, of meteorology is found in trajectory plots.

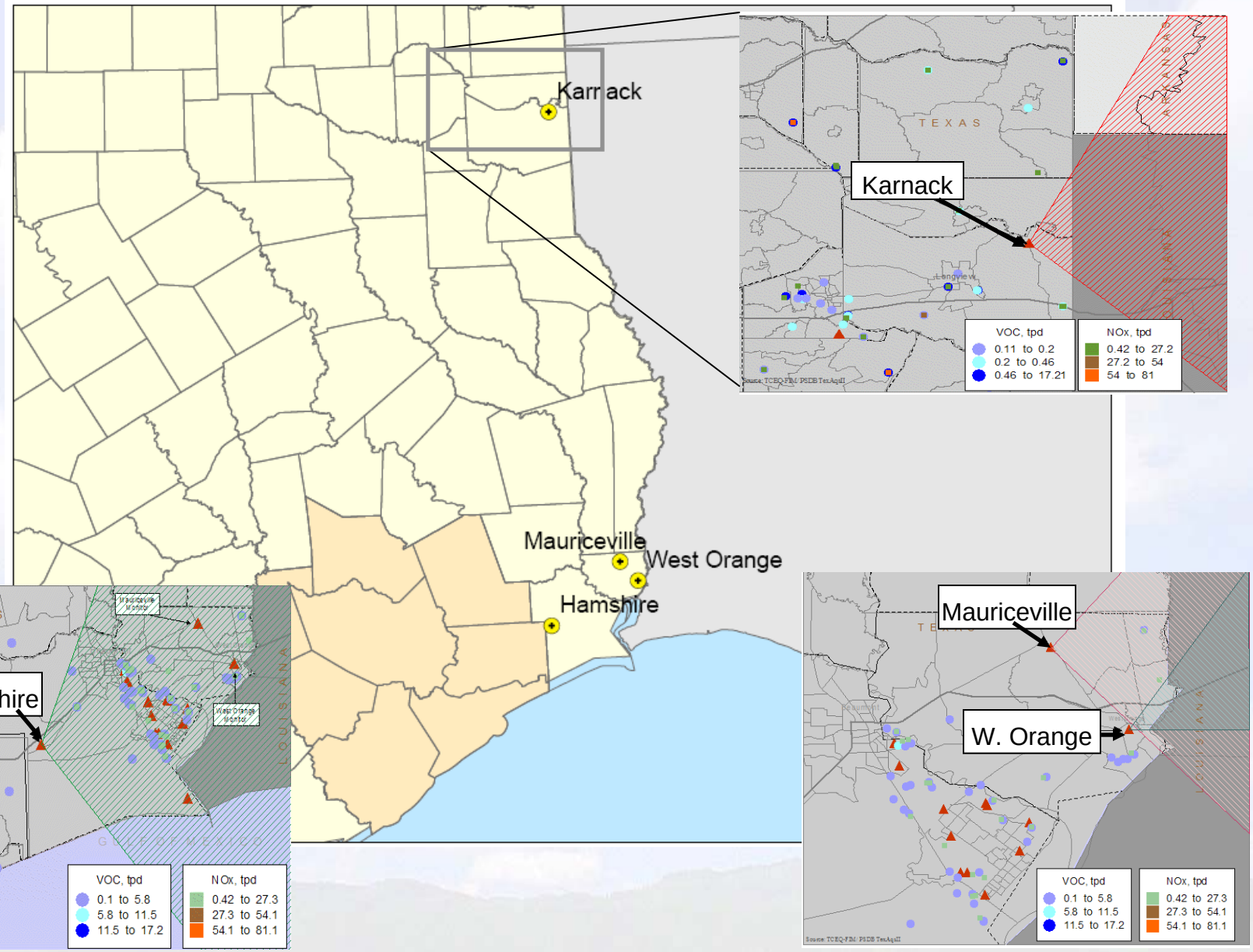
These plots record the number of 48-hour back trajectories originating from various directions, terminating in Houston.

Most trajectories originate from the south/southeast, varying in length (speed). Note that trajectories in 2000, a high ozone year, and 2008, a much lower ozone year are similar. **Comparable meteorology yielded dissimilar ozone.**

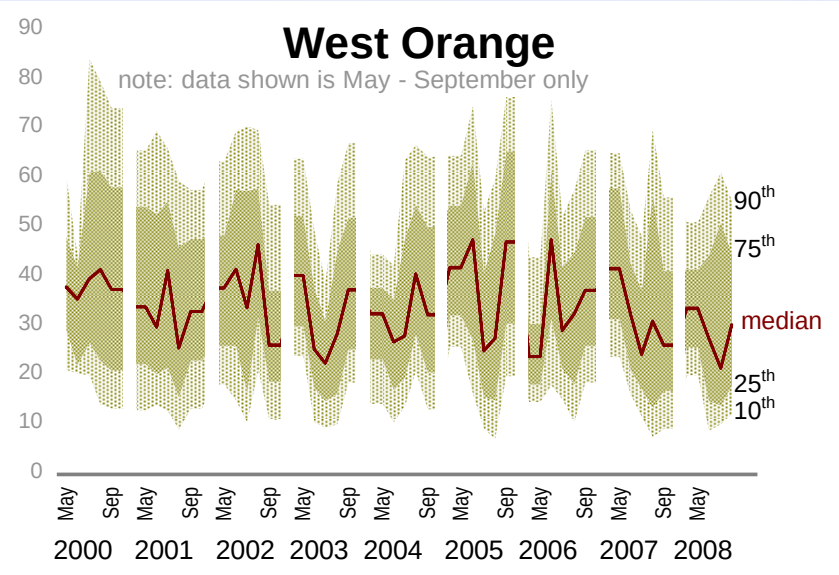
BACKGROUND OZONE

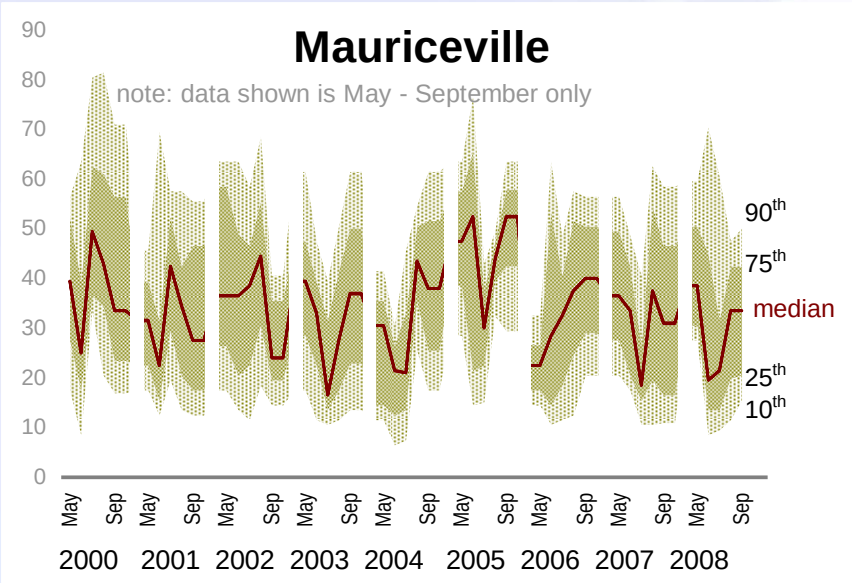
- DEFINITION.
  - We define “background” ozone as ozone transported into the HGB area that was not created from local emissions.
  - Background ozone includes ozone created in urban areas upwind of HGB, plus naturally-occuring ozone. That is, it is not necessarily free of anthropogenic (human) influences.
- IS BACKGROUND OZONE DECREASING?
  - If background ozone were found to be decreasing, it could explain observed decreases in ozone in the HGB area.
- PROCEDURE.
  - To test this, we selected four sites that measure background ozone and examined ozone at these sites over time.

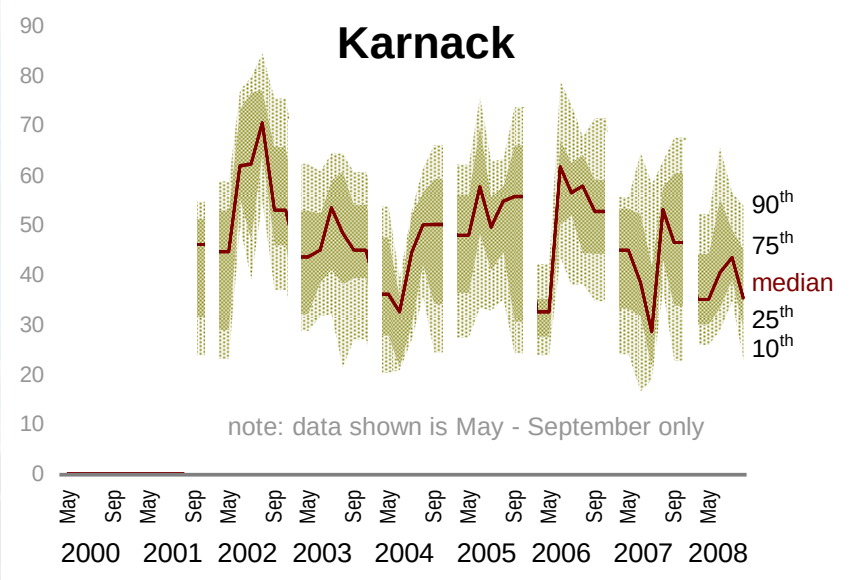
BACKGROUND OZONE TRENDS

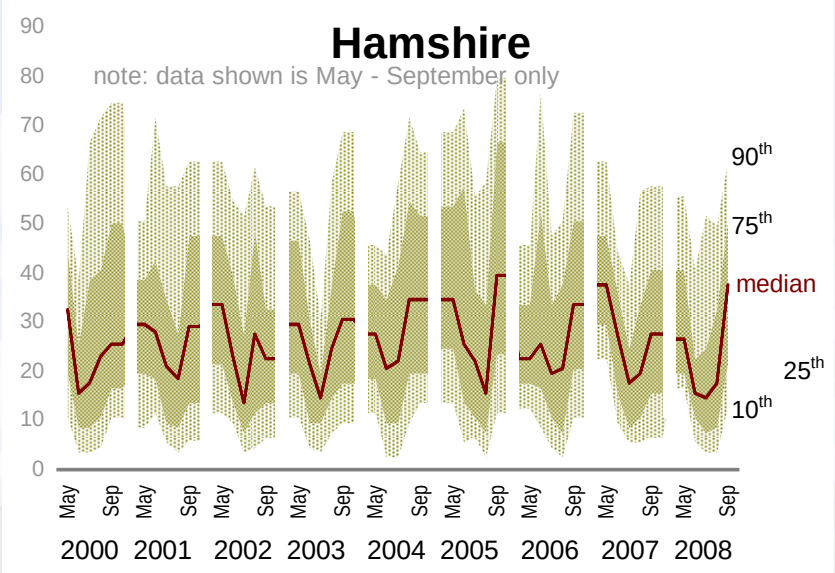


BACKGROUND OZONE TRENDS









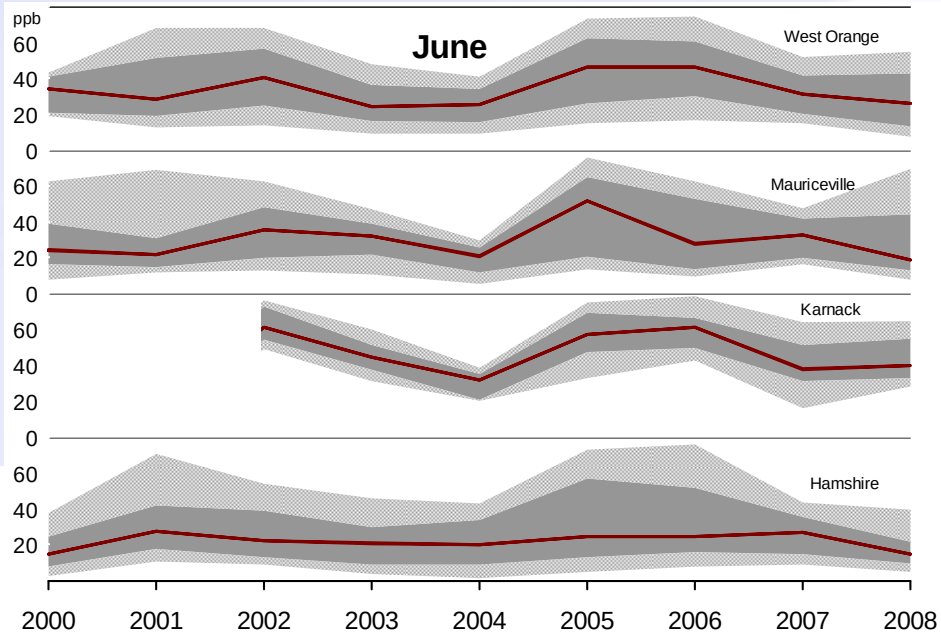
BACKGROUND OZONE

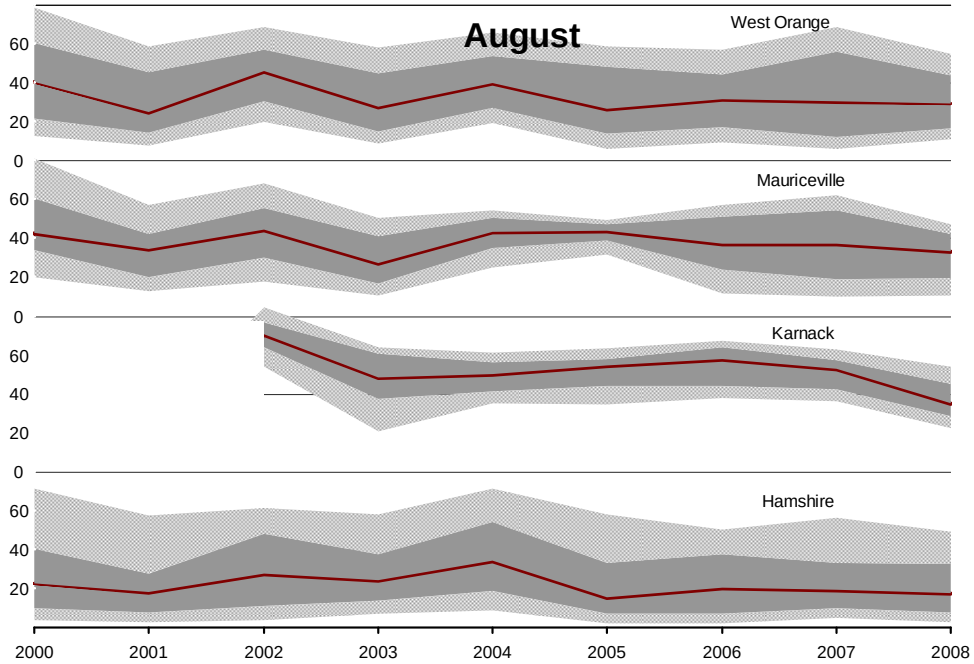
- NO TRENDS WERE OBSERVED.
  - No trends were identifiable at three of the four monitors: West Orange, Mauriceville, and Hamshire.
- EXCEPT (possibly) KARNACK.
  - Karnack may exhibit a slight downward trend, but it is not statistically robust. Further, the data record at Karnack is shorter than the other sites, perhaps too short to discern long-term trends.
- NO TREND IS APPARENT
  - No trend in background ozone was apparent with visual inspection or statistical methods (regression analysis).

BACKGROUND OZONE TRENDS

Examining background ozone for individual months enables us to eliminate seasonal fluctuations.

Neither visual inspection nor statistical analysis of the data was able to confirm any trends.





Thus, we conclude, there is no discernible trend in background ozone entering the HGB area.

CONCLUSIONS

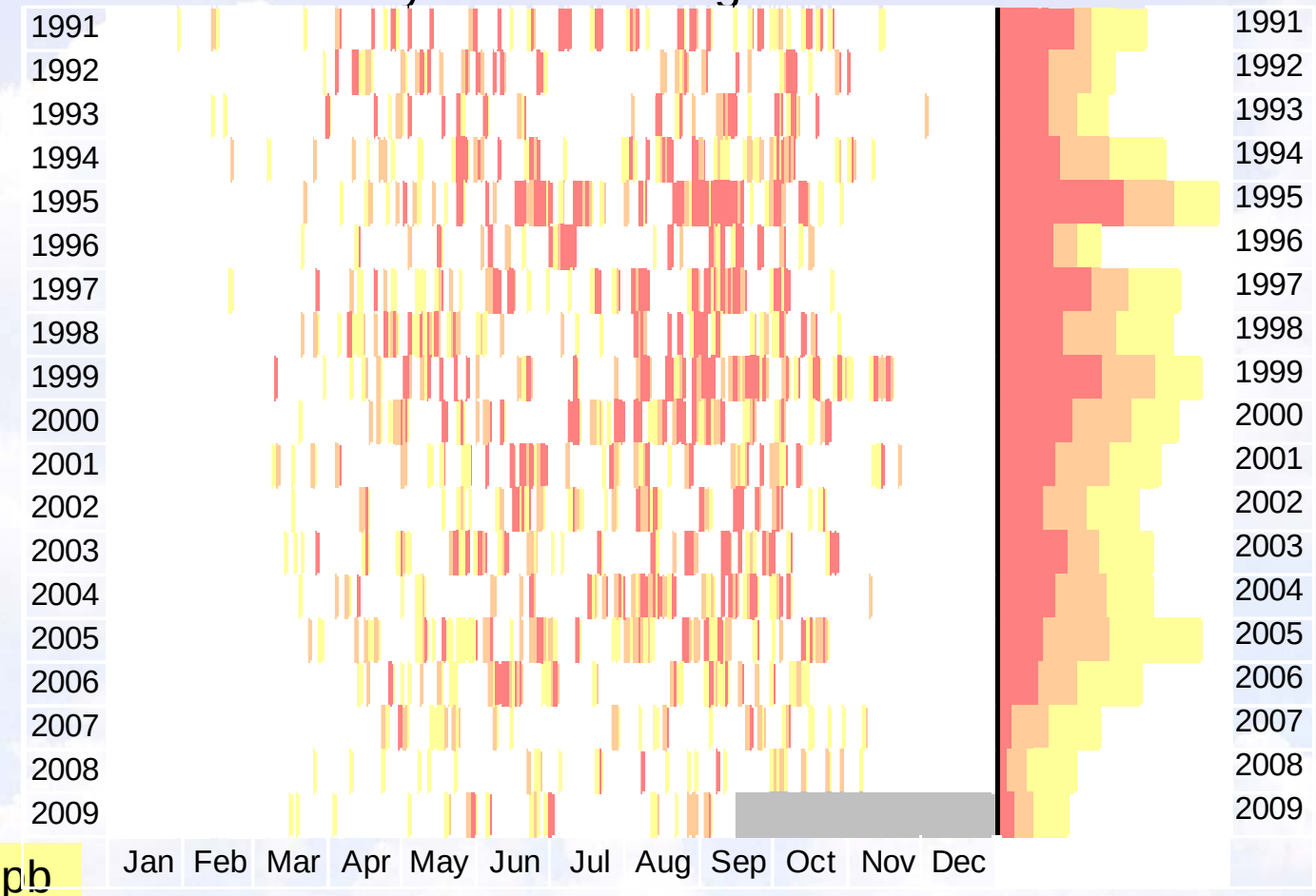
- Ozone concentrations have decreased dramatically in the HGB area since the 1990s.
- We examined:
  (1) trends in one-hour ozone and eight hour ozone
  (2) the number of ozone exceedance days
  (3) the spatial distribution of ozone
  (4) the seasonal distribution of ozone
  (5) the strength of ozone gradients
- All measures show substantial downward trends.
- Possible causes of the trends were investigated by:
  (1) evaluating local changes in ozone precursors
  (2) examining historical meteorological variability
  (3) examining trends in background ozone.

CONCLUSIONS

- Our analyses found:
  - inter-annual meteorological variations cannot explain the observed decreases in ozone, and
  - ozone precursors are on statistically significant downward trends.
  - background ozone transported from outside the region has not dropped substantially since 2000.
- This suggests that the significant ozone reductions observed in the HGB area are due in large part to **local emission controls**, not decreases in background ozone or variation in meteorology.
- These results complement detailed photochemical modeling and analysis contained in the Houston SIP and support the conclusion that the HGB area will attain the Federal eight-hour ozone NAAQS on schedule.

How is 2009 shaping up?

Daily maximum eight-hour ozone



75 – 85 ppb

85 – 95 ppb

over 95 ppb

How is 2009 shaping up?

Maximum through 4th high values, 2009

Area	Monitoring Site	POC	Highest			Second Highest			Third Highest			Fourth Highest		
			Date	Tim	Value	Date	Time	Value	Date	Tim	Value	Date	Tim	Value
Houston-Galveston-Brazoria														
	Danciger C618	1	5/28/2009	1100	86	5/20/2009	1200	85	5/29/2009	1000	80	5/21/2009	1000	74
	Mustang Bayou C619	1	5/29/2009	1100	81	9/3/2009	1100	74	5/28/2009	1000	74	5/20/2009	1100	71
	Manvel Croix Park C84	1	5/29/2009	1100	96	9/2/2009	1100	93	5/20/2009	1100	92	9/3/2009	1000	91
	Lake Jackson C1016	1	9/3/2009	1000	77	5/29/2009	1000	76	5/20/2009	1100	76	3/16/2009	1200	76
	U of H-Sugarland C696	1 N	9/2/2009	1100	94	7/1/2009	1100	90	5/20/2009	1100	90	9/3/2009	1000	81
	Texas City 34th St. C620	1	9/3/2009	1100	84	8/29/2009	1000	81	8/12/2009	1100	76	8/30/2009	900	73
	Clear Creek High School C571	1 N	7/1/2009	1000	92	9/3/2009	1100	91	8/29/2009	1000	87	9/2/2009	1100	79
	Galveston 99th St. C1034/A320/X183	1	8/30/2009	1200	85	5/29/2009	1000	80	8/29/2009	1000	76	8/22/2009	1000	76
	Houston Aldine C8/AF108/X150	2	5/30/2009	1100	94	9/3/2009	1000	86	6/23/2009	1100	81	7/2/2009	1000	80
	Channelview C15/AH115	3	5/30/2009	1000	92	8/27/2009	1000	88	9/3/2009	1000	85	6/26/2009	1000	80
	Northwest Harris Co. C26/A110/X154	2	6/6/2009	1000	103	7/2/2009	1100	101	8/14/2009	1100	89	5/30/2009	900	86
	Houston North Wayside C405	1	5/30/2009	1000	92	9/3/2009	1100	72	7/2/2009	1000	72	8/27/2009	1100	69
	Lang C408	2	7/2/2009	1000	91	9/3/2009	1000	90	5/30/2009	1000	90	6/6/2009	900	81
	Houston Croquet C409	2	9/3/2009	1100	100	9/2/2009	1100	90	7/1/2009	1100	90	5/30/2009	1000	80
	Houston Bayland Park C53/A146	1	9/3/2009	1000	106	7/1/2009	1100	98	9/2/2009	1100	88	6/24/2009	1100	86
	Houston Monroe C406	1	9/3/2009	1000	88	7/1/2009	1100	88	5/30/2009	1000	76	6/24/2009	1100	71
	Houston Westhollow C410	1	9/2/2009	1100	80	5/20/2009	1000	79	9/3/2009	1000	74	6/6/2009	900	71
	Houston Regional Office C81	1	5/30/2009	1000	103	9/3/2009	1000	82	6/24/2009	1100	80	5/29/2009	1000	80
	Houston Texas Avenue C411	1	5/30/2009	1000	95	9/3/2009	1100	81	7/1/2009	1000	79	6/24/2009	1100	79
	Park Place C416	1	9/3/2009	1100	96	7/1/2009	1100	91	6/24/2009	1100	87	8/29/2009	1100	73
	Sheldon C551	1 N	8/27/2009	1000	80	5/30/2009	1000	79	9/3/2009	900	77	6/26/2009	1000	71
	Baytown Wetlands Center C552	1 N	7/1/2009	1000	86	9/3/2009	1000	83	5/30/2009	1000	73	6/24/2009	1100	72
	Crosby Library C553	1 N	8/27/2009	1000	86	4/3/2009	1200	77	5/30/2009	1100	75	9/3/2009	1000	73
	West Houston C554	1 N	7/2/2009	1000	86	6/6/2009	900	85	9/3/2009	900	83	9/2/2009	1100	82
	Kingwood Library C555	1 N	9/3/2009	1000	76	4/3/2009	1200	76	8/27/2009	1200	74	6/26/2009	1100	71
	La Porte Sylvan Beach C556	1 N	7/1/2009	900	106	9/3/2009	1100	88	8/22/2009	1100	84	5/30/2009	1100	84
	Mercer Arboretum C557	1 N	5/30/2009	1000	82	6/6/2009	1100	79	9/3/2009	900	77	7/2/2009	1000	76
	Tom Bass C558	1 N	7/1/2009	1100	102	9/3/2009	1000	97	5/29/2009	1100	91	9/2/2009	1200	89
	Katy Park C559	1 N	9/2/2009	1100	78	5/20/2009	1100	77	9/4/2009	1100	76	9/3/2009	1100	73
	Atascocita C560	1 N	4/3/2009	1200	83	5/30/2009	1000	80	9/3/2009	900	77	6/26/2009	1100	76
	Meyer Park C561	1 N	7/2/2009	1100	87	6/6/2009	1000	87	5/30/2009	900	83	8/14/2009	1100	80
	Bunker Hill Village C562	1 N	9/3/2009	1000	99	6/24/2009	1100	89	5/30/2009	1000	87	9/2/2009	1100	85
	Clear Brook High School C570	1 N	9/3/2009	1100	92	7/1/2009	1000	86	8/29/2009	1000	85	5/20/2009	1000	82
	Clear Lake High School C572	1 N	7/1/2009	1000	96	9/3/2009	1100	93	5/30/2009	1100	84	8/29/2009	1000	83
	Wallisville Road C617	1	8/27/2009	1000	88	5/30/2009	1000	78	9/3/2009	1100	75	6/24/2009	1100	75
	Pasadena AAMS C672	1 N	1/29/2009	900	57	1/22/2009	1100	55	1/17/2009	1100	54	1/21/2009	1100	50
	HRM-3 Haden Road C603/A114	1	5/30/2009	1000	99	9/3/2009	1100	86	8/27/2009	1000	78	7/2/2009	1000	76
	Lynchburg Ferry C1015/A165	1	9/3/2009	1000	90	8/27/2009	1000	87	5/30/2009	1000	82	6/25/2009	1000	73
	Houston East C1/G316	2	5/30/2009	1000	110	9/3/2009	1100	90	6/24/2009	1100	83	8/27/2009	1000	79
	Clinton C403/C304/AH113	3	5/30/2009	1000	101	9/3/2009	1100	84	7/2/2009	1000	78	6/24/2009	1100	78
	Hou.DeerPrk2 C35/235/1001/AFH139FP239	1	9/3/2009	1000	102	7/1/2009	1000	99	5/30/2009	1000	94	6/25/2009	1000	82
	Seabrook Friendship Park C45	1	7/1/2009	1000	83	9/3/2009	1100	81	8/22/2009	1100	80	8/29/2009	1100	79
	Conroe Relocated C78/A321	1	5/30/2009	1000	67	6/1/2009	1000	66	9/3/2009	1000	65	6/6/2009	1200	65

How is 2009 shaping up?

Area	Monitoring Site	POC	Fourth Highest Average (ppb) 2007	2008	2009*	Current Three-Year Average (ppb)
Houston-Galveston-Brazoria						
	Houston East C1/G316	2	76	73	79	**76**
	Houston Aldine C8/AF108/X150	2	86	83	80	**83**
	Channelview C15/AH115	3	78	76	80	**78**
	Northwest Harris Co.	2	90	76	86	**84**
	Galveston Airport C34/A109/X152	1	51 *			
	Hou.DeerPrk2	1	86	76	82	**81**
	Seabrook Friendship Park C45	1	85	71	79	**78**
	Houston Bayland Park C53/A146	1	84	83	86	**84**
	Conroe Relocated C78/A321	1	76	73	65	**71**
	Houston Regional Office C81	1	68	68	80	**72**
	Manvel Croix Park C84	1	86	75	91	**84**
	Clinton C403/C304/AH113	3	74	71	78	**74**
	Houston North Wayside C405	1	78	70	69	**72**
	Houston Monroe C406	1	72	72	71	**71**
	Lang C408	2	73	71	81	**75**
	Houston Croquet C409	2	74	76	80	**76**
	Houston Westhollow C410	1	84	82	71	**79**
	Houston Texas Avenue C411	1	76	71	79	**75**
	Park Place C416	1	85	76	73	**78**
	HRM-3 Haden Road C603/A114	1	75	71	76	**74**
	Wallisville Road C617	1	92	85	75	**84**
	Danciger C618	1	77	77	74	**76**
	Mustang Bayou C619	1	86	75	71	**77**
	Texas City 34th St. C620	1	80	72	73	**75**
	Lynchburg Ferry C1015/A165	1	71	65 *	73	**69**
	Lake Jackson C1016	1	72	76	76	**74**
	Galveston 99th St.	1	87	69	76	**77**

*as of 3:16 pm C DT 9/15/2009

How is 2009 shaping up?

HGB compared to other areas in Texas

Area	Monitoring Site currently setting the DV	POC	Fourth Highest Average			Current Three-year Average
			2007	2008	2009 as of 10:17 am 9/16/2009	
			ppb	ppb	ppb	ppb
Houston-Galveston-Brazoria	Northwest Harris Co. C26/A110/X154	2	90	76	86	**84**
Dallas-Fort Worth	Keller C17	2	84	85	90	**86**
Tyler-Longview-Marshall	Longview C19/A127/C644	2	81	71	73	**75**
El Paso	Ivanhoe C414	1	78	78	69	**75**
Waco	Waco Mazanec C1037	1	72*	71	74	**72**
Beaumont-Port Arthur	SETRPC 43 Jefferson Co Airport C643	1	82	78	71	**77**
Austin	Austin Northwest C3/A322	2	76	74	76	**75**
San Antonio	San Antonio Northwest C23	2	71	78	75	**74**
Corpus Christi-Victoria	Corpus Christi Tuloso C21	1	68	73	68	**69**
Lower Rio Grande Valley	Brownsville C80/AGP180	1	58	69	60	**62**
Laredo	Laredo C44/AFGP144/P244	1	58	56	52	**55**

* The value shown for this site does not represent an entire year's worth of data (274 days of valid data).