Weekday/Weekend Differences of Toxic Air Pollutants in Houston, New York, and Philadelphia

CRC Project A-49

Presentation at Air Toxics Monitoring Data Analysis Workshop, RTP, NC

Betty Pun, Kristen Lohman, and Christian Seigneur

AER, San Ramon, CA

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Project Goals

Compare and contrast the weekday-weekend differences in three vehicle-related air toxics at three locations

Air Toxics

- elemental carbon (EC)
- formaldehyde
- benzene

Cities

- New York, NY
- Philadelphia, PA
- Houston, TX

Data Source

- EPA Air Quality System database
- Data requested August 2005
  - Most recent data May 2005; not available at all sites

Raw Data Description

- Benzene and Formaldehyde
  - Target species of the Photochemical Assessment Monitoring Station (PAMS) Network
  - Started in 1993
  - Sampling frequency (every 12th, 6th, 3rd day or everyday) and duration (1 hour, 3 hours, or 24 hours) vary among sites
- EC
  - Measured at $PM_{2.5}$ Speciation Trends Network (STN) and supplemental speciation sites
  - Started in 2000
  - Most stations operate every third day and collect 24-hour average measurements

Site Selection within Each City

- Sample record contains ≥ 30 data points for each day of the week

- Criteria satisfied due to different reasons at different sites
  - Long data record
  - Availability of data throughout the year vs. only during summer months
  - High sample frequency (daily vs. 1-in-x-days)

Data Processing

- Remove all null data and data flagged as invalid or extraordinary events
- If multiple frequencies, decimate high frequency data so that equal weights are placed on data in every month or season
- Aggregate subdaily (1-hour or 3-hour) samples (usually available during summer only) to daily averages, applying a data completeness criterion of 75%.
- Take average of co-located measurements on any given day
- Convert all gas measurements to volume mixing ratios (ppb); EC data are in $\mu g/m^3$

Quantifying Weekday/Weekend Differences

- For each
  - day of the week, or
  - a grouping of weekdays (Tuesdays, Wednesdays, Thursdays) and weekend days (Saturdays and Sundays)
- A statistic characterizing the concentration is calculated
  - mean
  - median
  - 75th percentile
- For example, say the Wednesday statistic is x $\mu g/m^3$ and the Sunday statistic is y $\mu g/m^3$, is the difference meaningful?

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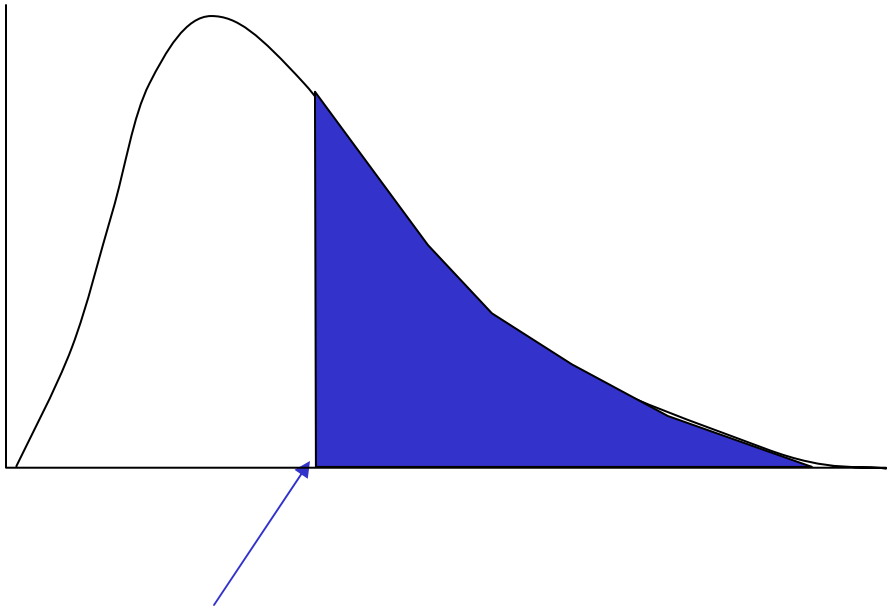
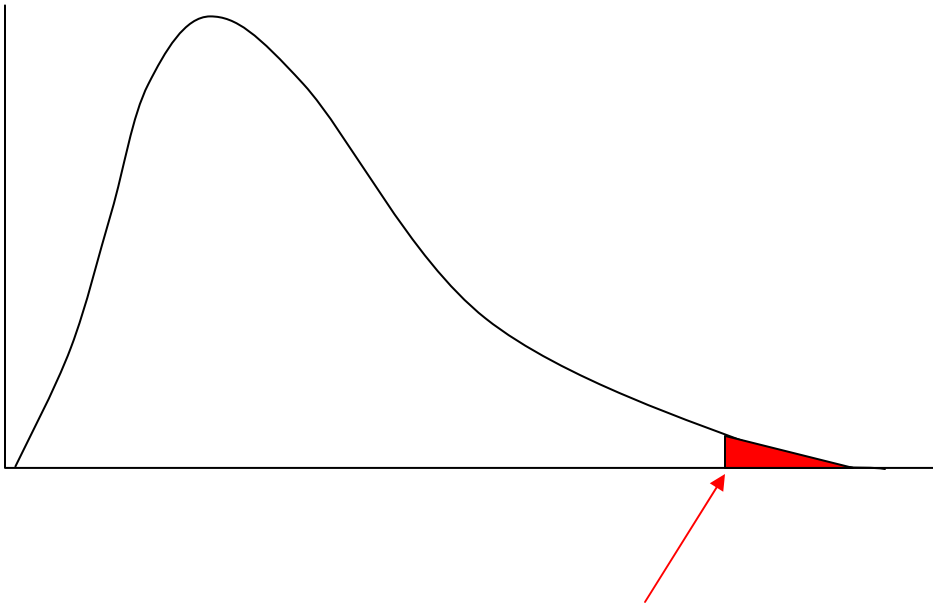
Hypothesis Testing

- Null hypothesis
  - there is no difference between weekday and weekend concentrations
- Test metric
  - a single valued function of the data
  - the larger the test statistic, the stronger the evidence that reality deviates from the null hypothesis
  - e.g., difference between Wednesday statistic and Sunday statistic (x $\mu g/m^3$ – y $\mu g/m^3$)

If the Distribution of Test Metric under Null Hypothesis (No Difference) is Known...

What is the probability of the observed metric under the null hypothesis?



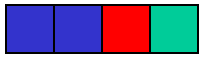


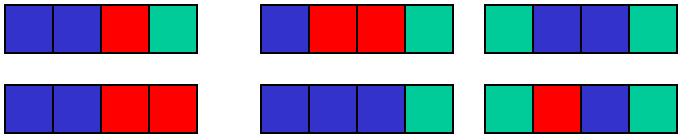
if the probability is high that the value is greater than or equal to the actual statistic, null hypothesis CANNOT be rejected

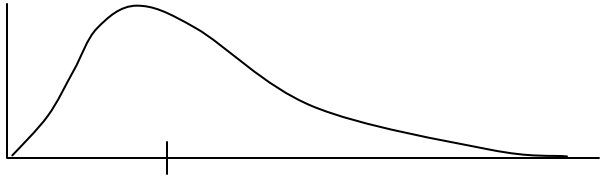
if the probability of the observed statistic is sufficiently low (e.g., less than 10% or 5%) then reject the null hypothesis

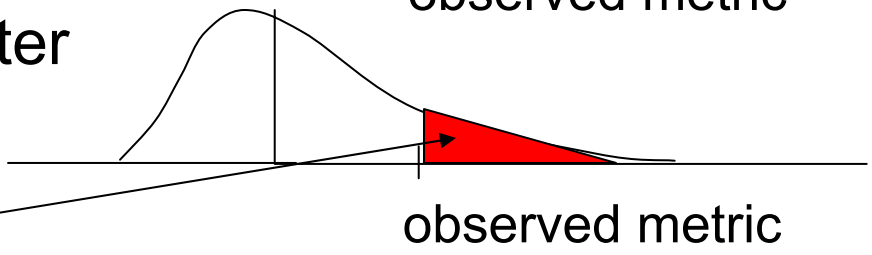
Bootstrap Resampling

- Observed data set is best estimate of population
- Bootstrap samples: resampling the observed data with replacement (each bootstrap sample represents another possible data set from the underlying population)
- Collection of metric from the boot strap samples gives the shape of the metric distribution
- Shift metric distribution to center around null hypothesis metric (e.g., 0 for no difference)
- Significant?







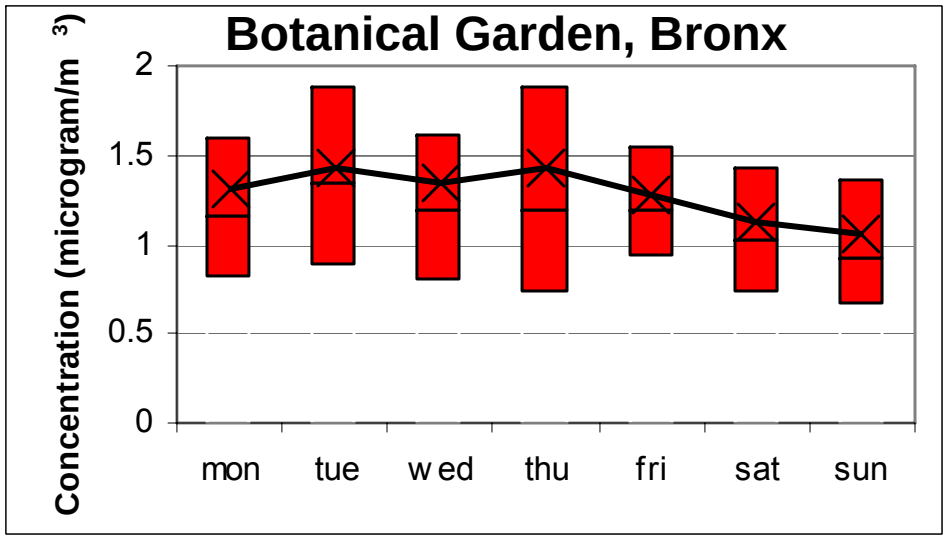


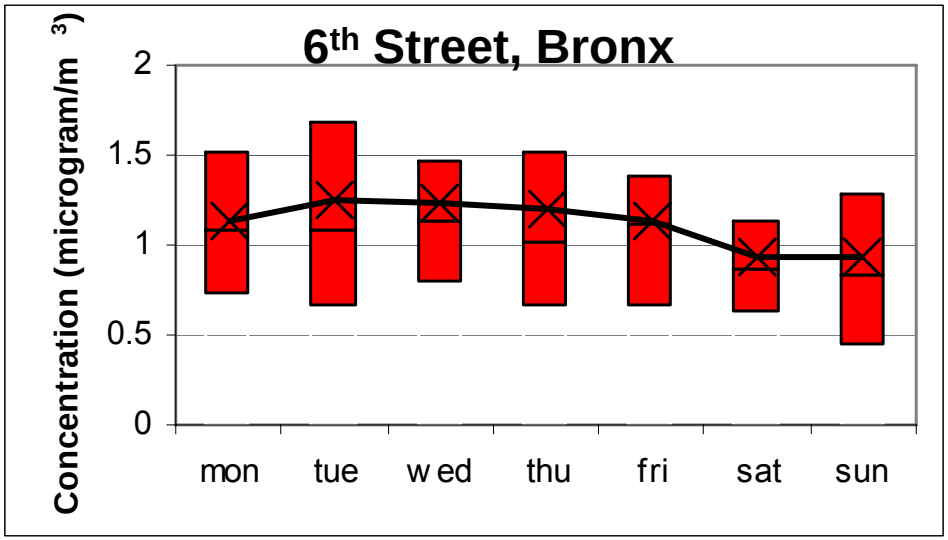
EC Sampling Sites

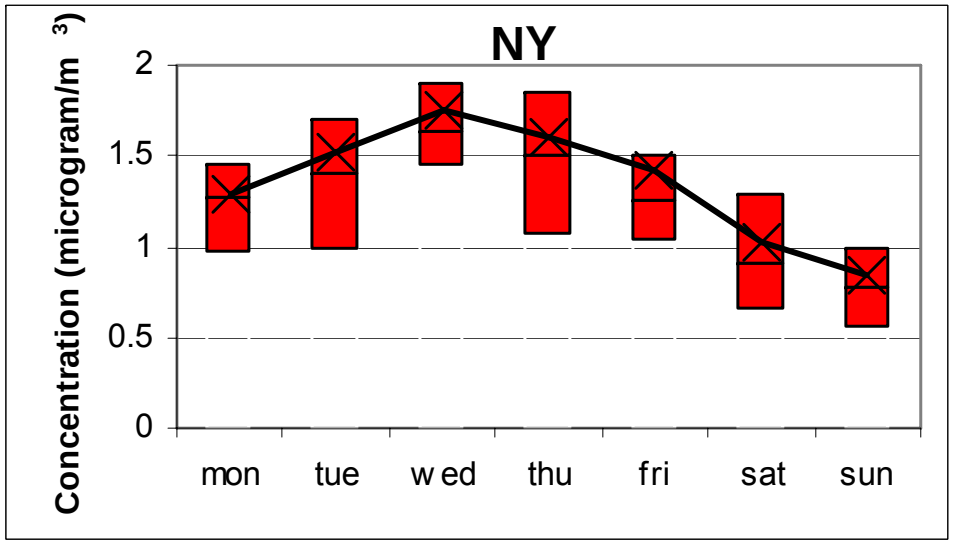
- New York
  - Bronx Botanical Garden (360050083): urban, commercial
  - Bronx 6th Street (360050110): urban, residential
  - New York (360610062): urban, commercial
  - Queens (360810124): suburban, residential
- Philadelphia
  - Philadelphia (421010004): urban, residential
- Houston
  - Aldine Mail Road (482010024): suburban, residential
  - Sheldon Road (482010026): suburban, residential
  - Bissonnet Street (482010055): urban, residential
  - Durant Street (482011039): suburban, residential
  - Hwy 1484 (483390078): urban, commercial

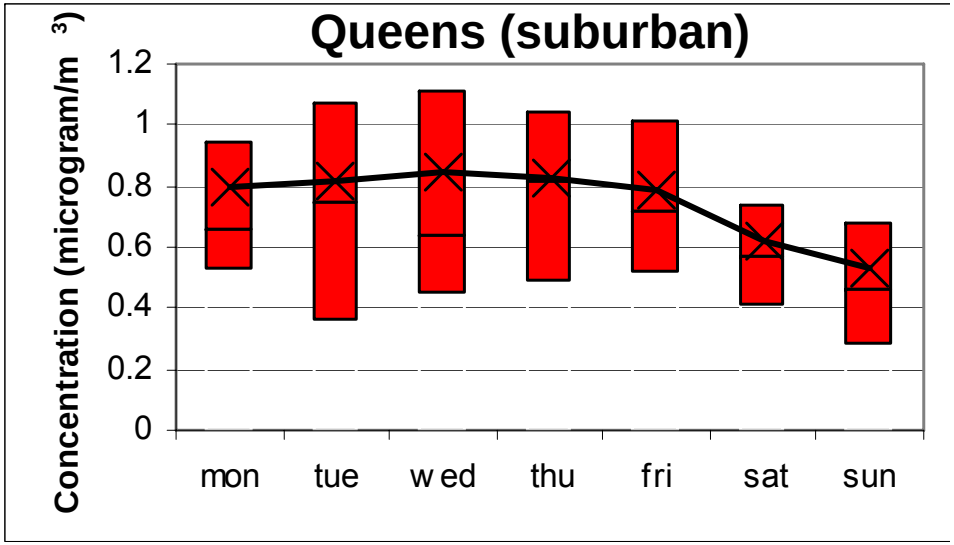
EC Mean (x) and 25th, 50th, and 75th Percentiles by Day of the Week (1)

New York



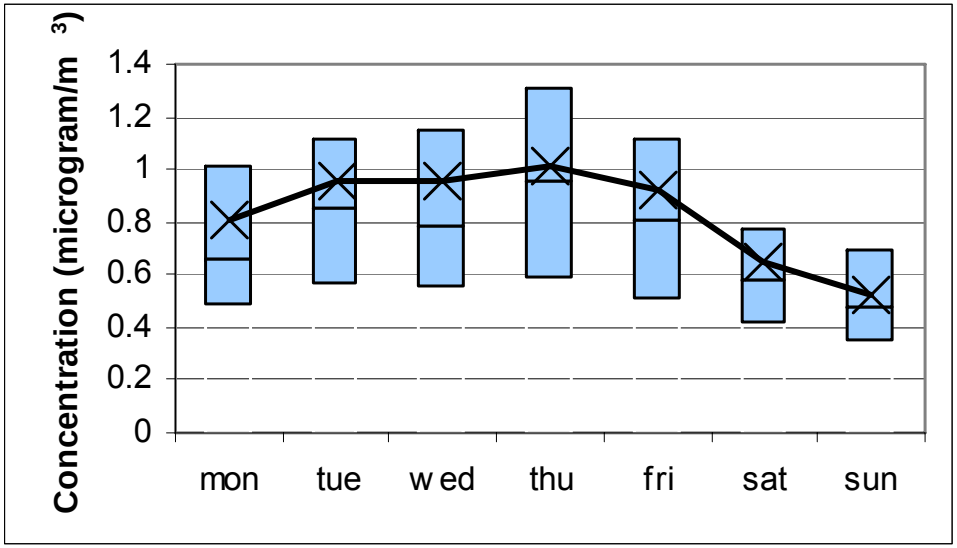






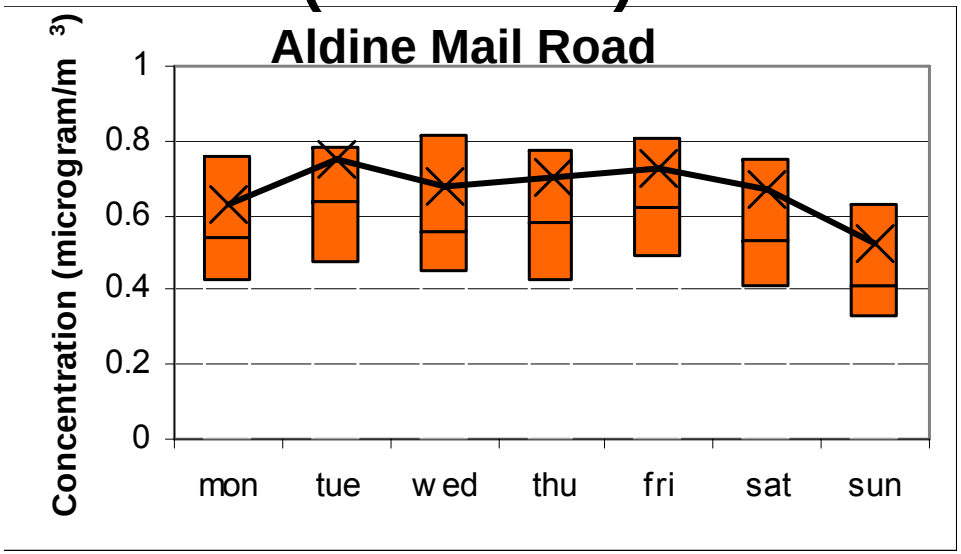
EC Mean (x) and 25th, 50th, and 75th Percentiles by Day of the Week (2)

Philadelphia

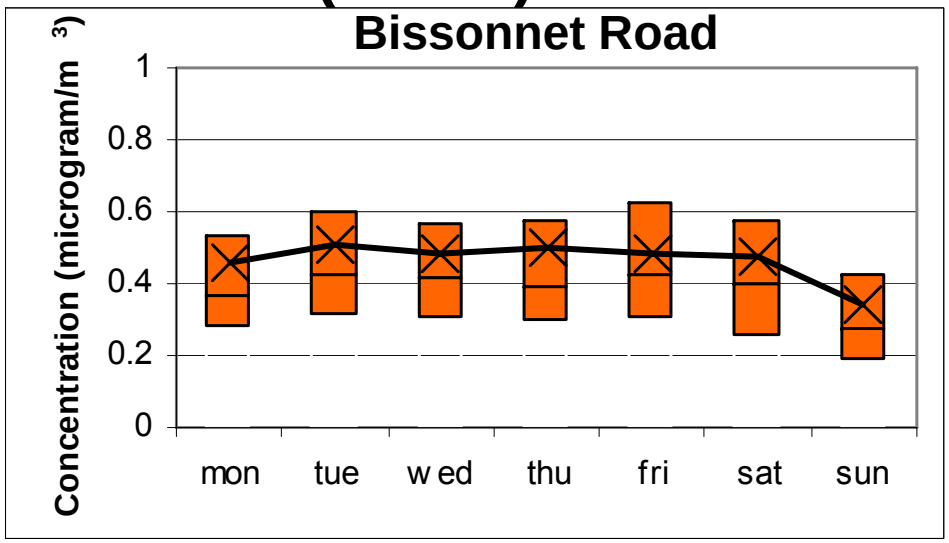


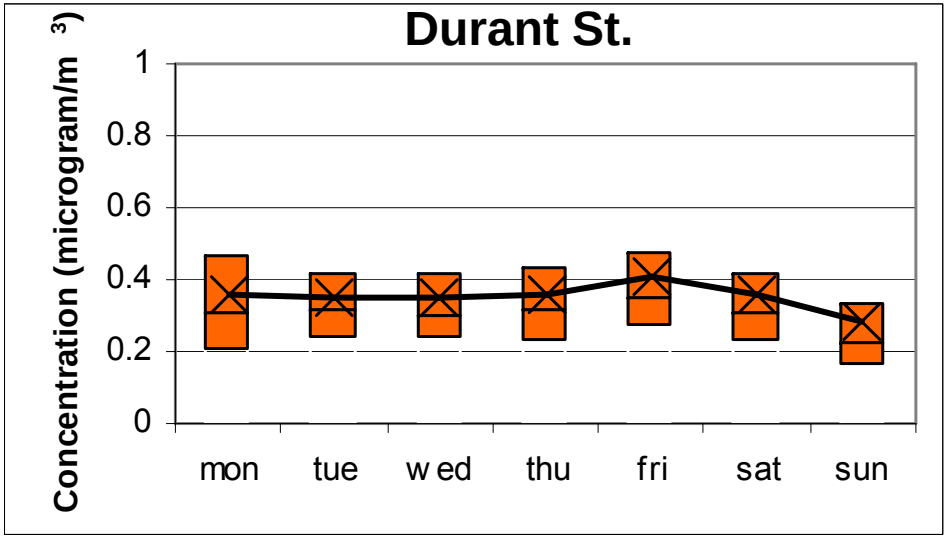
EC Mean (x) and 25th, 50th, and 75th Percentiles by Day of the Week (3)

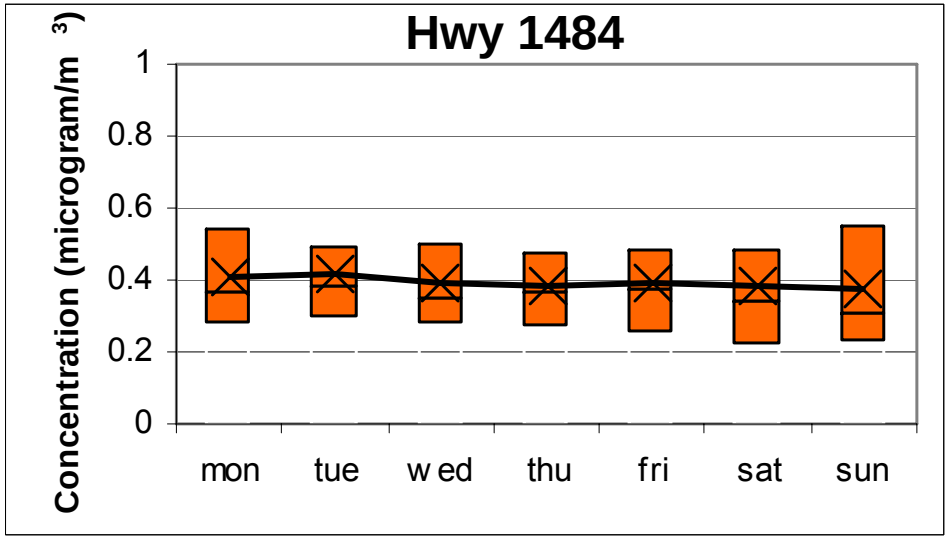
Houston (suburban)



Houston (urban)







Day-of-Week Differences in Mean EC Concentrations (μg/m³) (1)

New York (example)

6th St., Bronx

	Mon	Tue	Wed	Thu	Fri	Sat
Tue	-0.12					
Wed	-0.10	0.03				
Thu	-0.06	0.06	0.03			
Fri	0.00	0.12	0.09	0.06		
Sat	0.21	0.33	0.30	0.27	0.21	
Sun	0.21	0.33	0.30	0.27	0.21	0.00

Example: this is Monday mean – Sunday mean

Statistically significant differences in blue (90% confidence) or red (95% confidence)

Day-of-Week Differences in Mean EC Concentrations (μg/m³) (2)

Philadelphia

	Mon	Tue	Wed	Thu	Fri	Sat
Tue	-0.16					
Wed	-0.16	0.00				
Thu	-0.21	-0.05	-0.05			
Fri	-0.12	0.04	0.04	0.09		
Sat	0.16	0.31	0.31	0.36	0.28	
Sun	0.27	0.43	0.43	0.48	0.39	0.12

Statistically significant differences in blue (90% confidence) or red (95% confidence)

Day-of-Week Differences in Mean EC Concentrations ($\mu g/m^3$) (3)

Houston (suburban example)

Sheldon Rd.

	M	T	W	R	F	Sa
T	-0.03					
W	-0.02	0.02				
R	-0.02	0.02	0.00			
F	-0.03	0.00	-0.01	-0.01		
Sa	-0.05	-0.01	-0.03	-0.03	-0.02	
Su	0.06	0.09	0.07	0.07	0.09	0.10

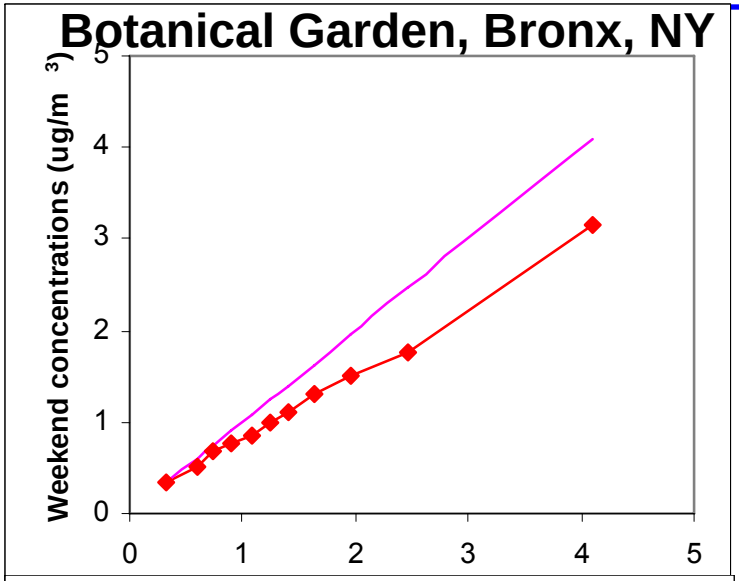
Houston (urban example)

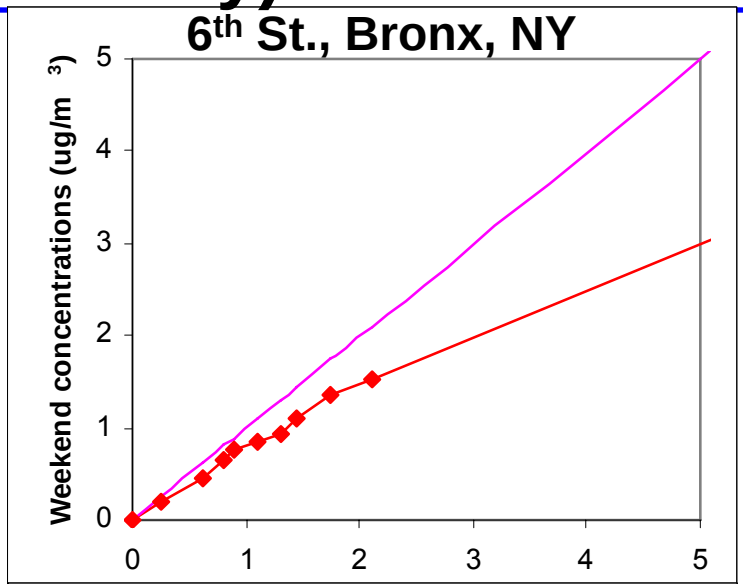
Bissonnet St.

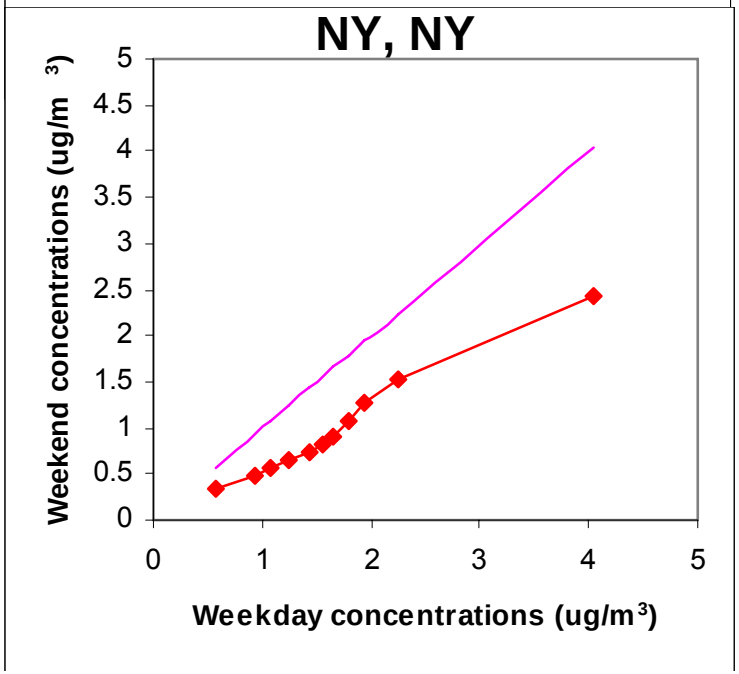
	M	T	W	R	F	Sa
T	-0.05					
W	-0.03	0.02				
R	-0.04	0.01	-0.02			
F	-0.03	0.02	0.00	0.01		
Sa	-0.02	0.04	0.01	0.03	0.02	
Su	0.11	0.16	0.14	0.15	0.14	0.13

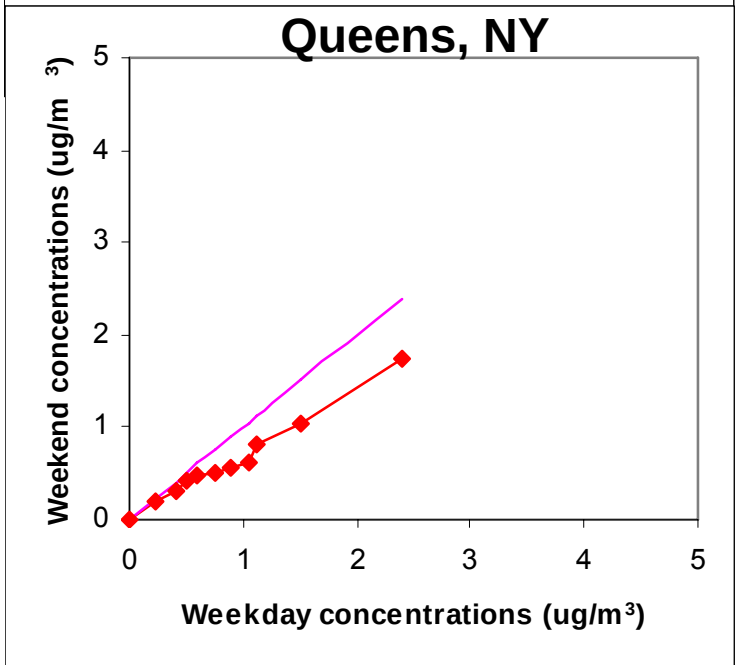
Statistically significant differences in blue (90% confidence) or red (95% confidence)

Quantile-Quantile Plots: Weekday (Tuesday, Wednesday, Thursday) vs. Weekend EC



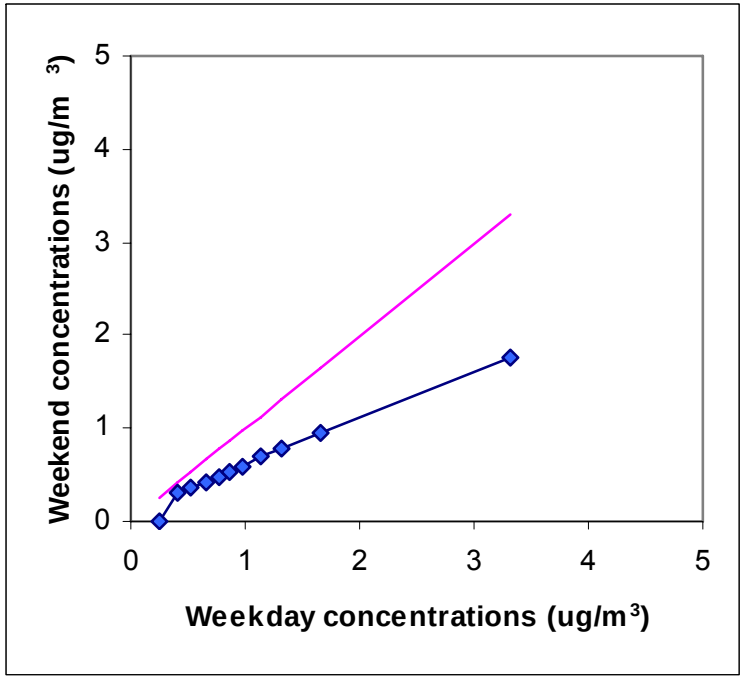






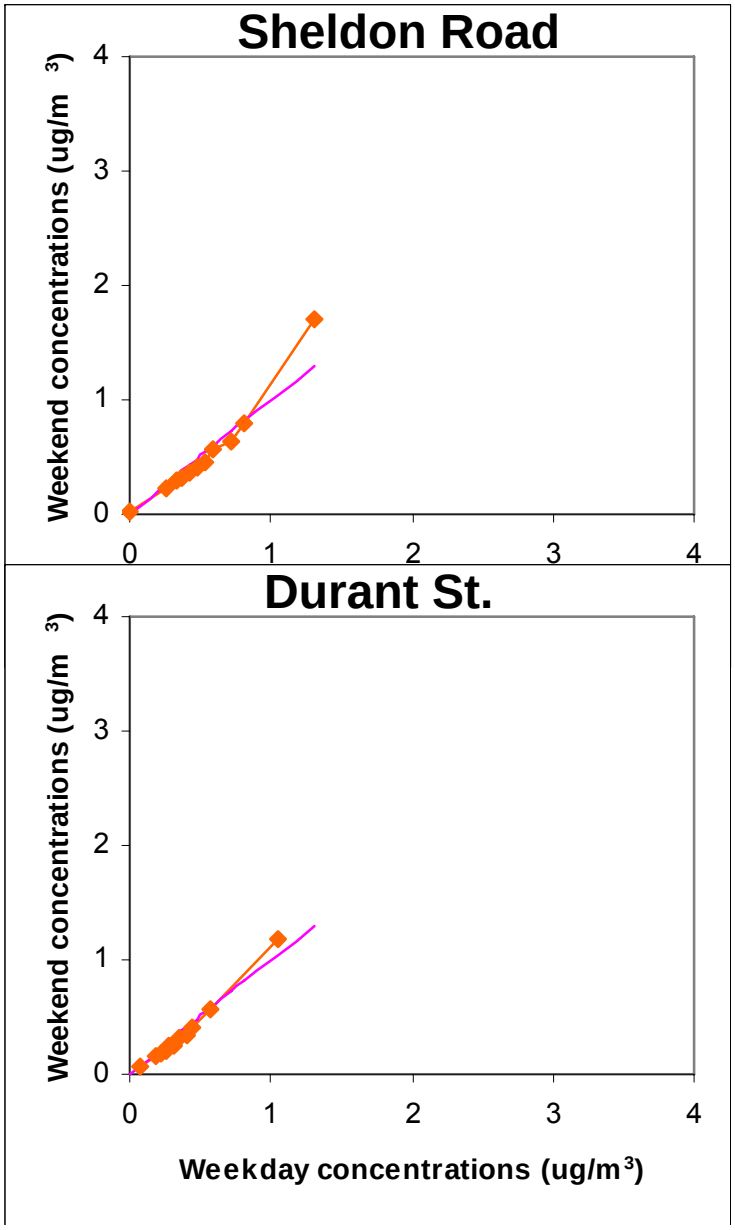
Quantile-Quantile Plots: Weekday (Tuesday, Wednesday, Thursday) vs. Weekend EC

Philadelphia

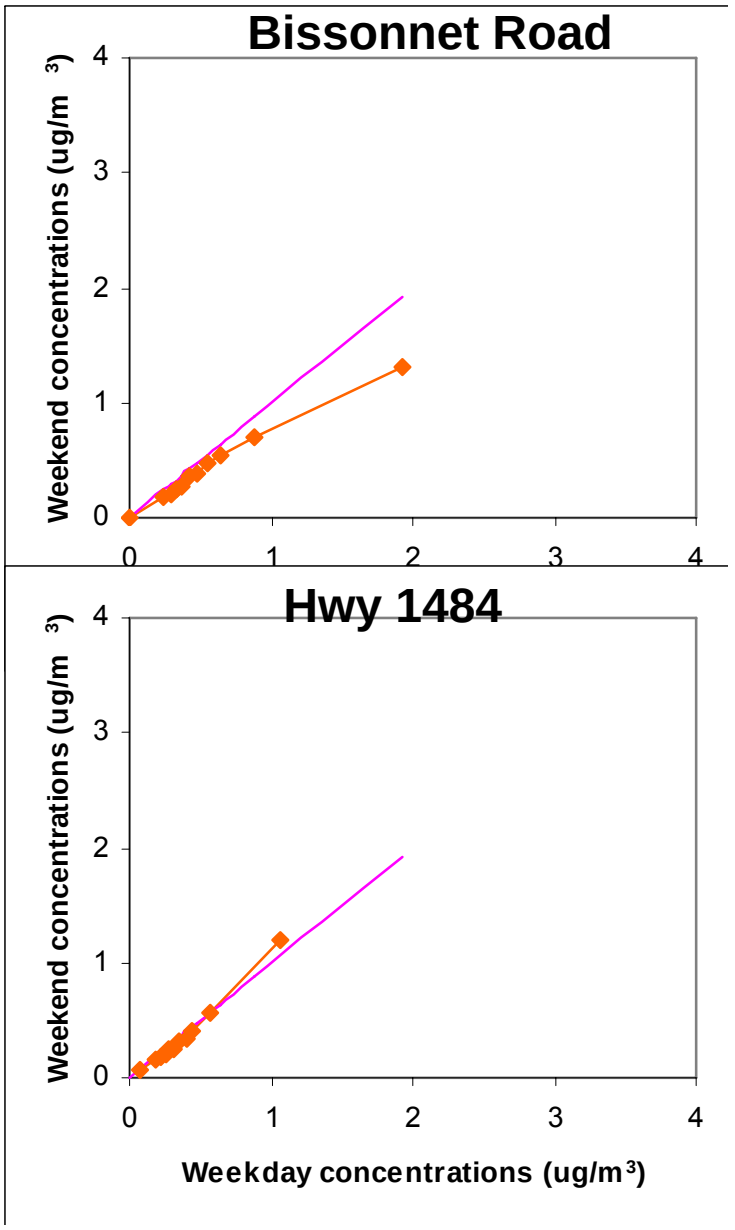


Quantile-Quantile Plots: Weekday (Tuesday, Wednesday, Thursday) vs. Weekend EC

Houston Suburban



Houston urban



Weekday-Weekend Differences in Mean EC Concentrations and Statistical Significance

Site	N_{wkd}	N_{wke}	C_{wkd}	C_{wke} ($\mu g/m^3$)	ΔC	Significant? 10%	5%
Bronx-BG	244	159	1.40	1.10	0.31	Y	Y
Bronx-6	179	110	1.23	0.93	0.30	Y	Y
NY	102	64	1.62	0.93	0.69	Y	Y
Queens	133	88	0.83	0.57	0.26	Y	Y
Philadelphia	226	147	0.98	0.59	0.39	Y	Y
Houston-A	134	98	0.71	0.59	0.11	Y	Y
Houston-S	168	119	0.51	0.48	0.03	N	N
Houston-B	197	137	0.50	0.41	0.09	Y	Y
Houston-D	242	148	0.35	0.32	0.03	Y	N
Houston-H	134	82	0.40	0.38	0.02	N	N

wkd = weekdays, Tuesdays, Wednesdays, and Thursdays
wke = weekend days, Saturdays and Sundays

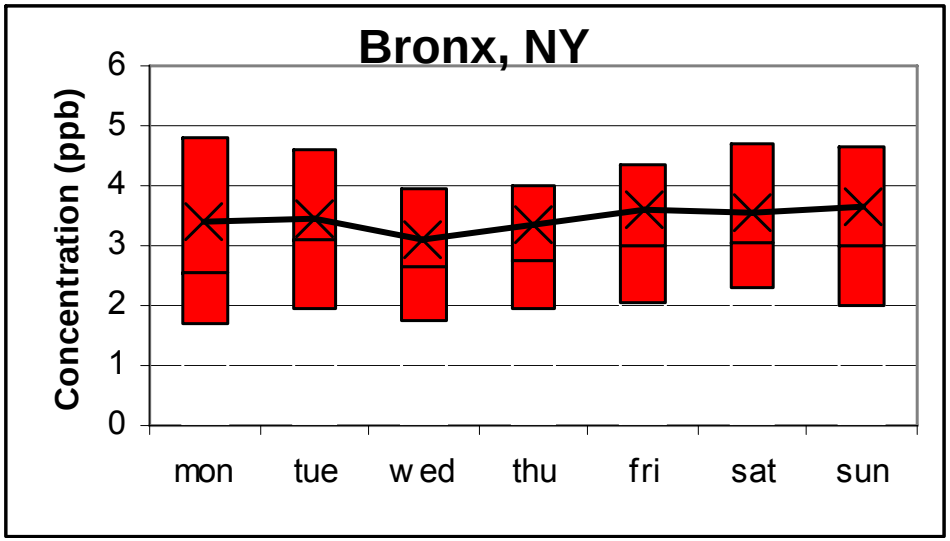
Summary: EC

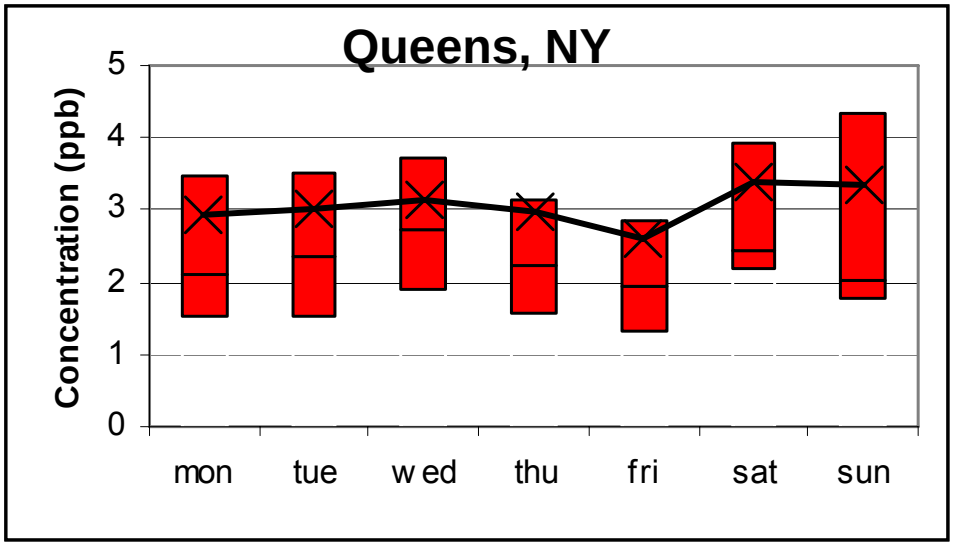
- EC concentrations in New York and Philadelphia are lower on weekends (Saturdays and Sundays) than on weekdays with differences that are statistically significant at all sites
- EC concentrations in Houston show less differences due in part to lower concentrations
  - median concentrations are lower on weekends (Saturdays and Sundays) than on weekdays with differences that are statistically significant at all sites
  - mean concentrations are lower on weekends than on weekdays but differences are statistically significant (10% level) at 3 sites out of 5
  - mean concentrations significantly lower on Sundays than on weekdays at 4 sites out of 5 and they are not significantly different on Saturdays than on weekdays

Formaldehyde Sampling Sites

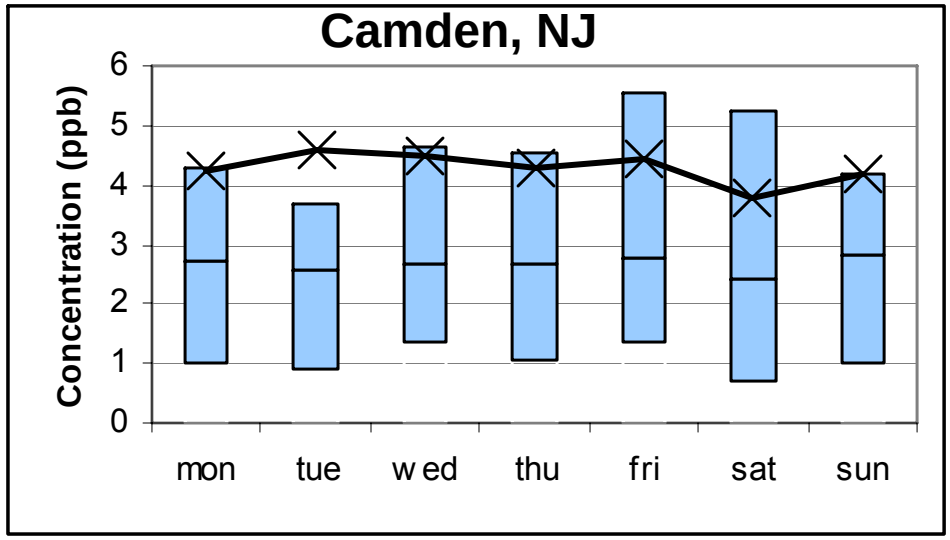
- New York
  - Bronx (360050083): urban, commercial
  - Queens (360810097): urban, residential
- Philadelphia
  - Camden (340070003): suburban, residential
  - Philadelphia (421010004): urban, residential
- Houston
  - Clinton Drive (482011035): suburban, industrial
  - Durant Street (482011039): suburban, residential

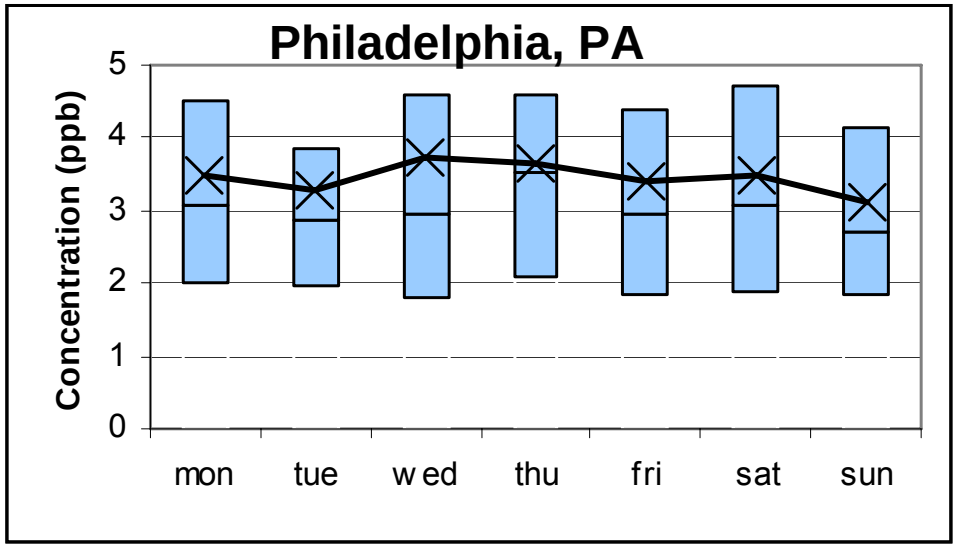
Formaldehyde Mean (x) and 25th, 50th, and 75th Percentiles by Day of the Week (1)



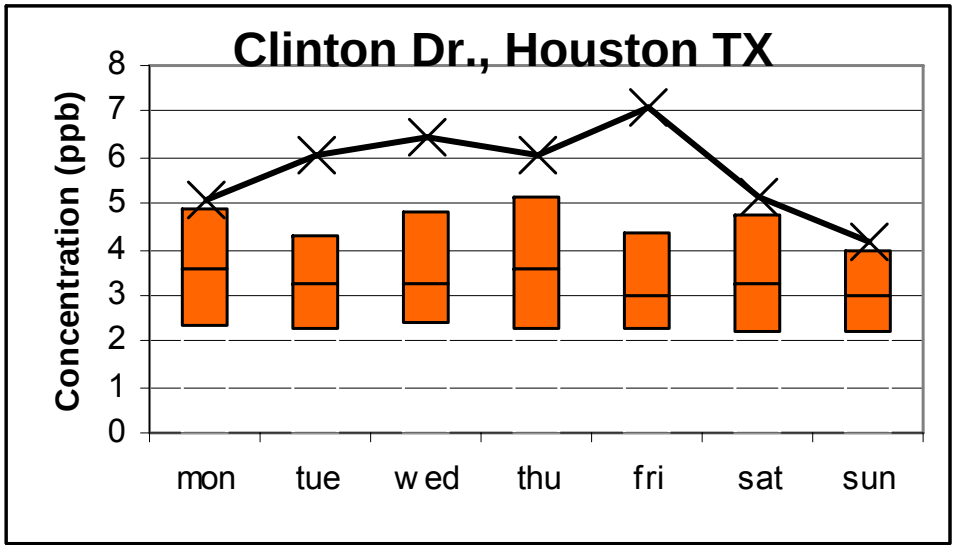


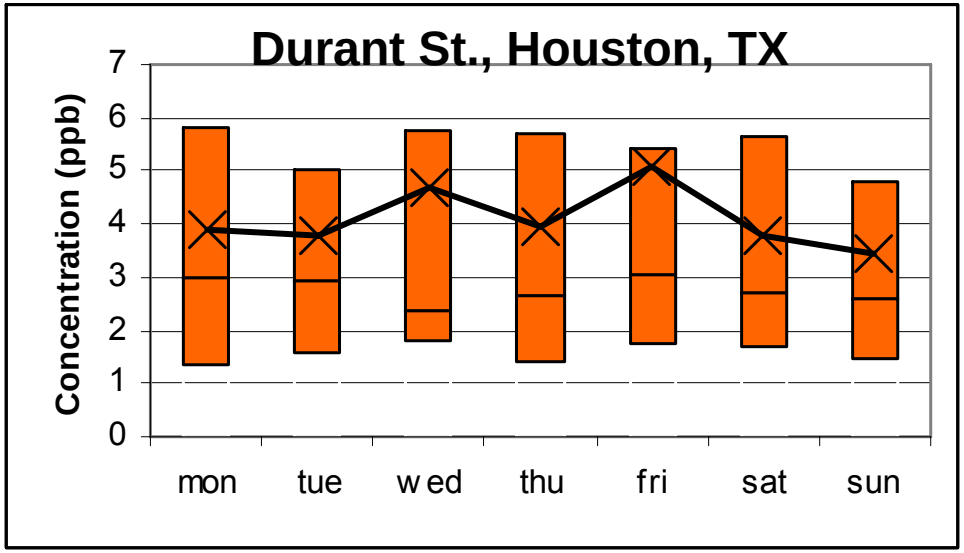
Formaldehyde Mean (x) and 25th, 50th, and 75th Percentiles by Day of the Week (2)





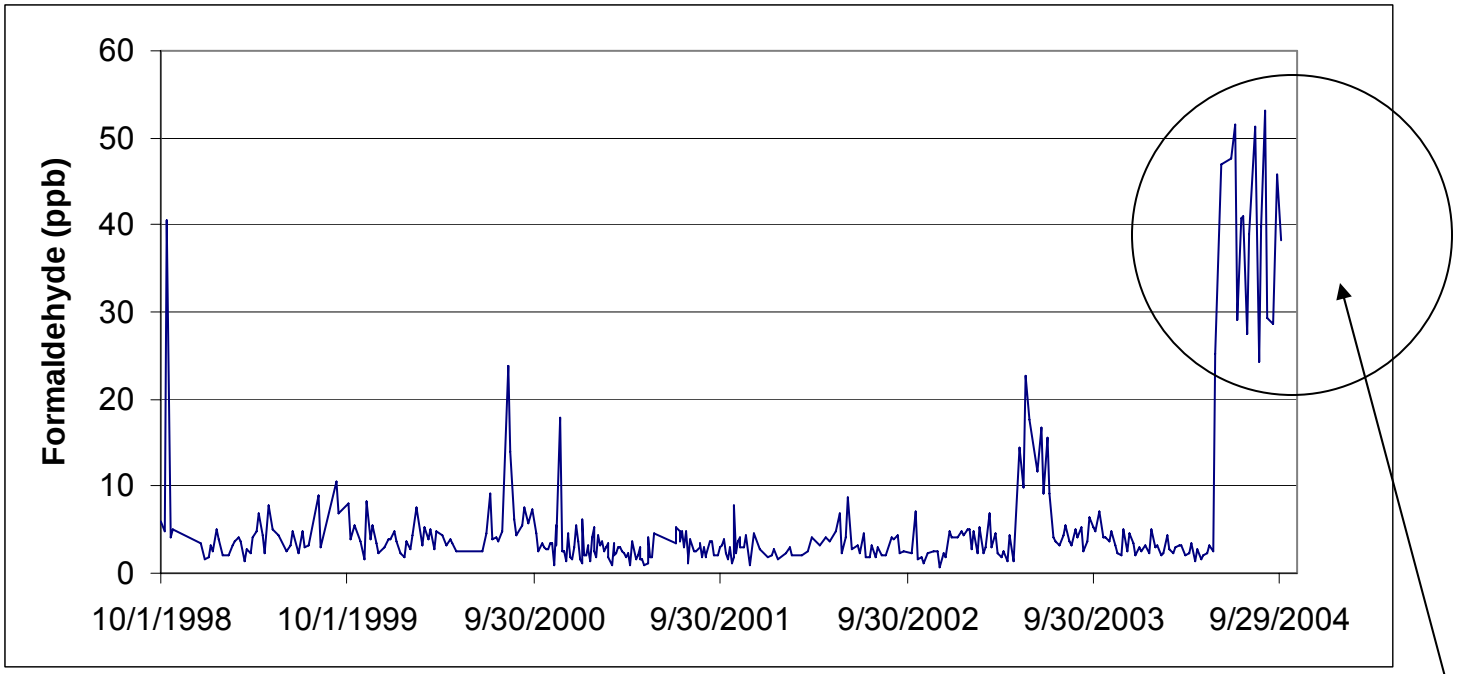
Formaldehyde Mean (x) and 25th, 50th, and 75th Percentiles by Day of the Week (3)





Mean Statistic Sensitive to High Concentrations - Example

HCHO time series at Clinton Drive, Houston



Unflagged sampling problem?
New formaldehyde source?

Day-of-Week Differences in Median HCHO Concentrations (ppb) (1)

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New York (Example)
Queens

	Mon	Tue	Wed	Thu	Fri	Sat
Tue	-0.26					
Wed	-0.62	-0.35				
Thu	-0.15	0.11	0.47			
Fri	0.15	0.41	0.77	0.30		
Sat	-0.35	-0.08	0.27	-0.20	-0.50	
Sun	0.08	0.34	0.69	0.23	-0.07	0.42

Statistically significant differences in blue (90% confidence) or red (95% confidence)

Day-of-Week Differences in Median HCHO Concentrations (ppb) (2)

Philadelphia, PA

	Mon	Tue	Wed	Thu	Fri	Sat
Tue	0.23					
Wed	0.12	-0.11				
Thu	-0.44	-0.67	-0.56			
Fri	0.13	-0.10	0.01	0.57		
Sat	-0.01	-0.24	-0.13	0.43	-0.14	
Sun	0.39	0.16	0.27	0.83	0.26	0.40

Statistically significant differences in blue (90% confidence) or red (95% confidence)

Day-of-Week Differences in Median HCHO Concentrations (ppb) (3)

Houston (Example)
Durant St.

	Mon	Tue	Wed	Thu	Fri	Sat
Tue	0.04					
Wed	0.60	0.56				
Thu	0.30	0.26	-0.30			
Fri	-0.08	-0.12	-0.68	-0.38		
Sat	0.28	0.23	-0.33	-0.03	0.35	
Sun	0.37	0.33	-0.23	0.07	0.44	0.09

Statistically significant differences in blue (90% confidence) or red (95% confidence)

Weekday-Weekend Differences in Median HCHO Concentrations and Statistical Significance

Site	N_{wkd}	N_{wke}	C_{wkd}	C_{wke} (ppb)	ΔC	Significant? 10%	5%
NY-Bronx	221	137	2.78	3.02	-0.24	N	N
NY-Queens	106	72	2.66	2.38	0.27	N	N
Camden	167	103	2.66	2.64	0.02	N	N
Philadelphia	230	154	3.09	2.82	0.27	N	N
Houston-C	161	90	3.32	3.23	0.09	N	N
Houston-D	156	101	2.84	2.68	0.16	N	N

wkd = weekdays, Tuesdays, Wednesdays, and Thursdays
wke = weekend days, Saturdays and Sundays

Summary: HCHO

- Formaldehyde concentrations are not statistically significantly different on weekends (Saturdays and Sundays) than on weekdays in NY, Philadelphia, and Houston
  - median concentrations on Sundays can be lower (as much as 0.7 ppb) or higher (as much as 0.3 ppb) than those on Wednesdays at different sites within each city
  - 75^{th} percentile concentrations on Sundays higher than those on Wednesdays in NY (by 0.6-0.7 ppb), but lower in Philadelphia (by 0.4 ppb) and Houston (0.8-1.0 ppb)

Benzene Sampling Sites

New York

- Bronx Botanical Garden (360050083): u, c
- Kings (360470118): s, r
- Queens (360810098): u, r
- Richmond (360850055): u, r

Philadelphia

- Camden (340070003): s, r
- Philadelphia (421010004): u, r
- Philadelphia Amtrak (421010136): u, r

Houston

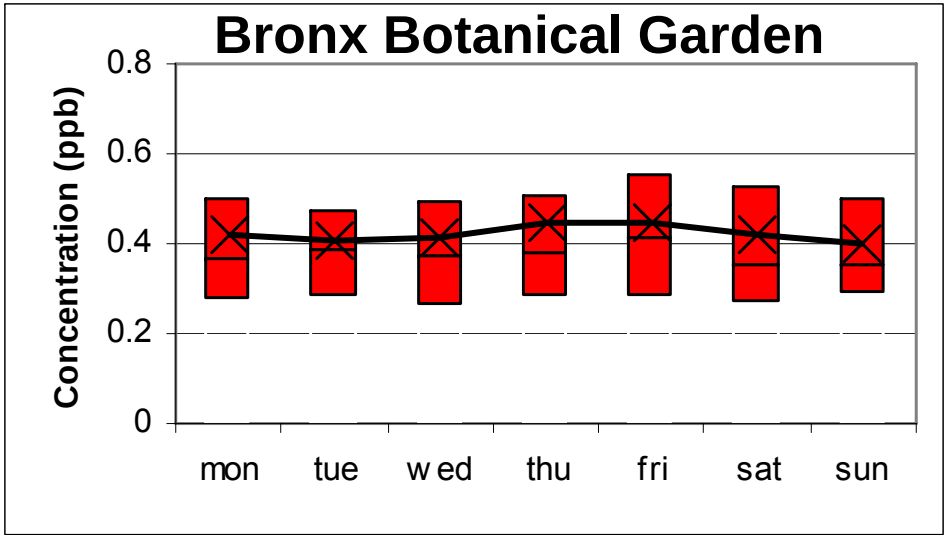
- Aldine Mail Rd. (482010024): s, r
- Sheldon Rd. (482010026): s, r
- Kitzman (482010029): u, r
- Bissonnet St. (482010055): u, r
- Stewart St. (482010057): u, r
- Bayway Dr. (482010058): u, r
- Old Hwy 146 (482010061): s, c
- Old Galveston Rd. (482010064): s, i
- Central St. (482010069): s, r
- Haden Rd. (482010803): s, i
- Clinton Dr. (482011035): s, i
- Durant St. (482011039): s, r

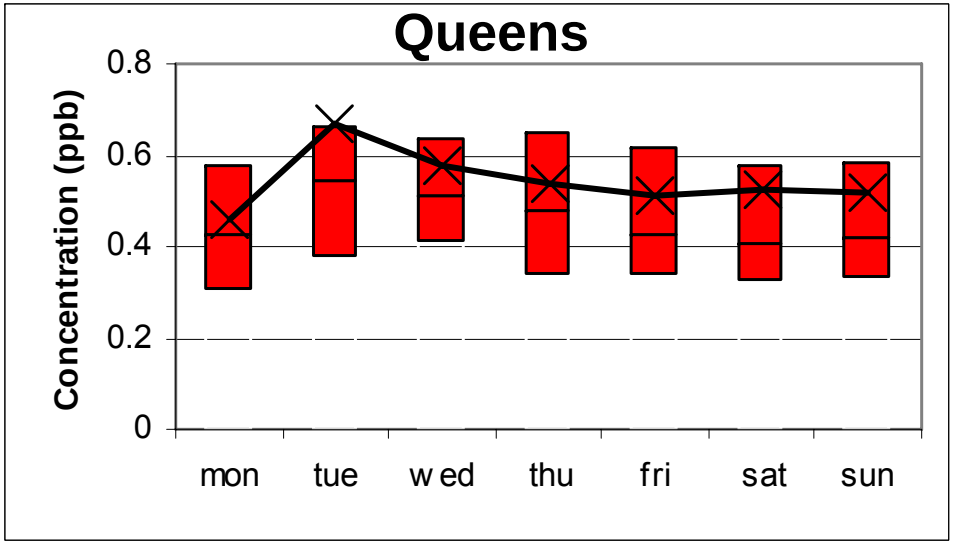
Key:

u = urban
c = commercial
r = residential
s = suburban
i = industrial

Benzene Mean (x) and 25th, 50th, and 75th Percentiles by Day of the Week (1)

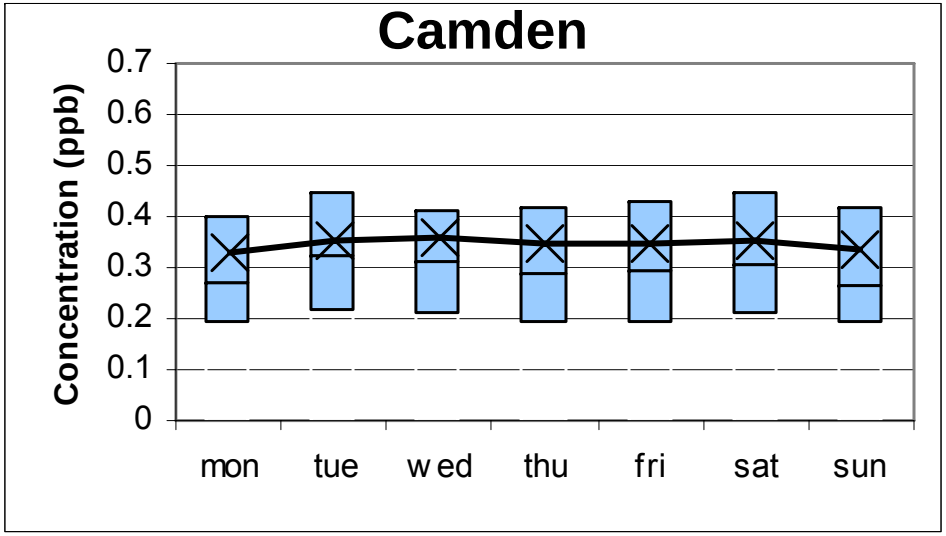
New York (Examples)

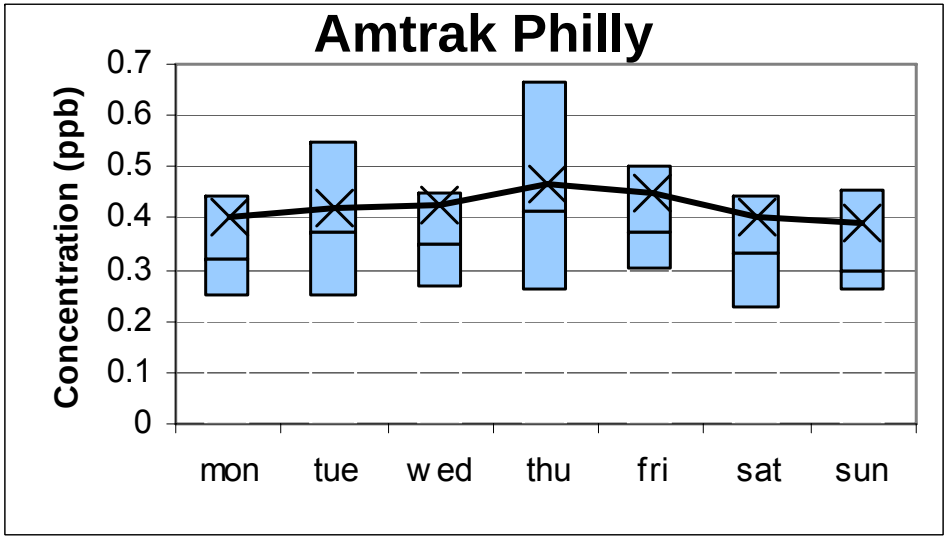




Benzene Mean (x) and 25th, 50th, and 75th Percentiles by Day of the Week (2)

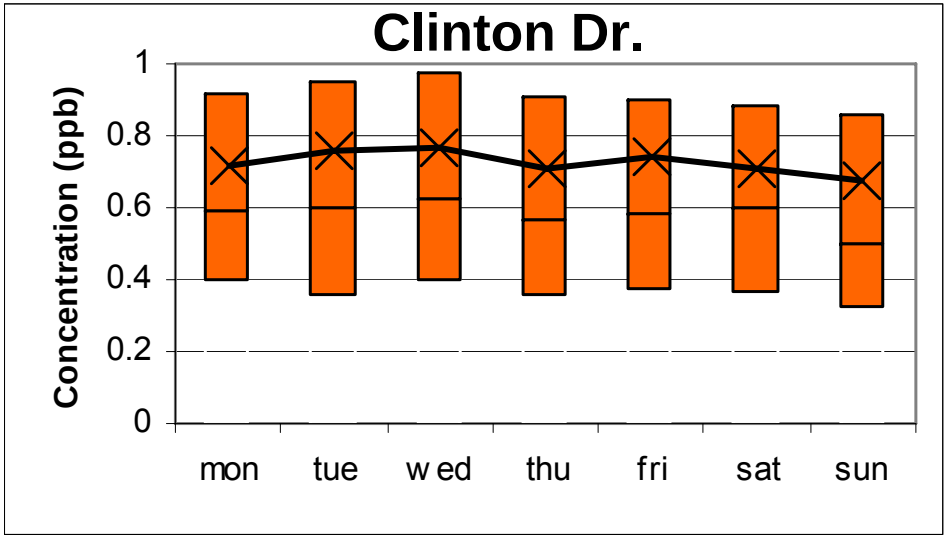
Philadelphia (Examples)

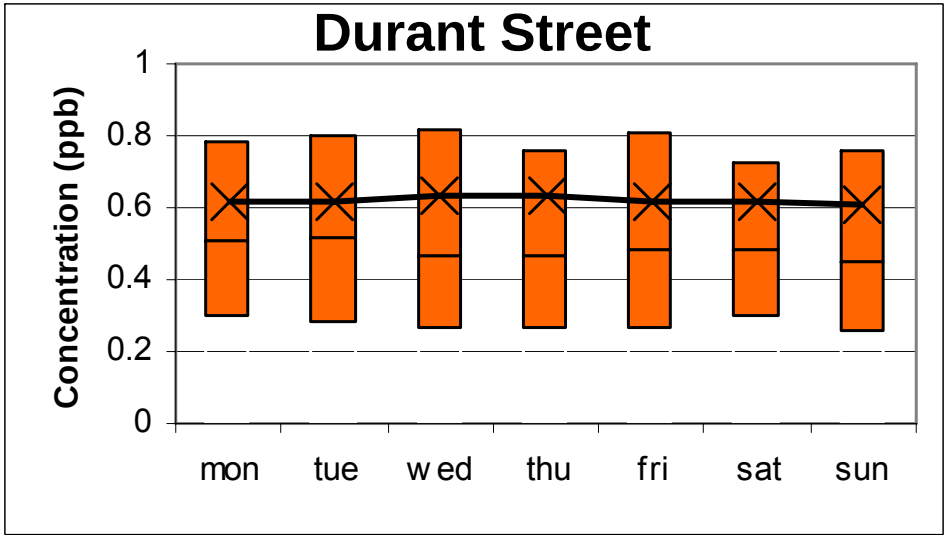




Benzene Mean (x) and 25th, 50th, and 75th Percentiles by Day of the Week (3)

Houston (Examples)





Day-of-Week Differences in Median Benzene Concentrations (ppb) (1)

Atmospheric and Environmental Research, Inc.

New York (Example)
Bronx Botanical Garden

	Mon	Tue	Wed	Thu	Fri	Sat
Tue	-0.02					
Wed	0.00	0.02				
Thu	-0.01	0.01	-0.01			
Fri	-0.05	-0.02	-0.04	-0.03		
Sat	0.02	0.04	0.02	0.03	0.06	
Sun	0.02	0.04	0.02	0.03	0.06	0.00

Statistically significant differences in blue (90% confidence) or red (95% confidence)

Day-of-Week Differences in Median Benzene Concentrations (ppb) (2)

Philadelphia (Example)
Camden

	Mon	Tue	Wed	Thu	Fri	Sat
Tue	-0.05					
Wed	-0.04	0.01				
Thu	-0.01	0.04	0.02			
Fri	-0.02	0.03	0.01	-0.01		
Sat	-0.03	0.02	0.01	-0.02	-0.01	
Sun	0.01	0.06	0.04	0.02	0.03	0.04

Statistically significant differences in blue (90% confidence) or red (95% confidence)

Day-of-Week Differences in Median Benzene Concentrations (ppb) (3)

Houston (Suburban example) Clinton Dr.

	Mon	Tue	Wed	Thu	Fri	Sat
T	-0.01					
W	-0.04	-0.03				
R	0.02	0.03	0.06			
F	0.01	0.01	0.04	-0.02		
Sa	-0.01	0.00	0.03	-0.03	-0.01	
Su	0.09	0.10	0.12	0.07	0.08	0.09

Houston (Urban example) Bissonnet St.

	Mon	Tue	Wed	Thu	Fri	Sat
T	0.01					
W	0.01	0.00				
R	0.03	0.02	0.02			
F	0.03	0.02	0.02	0.00		
Sa	0.03	0.02	0.02	0.00	0.00	
Su	0.02	0.01	0.01	-0.01	-0.01	-0.01

Statistically significant differences in blue (90% confidence) or red (95% confidence)

Weekday-Weekend Differences in Median Benzene Concentrations & Statistical Significance

Site	N_{wkd}	N_{wke}	C_{wkd}	C_{wke} (ppb)	ΔC	Significant? 10%	5%
NY-Bronx	232	163	0.38	0.35	0.03	Y	Y
NY-Queens	125	84	0.51	0.43	0.08	Y	Y
(statistically significant differences not observed at other NY sites)							
Camden	279	191	0.31	0.30	0.01	N	N
Philadelphia	102	68	0.38	0.33	0.05	Y	N
Houston-C	1078	771	0.59	0.55	0.04	Y	N
Houston-B	308	207	0.31	0.30	0.01	N	N

wkd = weekdays, Tuesdays, Wednesdays, and Thursdays
wke = weekend days, Saturdays and Sundays

Summary: Benzene

- Benzene concentrations are statistically significantly different on weekends than on weekdays at some sites within each city but not all sites
  - median concentrations on Sundays are slightly lower (0.1 to 0.2 ppb) than or very similar to those on Wednesdays at different sites within each city
  - 75th percentile concentrations on Sundays very similar to those on Wednesdays, except one site in Houston (Wednesday greater by 0.5 ppb)

Conclusions - EC

- Significant decrease in concentrations during weekends at most sites
- Differences more significant at NY and Philadelphia then Houston, due in part to lower concentrations at Houston
- EC is emitted from combustion sources, including heavy duty diesel trucks, whose activities are known to decrease by 40-80%[(1)] on weekends compared to weekdays

(1) Chinkin et al. (2003) J. AWMA, 53:829-843

Conclusions - HCHO

- Differences between weekend (Saturday + Sundays) and weekday (Tuesday through Thursday) concentrations not statistically significant
- Pairs of weekend day and weekdays show statistically significant differences at individual sites, but no consistent trend identified
- HCHO is both emitted and formed in the atmosphere; the weekday-weekend change depends on
  - emissions of VOC as well as HCHO
  - chemistry of formation and destruction of HCHO

Conclusions - Benzene

- Differences between weekend (Saturday + Sundays) and weekday (Tuesday through Thursday) concentrations statistically significant at some sites in each city but not all
- Benzene is emitted from gasoline vehicles (and other sources). The change in activity in gasoline vehicles on weekends (~10-15%)[1] is less than that that of diesel trucks
- Factors such as proximity to roads may affect a monitor's ability to detect the change in benzene concentrations on weekends vs. weekdays

(1) Chinkin et al. (2003) J. AWMA, 53:829-843

On-going Work

- For sites with sufficient data, perform weekday/weekend analysis for the summer season
- Understand factors contributing to the weekday/weekend differences (or the lack of differences)
  - Emissions
  - Chemistry
  - Other factors
- Next step: model application

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- Coordinating Research Council provided funding for this work under Project A-49
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