Operational Use of Air Quality Numerical Forecast Model Guidance

William Ryan

Michelle Palmer

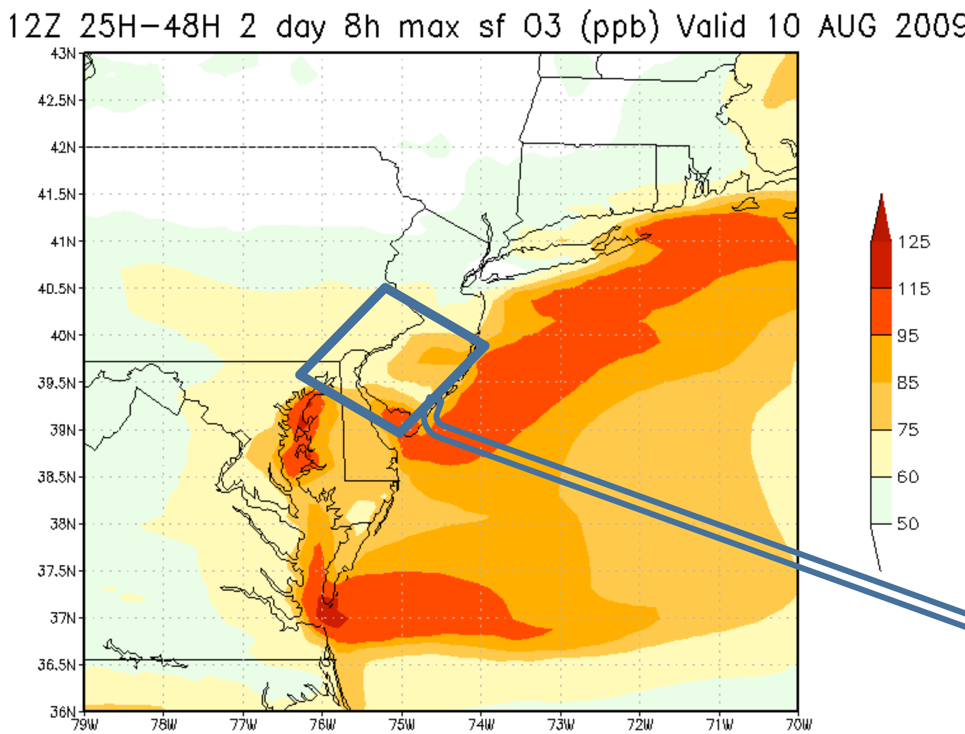
Department of Meteorology

The Pennsylvania State University

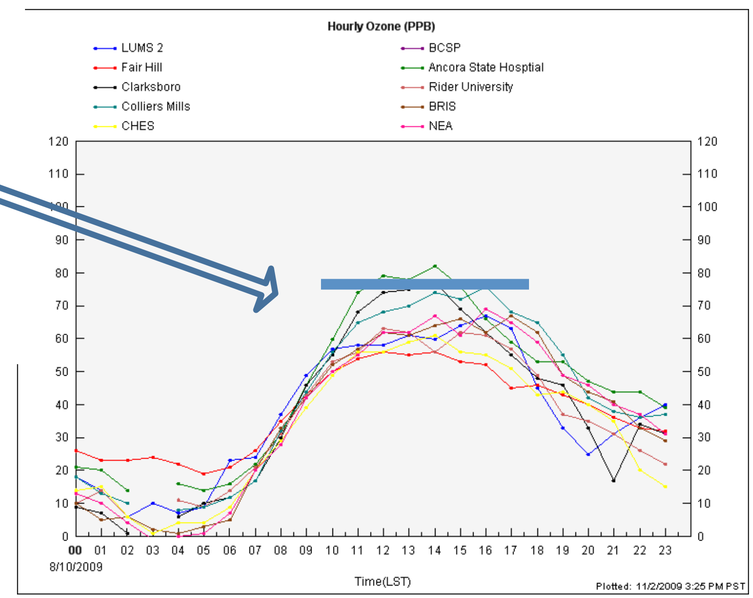
International Workshop on Air Quality Forecasting Research

Boulder, CO   December, 2009

What Do We Forecast?



Forecasts are verified by peak 8-hour averaged O_3 at location of state and local monitors



While model forecast location of peak O_3 is of interest, air quality alert applies to entire metropolitan area in order to reduce emissions as well as protect health

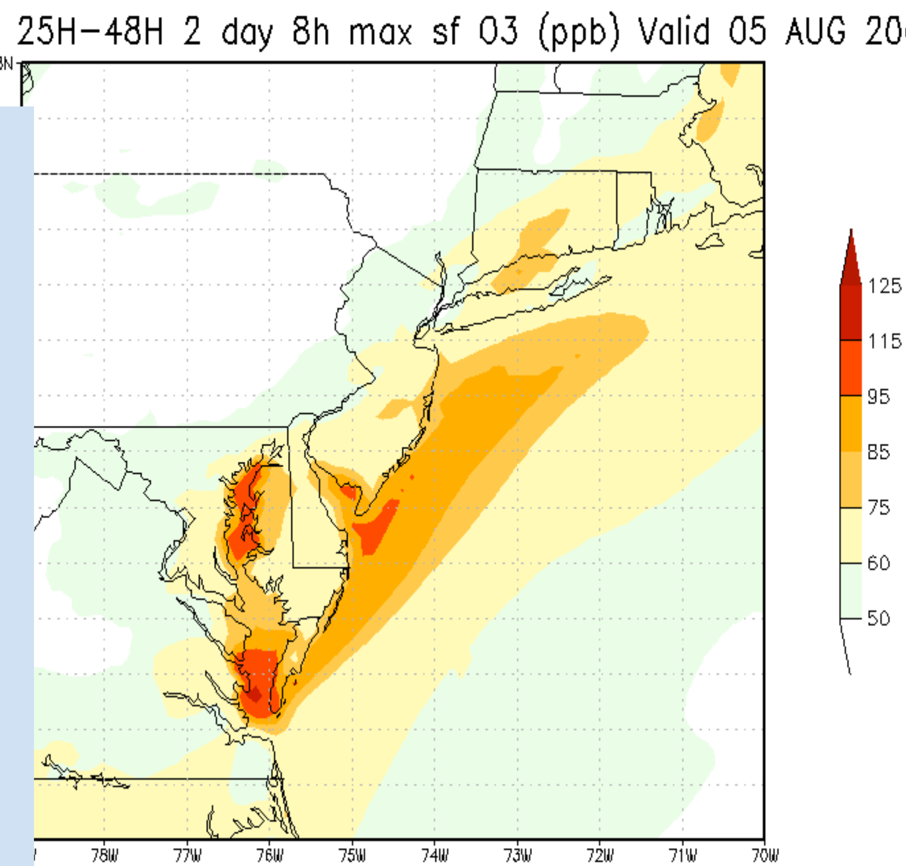
Complex Land-Sea Boundary Effects

Numerical O_3 models (NAQC shown at right) often forecast high O_3 along land-sea boundaries.

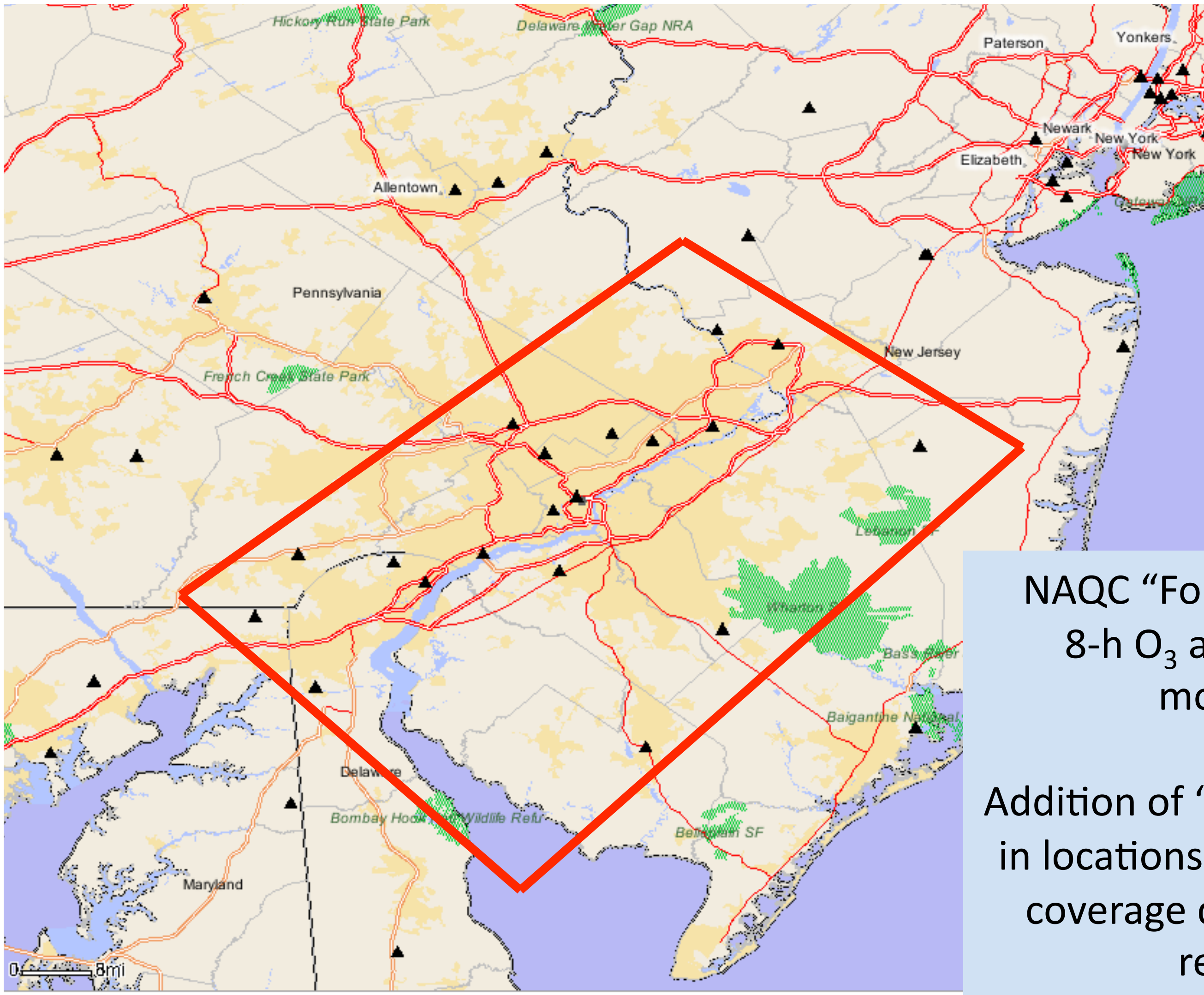
These areas of high concentrations can "bleed" inland.

First Order Post-Processing: Restrict domain peak O_3 guidance to location of monitors.

Can retrieve "point" data quickly from www/weather.gov/aq using Firefox



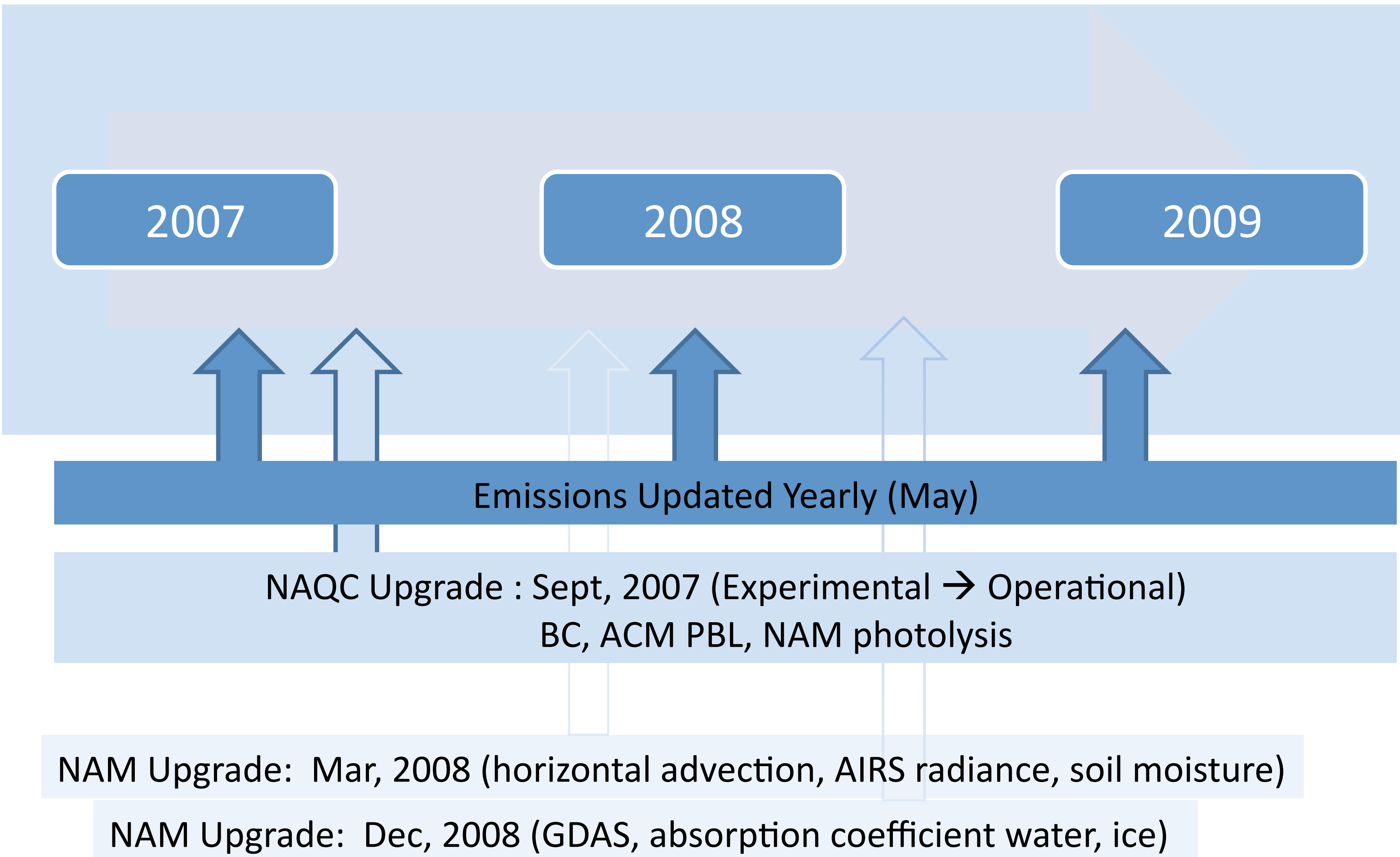
Philadelphia O_3 Monitor Network (2007-2009)



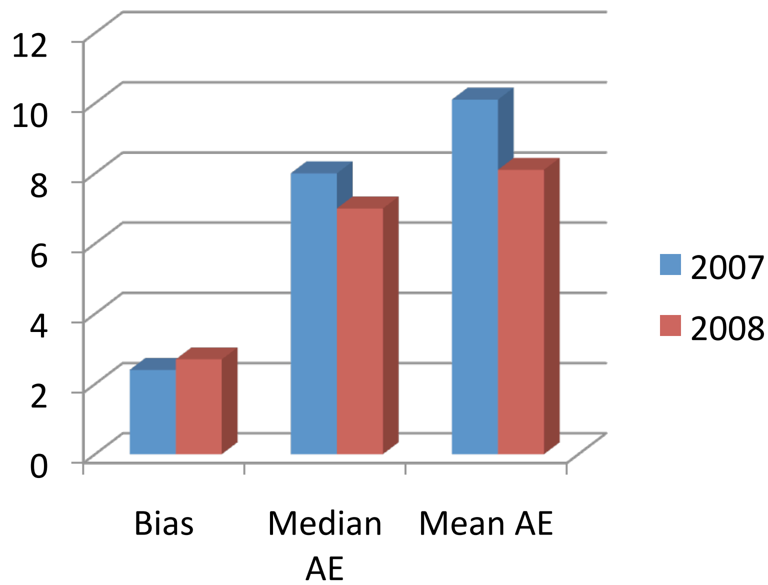
NAQC "Forecast" is peak 8-h O_3 at location of monitors.

Addition of "proxy" monitors in locations with less dense coverage does not affect results.

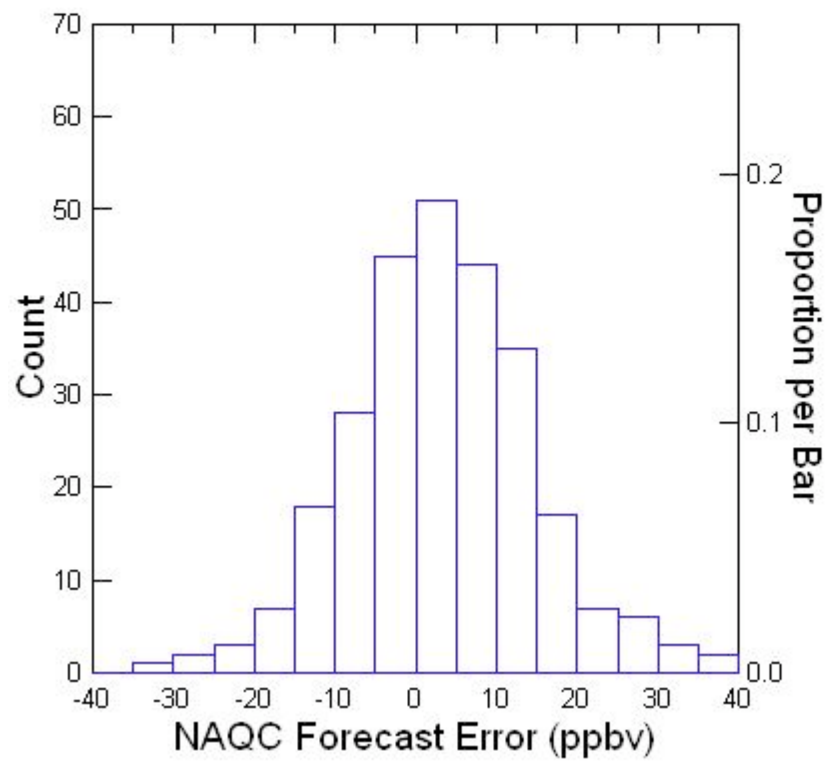
Numerical Forecast Model Guidance:
NAQC Model Changes During Period of Interest



NAQC Forecast Skill in PHL 2007-2008

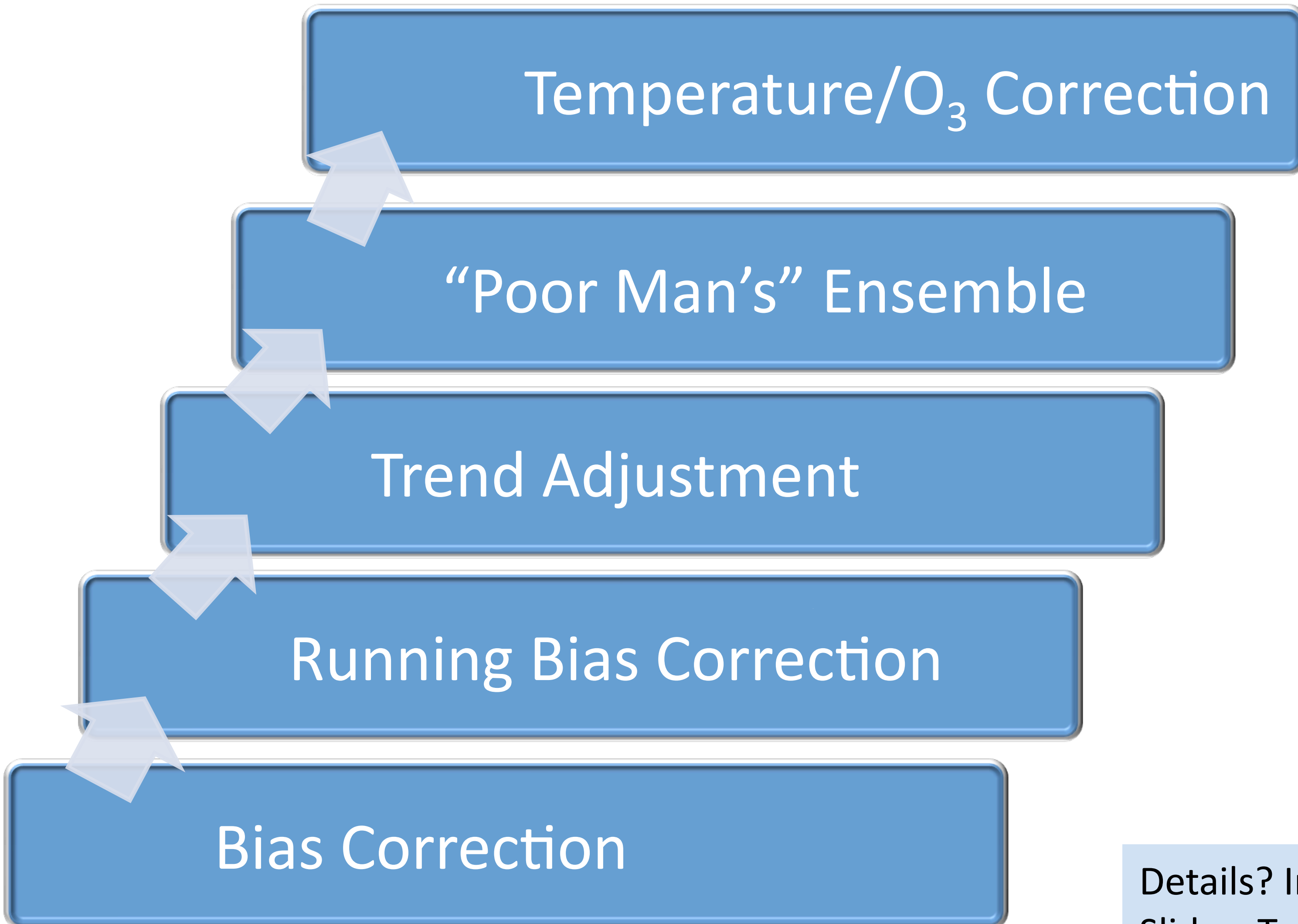


PHL NAQC Forecasts		
	r	r^2
2007	0.76	0.58
2008	0.76	0.58



NAQC Forecast Error for PHL Area (2007-2008)

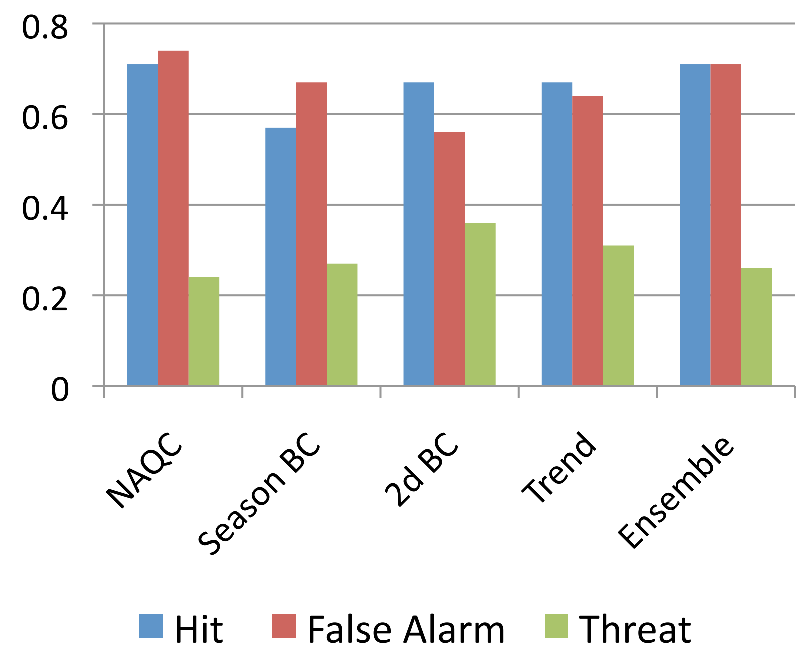
Ladder of Simple Post Processing in the Operational Environment



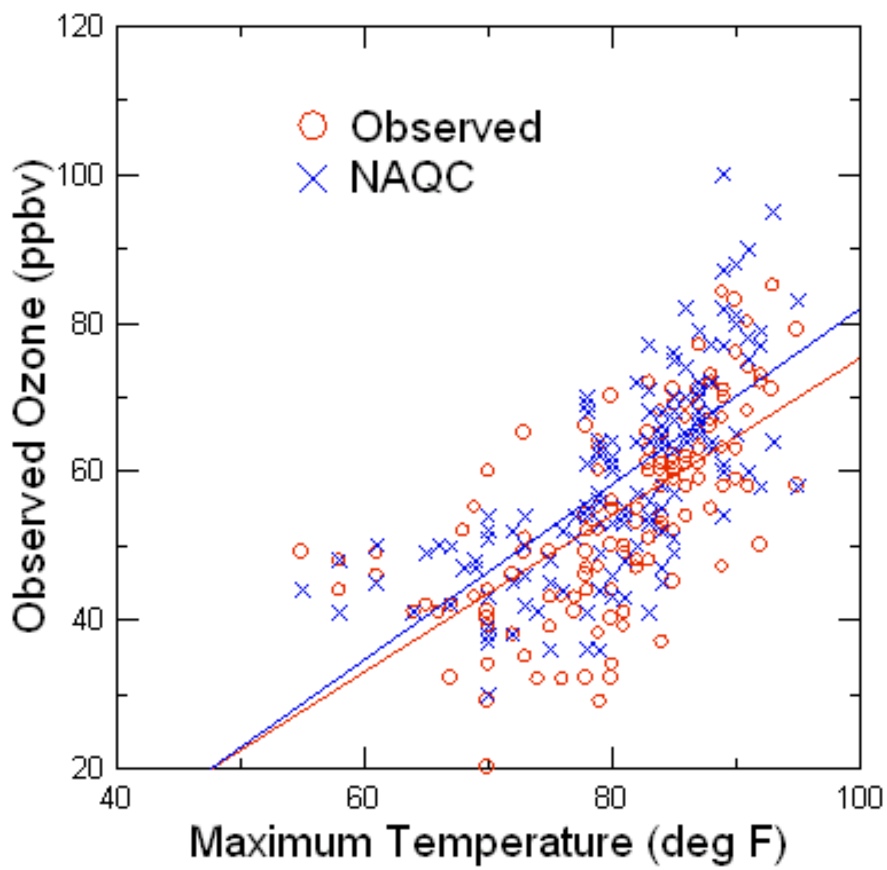
Details? In-Depth Slides: Topic 1

Results of Bias, Trend and Ensemble Methods

- All methods showed slight improvement in overall skill. Bias removed, mean absolute error improvement from 0-9%.
- 2-Day Running Bias Correction reduced False Alarms with only slight reduction of the Hit Rate.
- NB: 2009 may be ananomolous O_3 season (**In Depth Slides: Topic 2**)



Temperature and NAQC Forecast Guidance



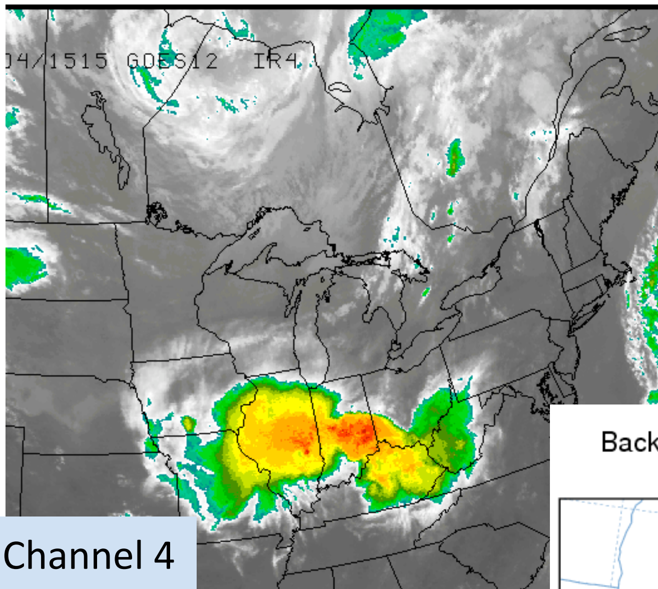
Peak O_3 concentrations, either forecast or observed, are correlated to T_{max}.

NAQC forecasts (2009 shown left) appear to be sensitive at $T_{max} > 82^oF$

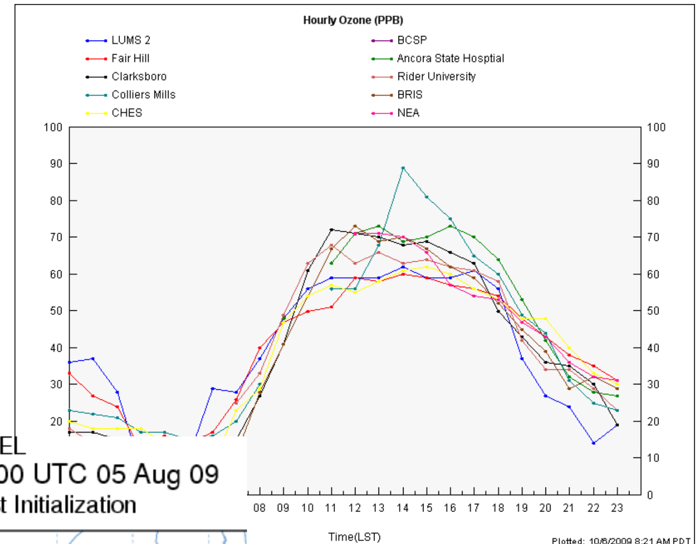
Evidence of decoupling of T_{max}-O_3 association in recent years?

In-Depth Slides: Topic 3

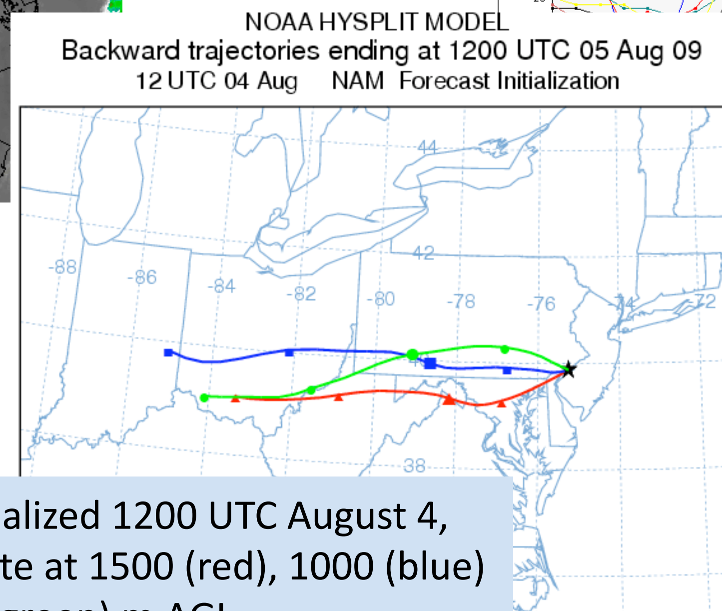
Transported O_3 and NAQC Forecast Guidance



IR Channel 4
1515 UTC
August 4



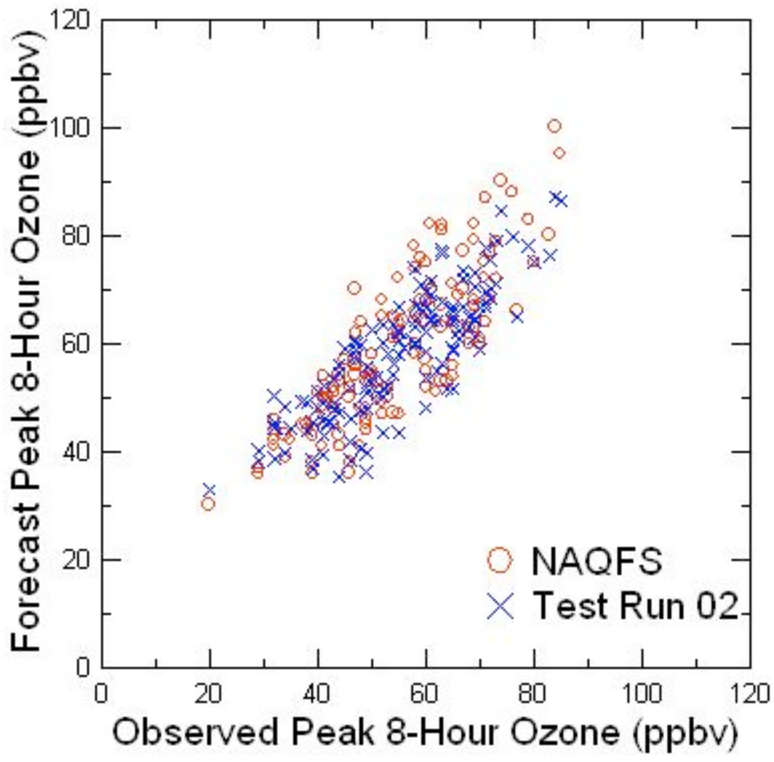
Hourly O_3 in
PHL on August 5
Peak 8-h Ave: 69 ppbv



Back Trajectories Initialized 1200 UTC August 4,
24-h Duration, Terminate at 1500 (red), 1000 (blue)
and 500 (green) m AGL.

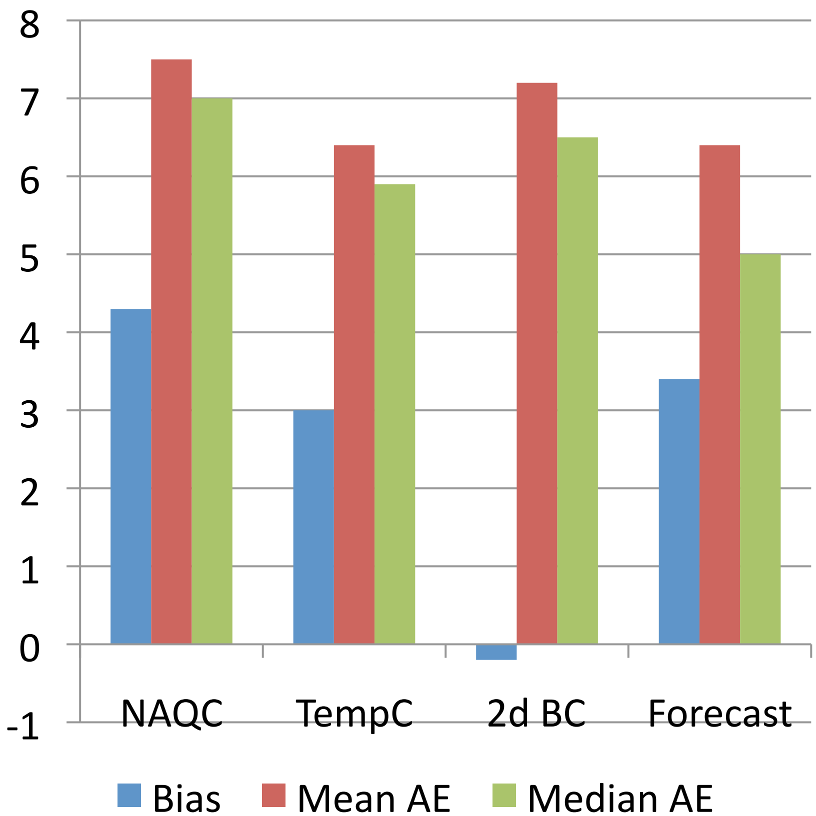
Temperature and Persistence Adjustment

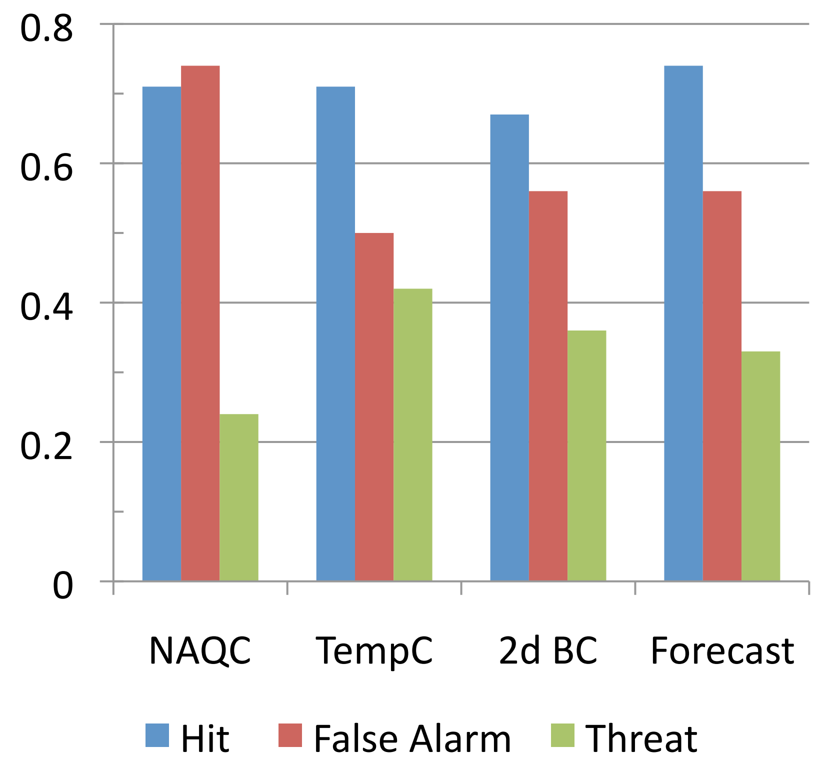
- Fit regression model with observed O_3 (2007-2008) as predicand, T_{max}, persistence O_3 and NAQC forecast O_3 as predictors.
- Modest improvement overall but **large reduction** in false alarms with only minor reduction in hit rate.



Details? In-Depth Slides: Topic 4

2009 Results





"NAQC" is uncorrected model forecast, "TempC" is temperature and persistent adjusted forecast, "2dBC" is running two-day bias correction, "Forecast" is expert forecast issued to public.

Summary

- Metric of interest to forecasters is peak domain wide O_3 and particularly at the threshold of 76 ppbv (Code Orange).
- Numerical model forecasts in PHL are skillful but suffer from over-prediction at the Code Orange threshold.
- Overall forecast skill is improved by running bias corrections.
- Skill at Code Orange threshold improved by excluding coastal regions and correcting for temperature and persistence O_3.
- Another year of data is necessary to fully test these conclusions due to unusual circumstances in 2009.

Acknowledgements

- Air quality forecasting and research in the Philadelphia Metropolitan area is supported by the Delaware Valley Regional Planning Commission (www.dvrpc.org) and the States of PA, NJ and DE.
- Additional research support was provided by the Air and Radiation Management Administration of the Maryland Department of the Environment (http://www.mde.state.md.us).

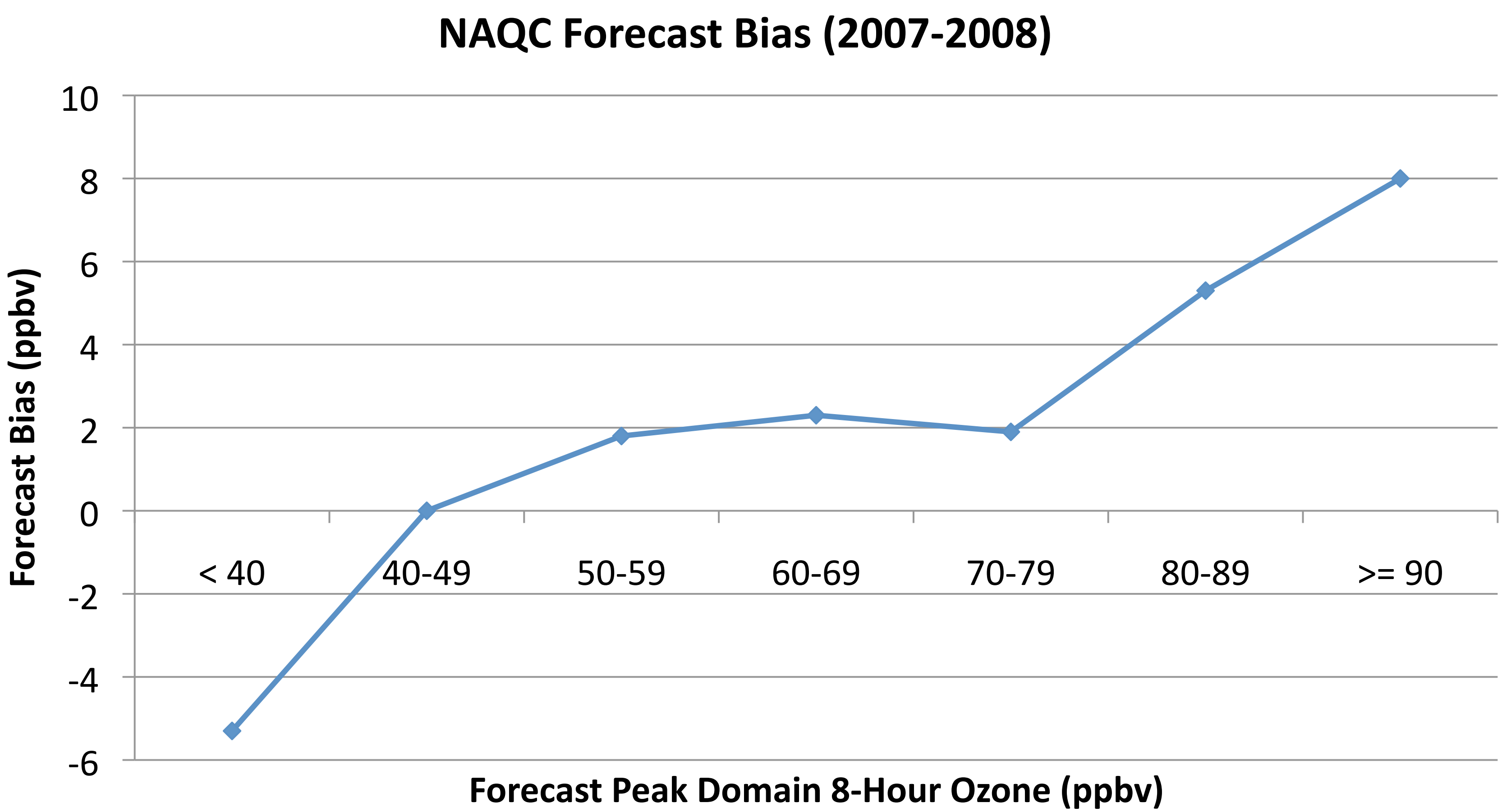
In Depth Slides

- Topic 1: Post Processing of Numerical Guidance
- Topic 2: Comments on the 2009 Ozone Season in the mid-Atlantic
- Topic 3: Temperature-Ozone Relationship Following the NO_x SIP Rule Implementation
- Topic 4: Using Temperature and Persistence O_3 to Adjust NAQC Forecasts

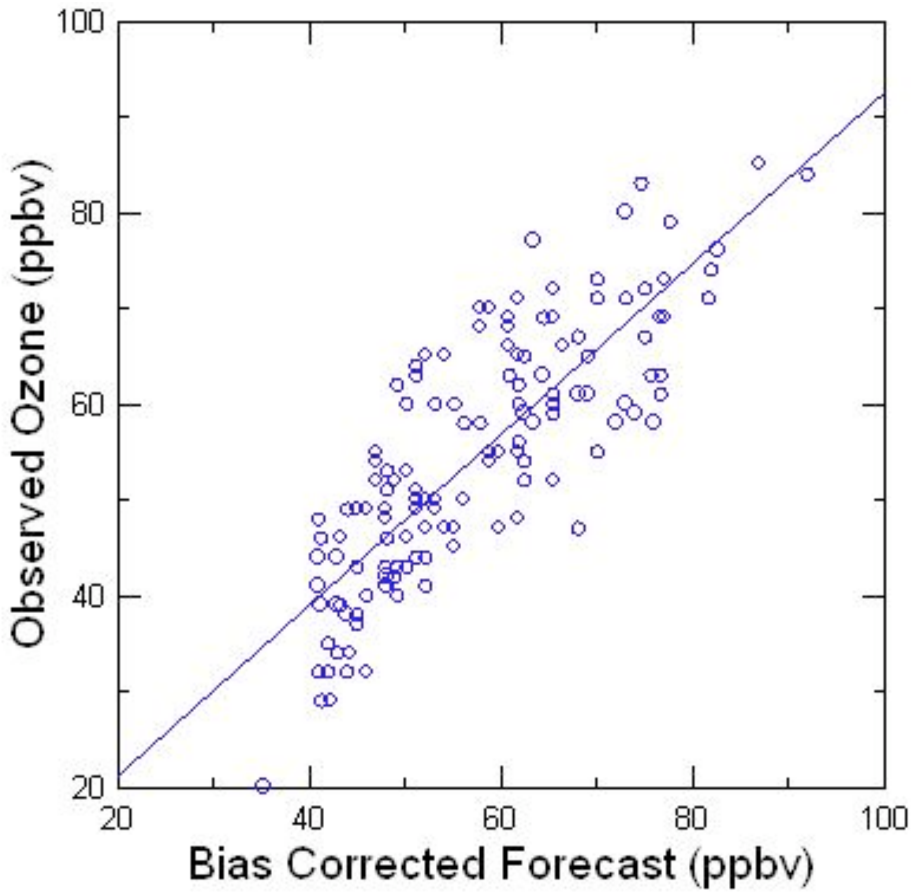
In Depth Slides: Topic 1
Post-Processing of Numerical Guidance

- Simple bias correction (BC)
  - Bin forecasts by concentration and correct for historical bias in those ranges.
- Running bias correction (RBC)
  - 2 day running bias correction.
- Trend correction
  - Add recent trend in forecast O_3 to current day observed O_3
- Blend with statistical models
  - "Poor Man's Ensemble"
- Statistical post-processing
  - Predictors: Forecast, temperature and persistence O_3

Simple Bias Correction Applied to 2009



2009 Bias Corrected Forecasts



N = 143

r = 0.82
$r^2 = 0.67$

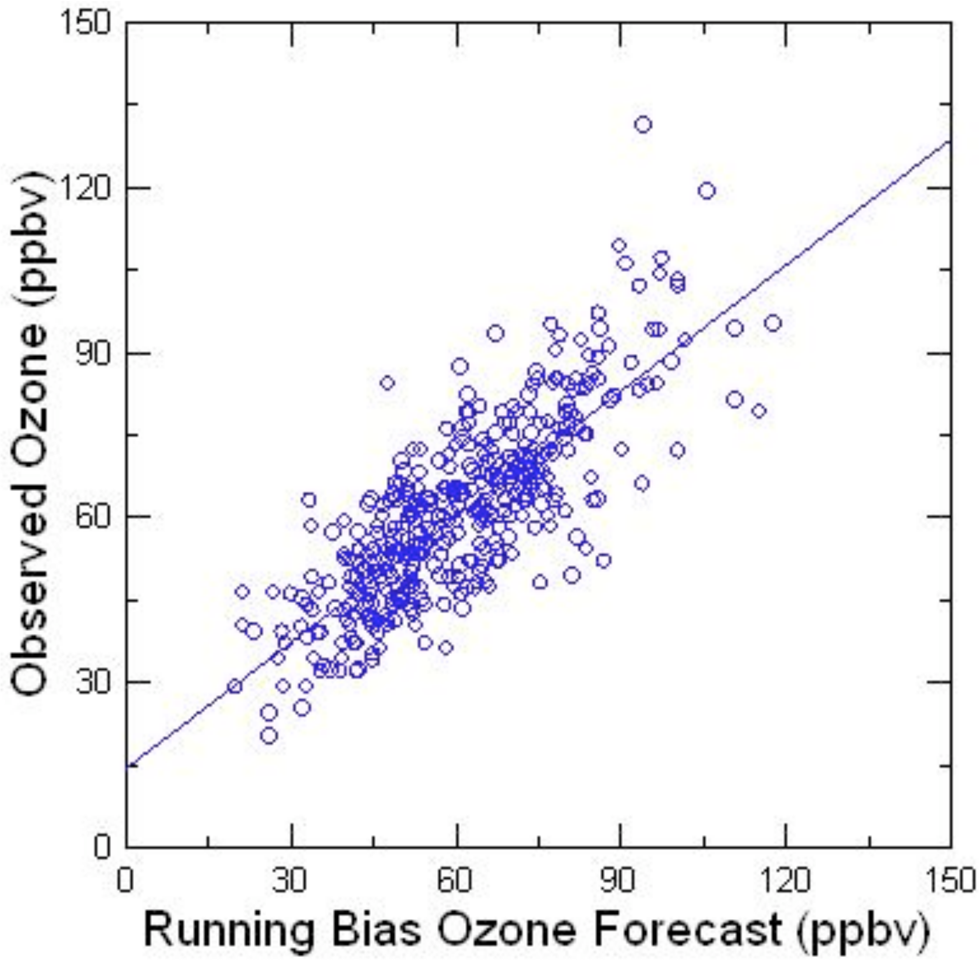
$[O_3] = 3.52 + 0.89*[O_3]_{BC}$

Overall absolute error similar to uncorrected forecast. No improvement in higher end of observed O_3 distribution.

Running Bias Correction (Two Day)

- RB $O_3 = f_{d+1} - [((f_{d0} – obs_{d0}) + (f_{d-1} - obs_{d-1}))/2]$
- Current day (d_o) O_3 must be estimated from early afternoon observations.
- Running bias correction is the average forecast bias over two days preceding the forecast day.
- "f" is peak 8-hour O_3 forecast at monitor locations by the NAQC model. "obs" is observed peak 8-hour O_3 from same locations.

Two-Day Running Bias Correction



2007-2009

N = 406

r = 0.80
$r^2 = 0.64$

$[O_3] = 14.4 + 0.76*[O_3]_{2dBias}$

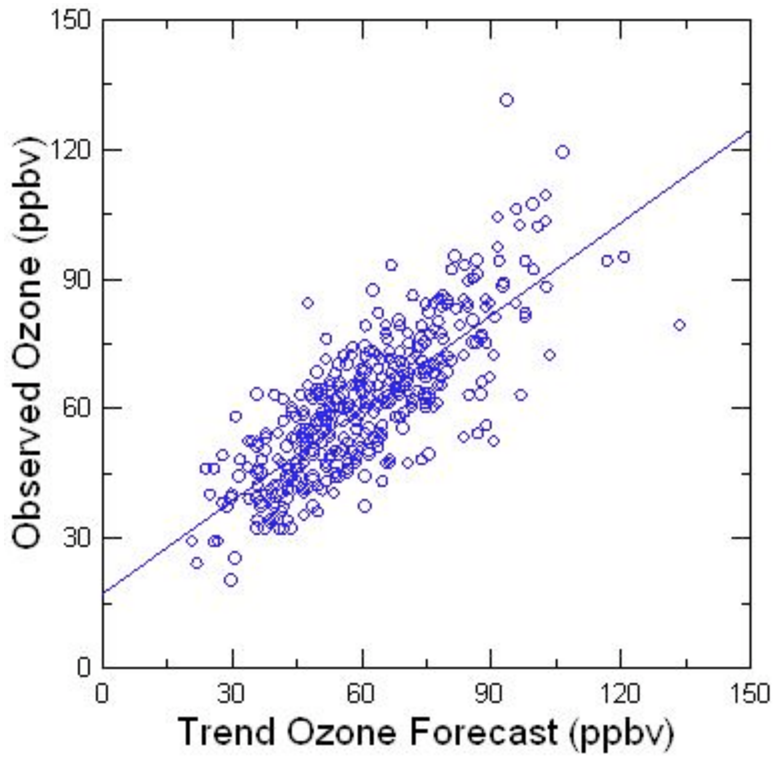
Overall, little change in absolute error from NAQC. Some improvement in bias.

In 75^{th}%ile (> 65 ppbv), slight degradation in absolute error.

Trend Correction

- Trend Corrected O_3 = $(obs_{d_0} + [fc_{d+1} – fc_{d_0}])$
  - Today's Peak O_3 + [Tomorrow's Forecast O_3 – Yesterday's Forecast O_3 for Today]
- Shortcoming: Forecast is issued before today's peak observed O_3 is known.
- Current day forecast from either 0600 or 1200 UTC NAQC runs have not proven reliable so current day peak is typically extrapolated from early afternoon O_3 observations.

Trend Correction Results (2007-2009)



2007-2009

N = 409

r = 0.79

$r^2 = 0.62$

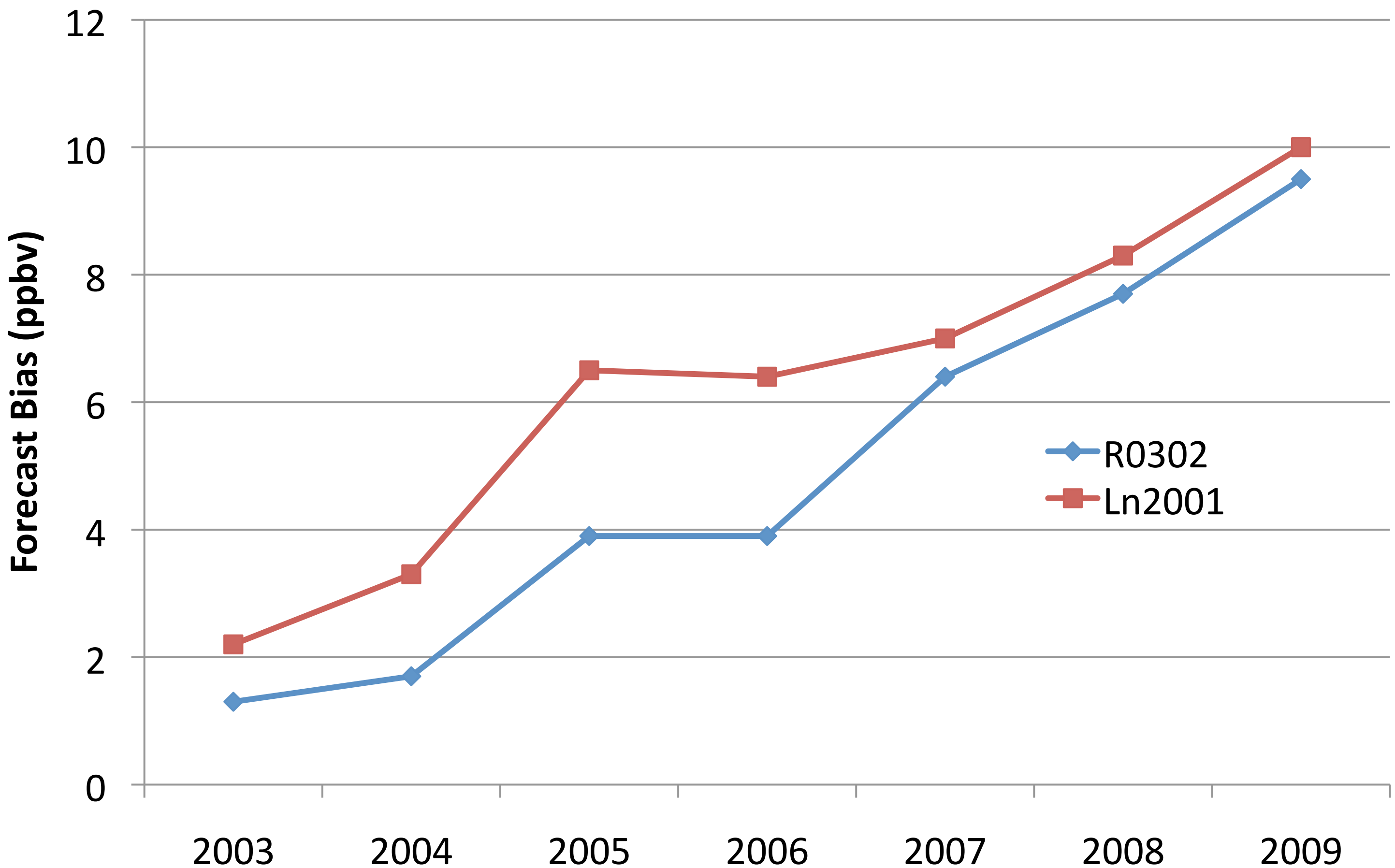
$[O_3] = 17.2 + 0.72*[O_3]_{Trend}$

Overall, little improvement to NAQC forecast.

Blend of Statistical and Numerical Models

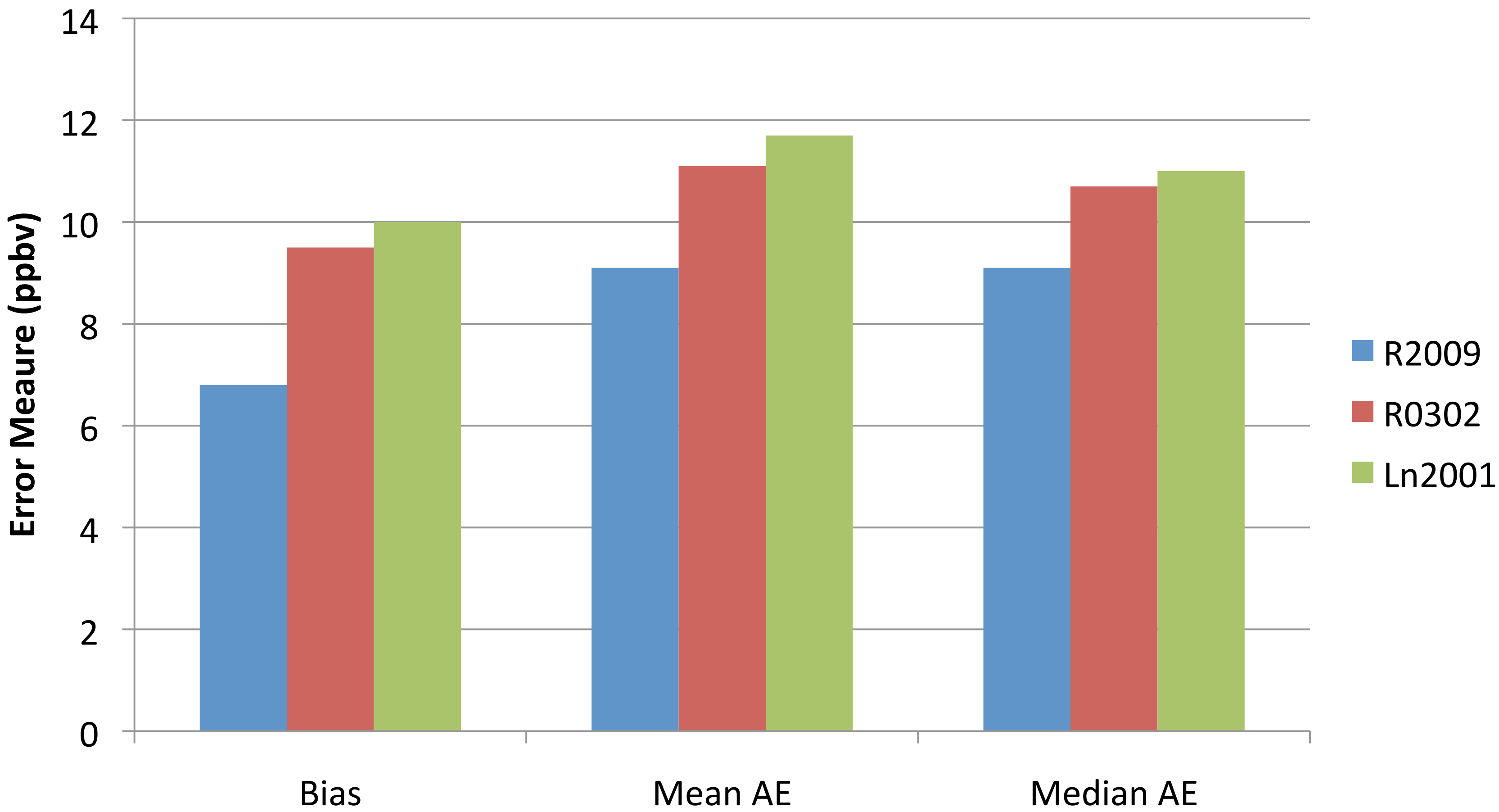
- Statistical models typically use meteorological, seasonal and persistence predictors to forecast peak domain-wide O_3.
- These models are simple and cost-effective and have historically provided reasonably accurate forecast guidance.
- Statistical models require relatively long training data sets. Usually 5 or more summer seasons of data.
- Significant changes in regional scale NO_x emissions beginning in 2002 due to the "NO_x SIP Rule" have had an impact on the skill of statistical models that are "tuned" to earlier years.

Statistical Model Bias (2003-2009)

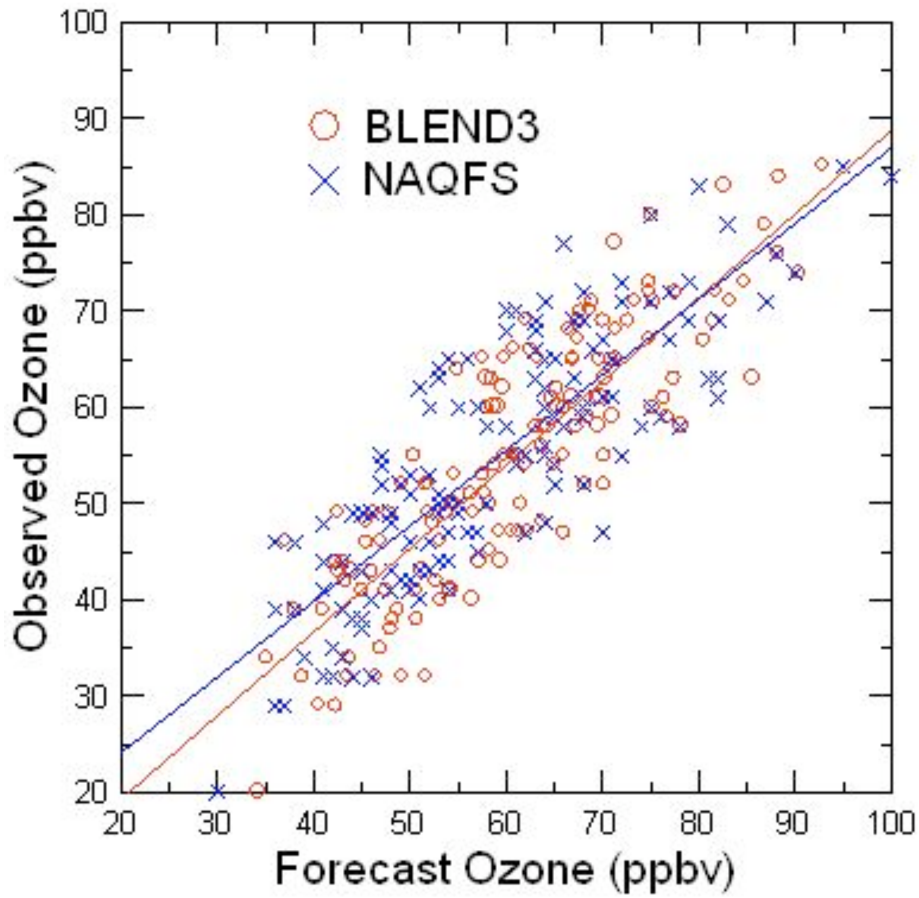


Bias in forecasts of peak domain-wide 8-hour O_3 by two models used in PHL and trained on pre-NO_x SIP Rule historical data.

Newest Statistical Model (Trained on Post-NO_x SIP Rule data) Improves Performance



Weighted Blend of Statistical and Numerical Models



2009

N = 143

	NAQC	**Blend**
r	0.83	0.85
r^2	0.68	0.73

NAQFS:

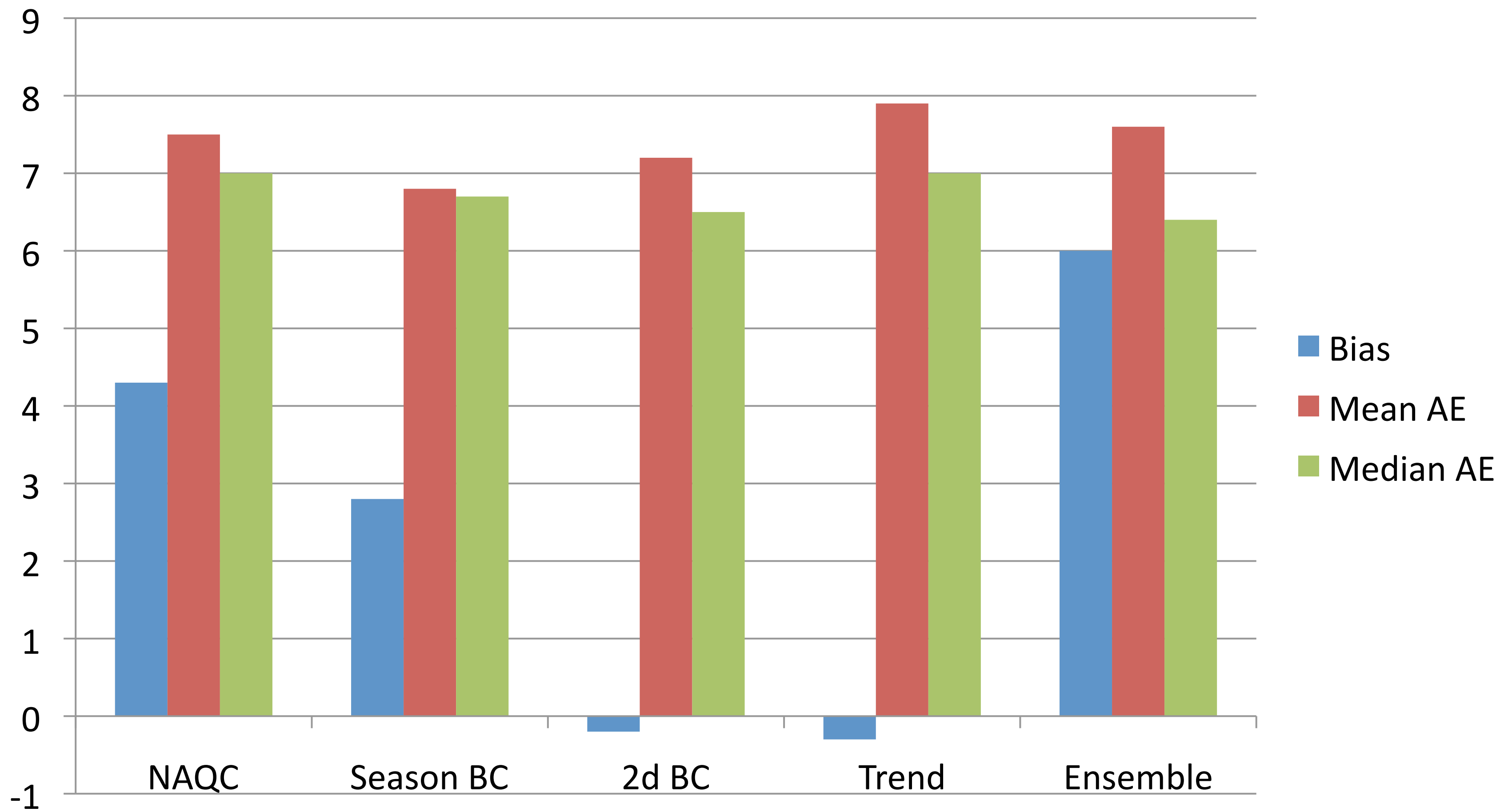
$[O_3] = 8.5 + 0.78 * [O_3]_{FC}$

Blend:

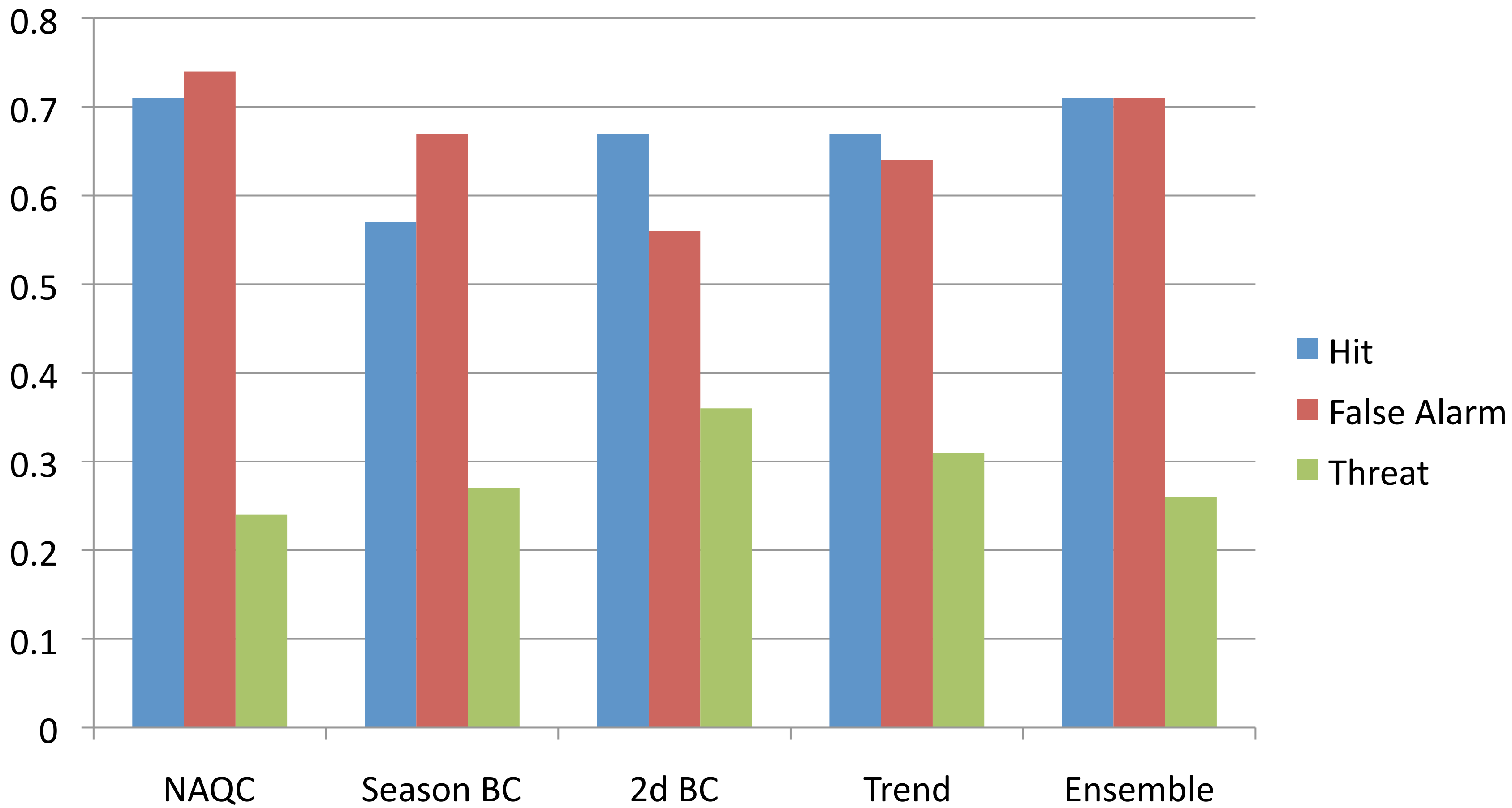
$[O_3] = 2.0 + 0.87 * [O_3]_{FC}$

Blend 3: 30% R2009 (post-NOx SIP), 20% R0302 (pre-NOx SIP), 50% NAQFS

Bias and Absolute Error Statistics for 2009



Skill Score for Code Orange Threshold (2009)



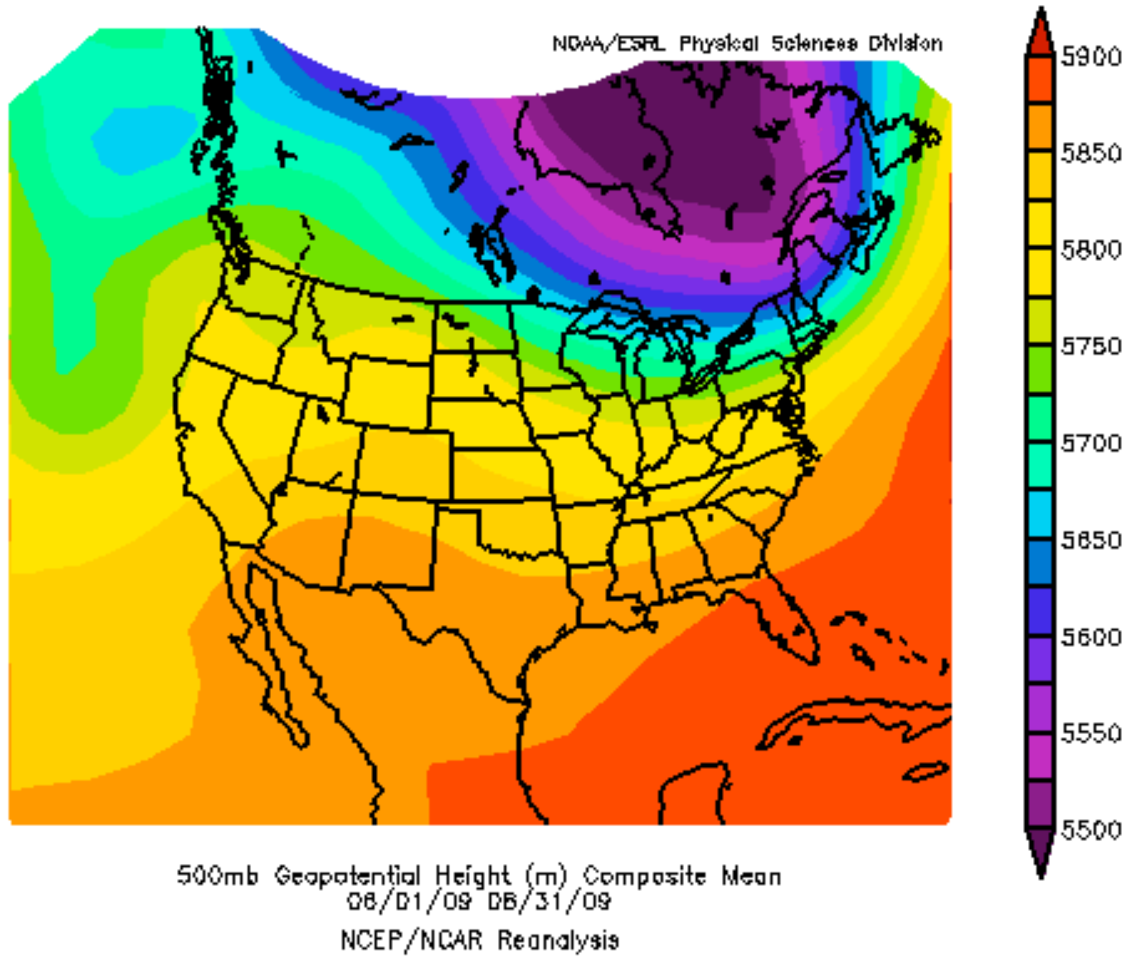
In Depth Slides: Topic 2

Comments on the 2009 O_3 Season

- 2009 was a very unusual summer. Low frequency of O_3 conducive weather locally and regionally.
- "Standard" high O_3 weather – westward extension of the Bermuda High, sustained westerly transport from the Ohio River Valley – was infrequent.
- This weather pattern contributed to historically low frequency of high O_3 cases but there may have been lower emissions due to economic recession.

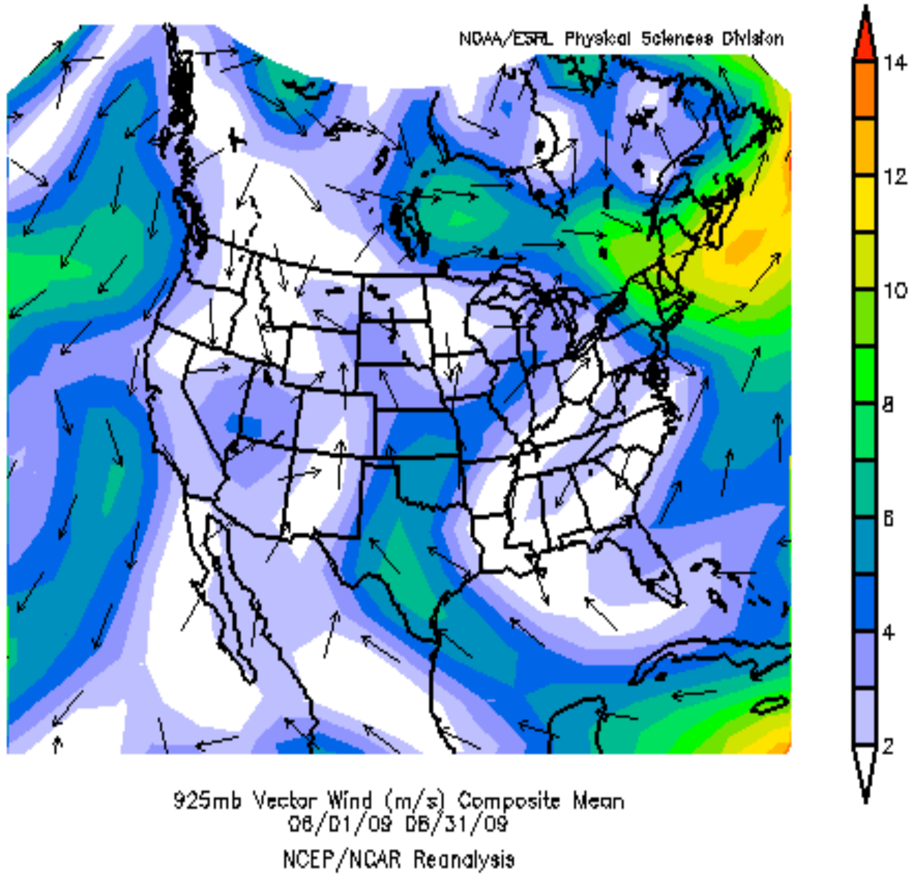
Mean Summer Upper Air Pattern Featured a Strong and Persistent Area of Low Pressure in Eastern Canada

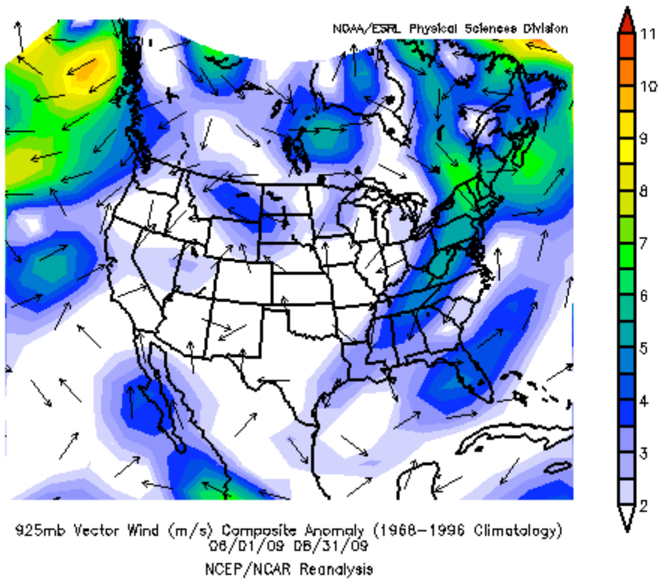
Mean 500 mb Geopotential Height June-August



Climate figures courtesy of NOAA-CDC, http://www.cdc.noaa.gov/data/composites/day/

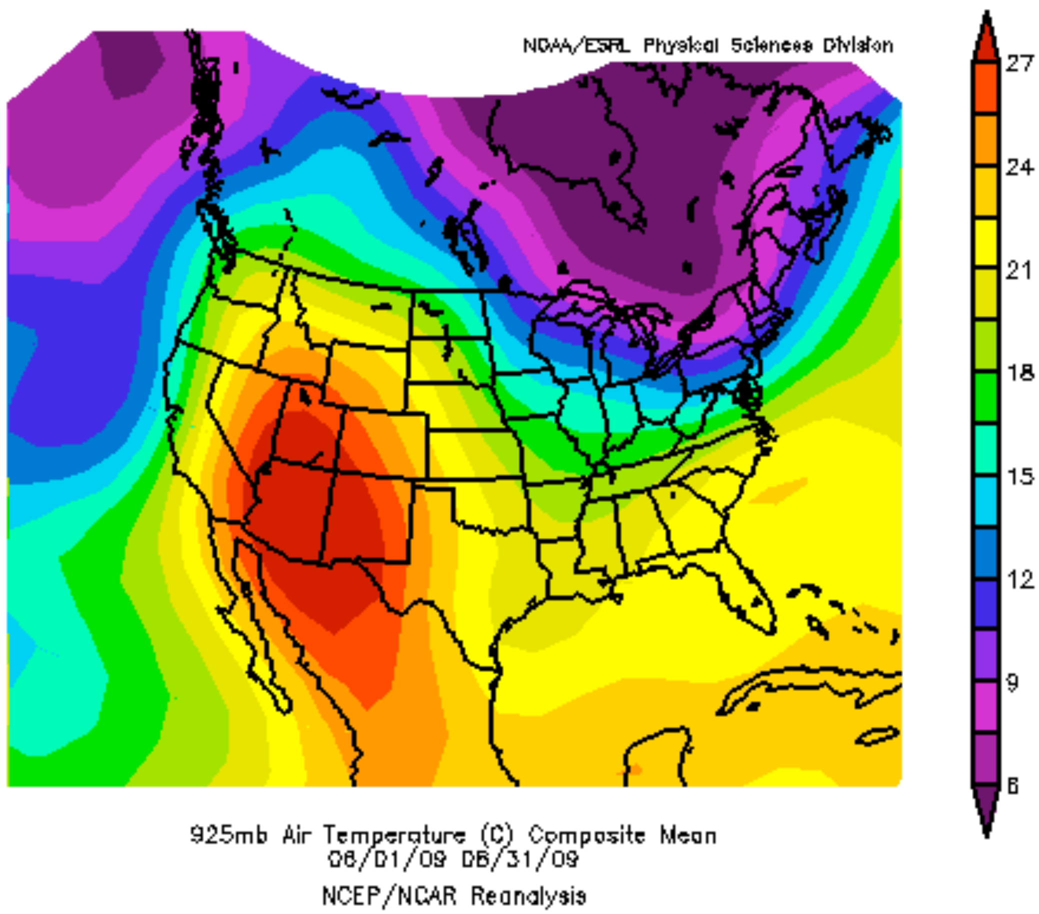
Boundary Layer (925 mb) Mean Winds



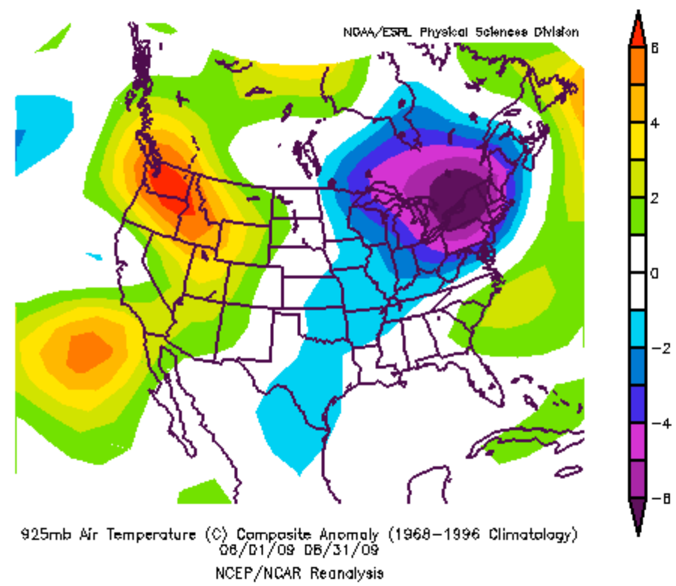


For June-August, mean winds (left panel) are NW for PHL and northeastern US. Change from normal (right panel) show stronger winds with northerly component

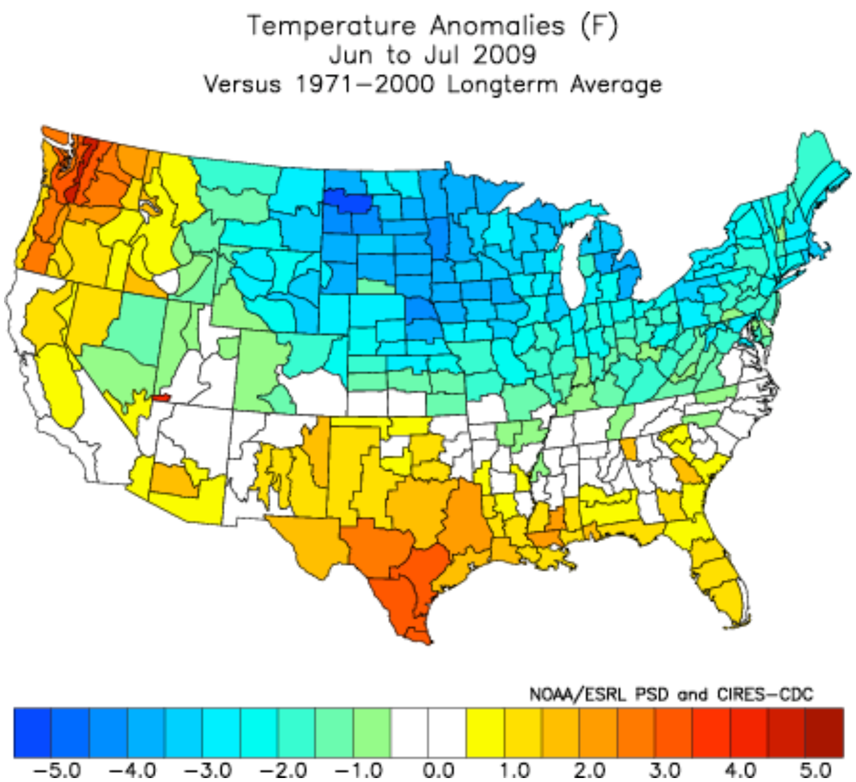
This Resulted in Very Cool Boundary Layer Temperatures Across the Northeast

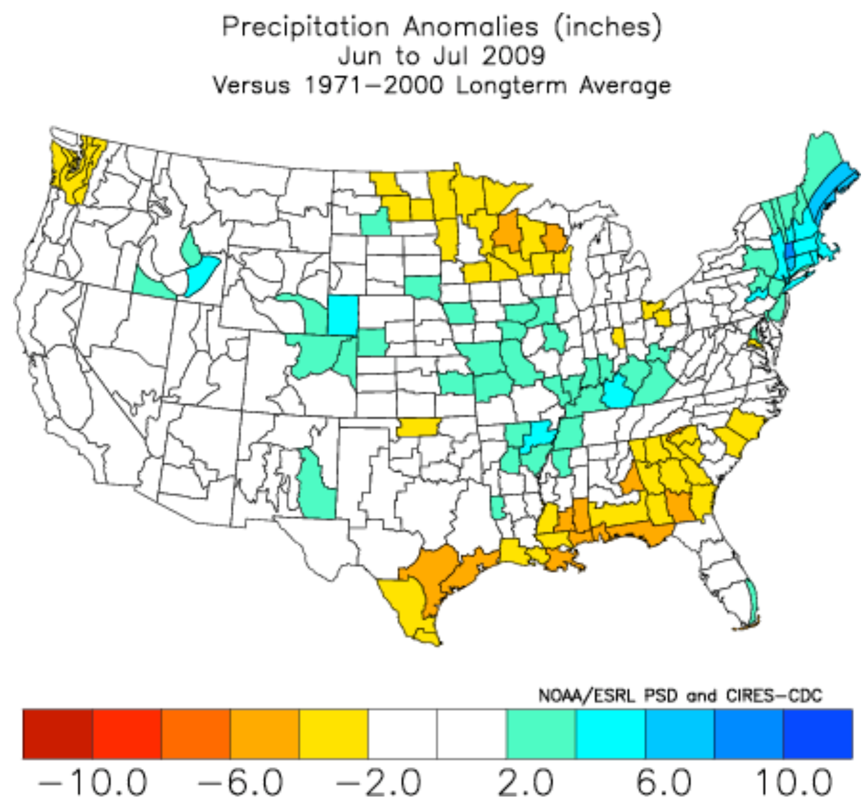


Mean 925 mb Temperature For JJA (left panel). Departure from normal (bottom panel).



The northern US was quite cool in June and July with slightly higher than normal precipitation





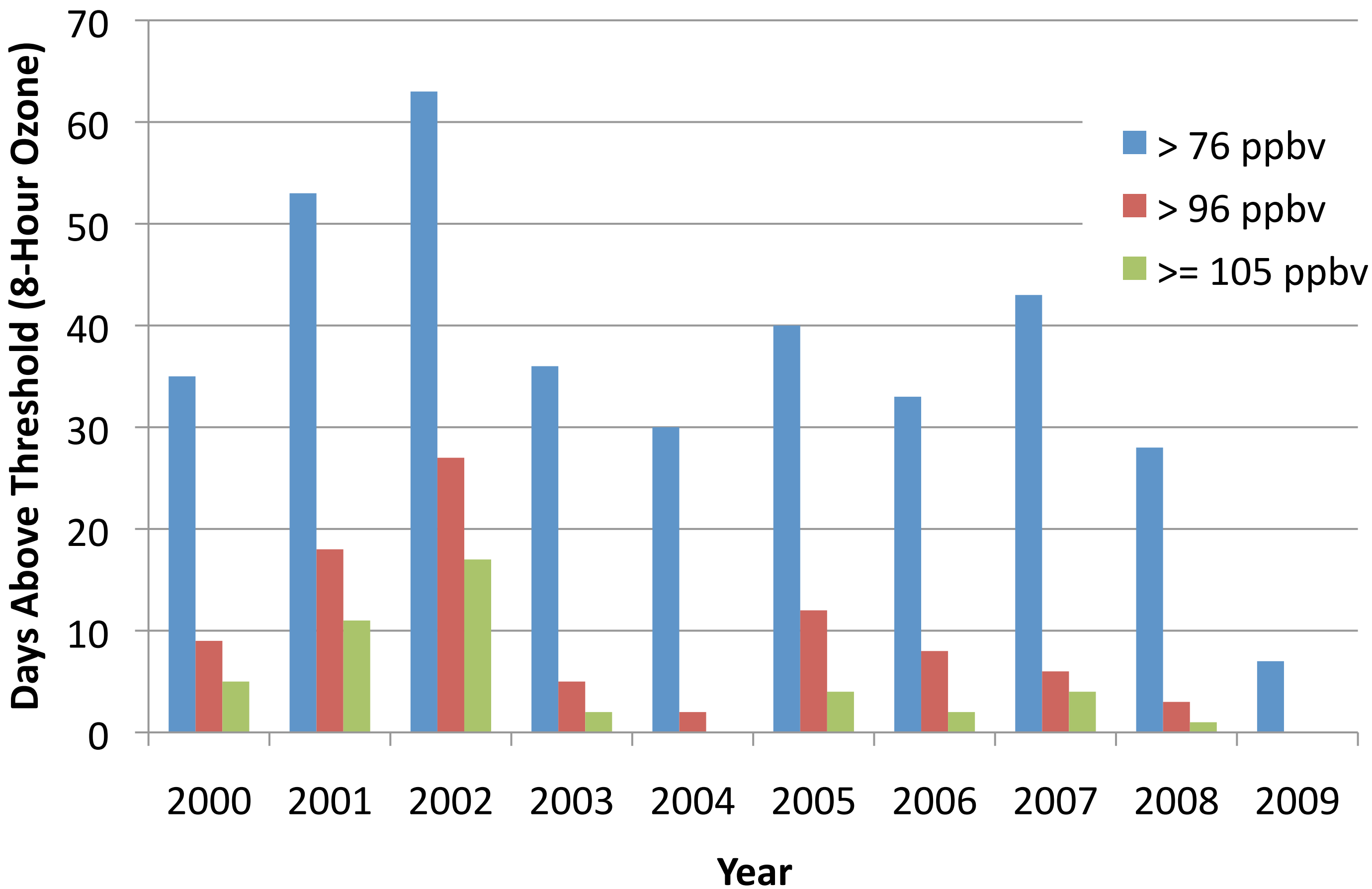
Philadelphia Summer Weather

- Average temperature for MJJA was near normal. However, June and July were 1.5°F below normal.
- August had an average number of hot days (≥ 90°F) but MJJ had only 5 hot days compared to ≈ 11 on average.
- All months had more than average number of days with measureable precipitation (17 days in June alone). For the season, 14 additional days of measureable rain (≥ 0.01”).
- August was excessively wet with 10.3” of rain, primarily due to 5 days with > 1” of rain (average is 1.2 days).

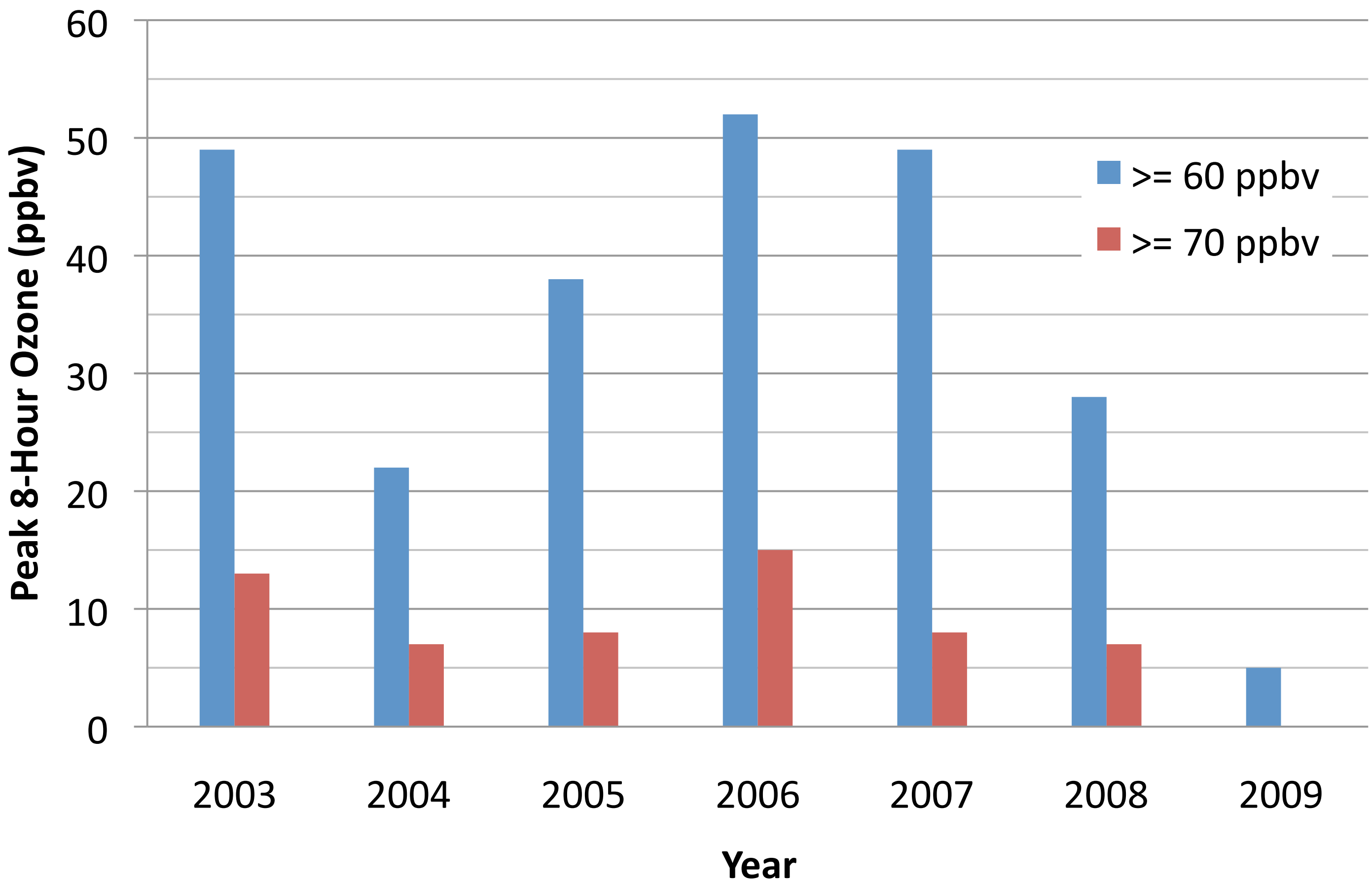
Weather and Air Quality

- The combination of cooler and wetter than normal weather, and the absence of persistent Bermuda High circulation, led to lower than normal O_3 regionally and locally
  - Shenandoah National Park has historically low frequency of high O_3 days.
  - $PM_{2.5}$ concentrations in PHL very low - pointing to few “dirty” air mass episodes.
  - Almost no high O_3 episodes in Philadelphia.

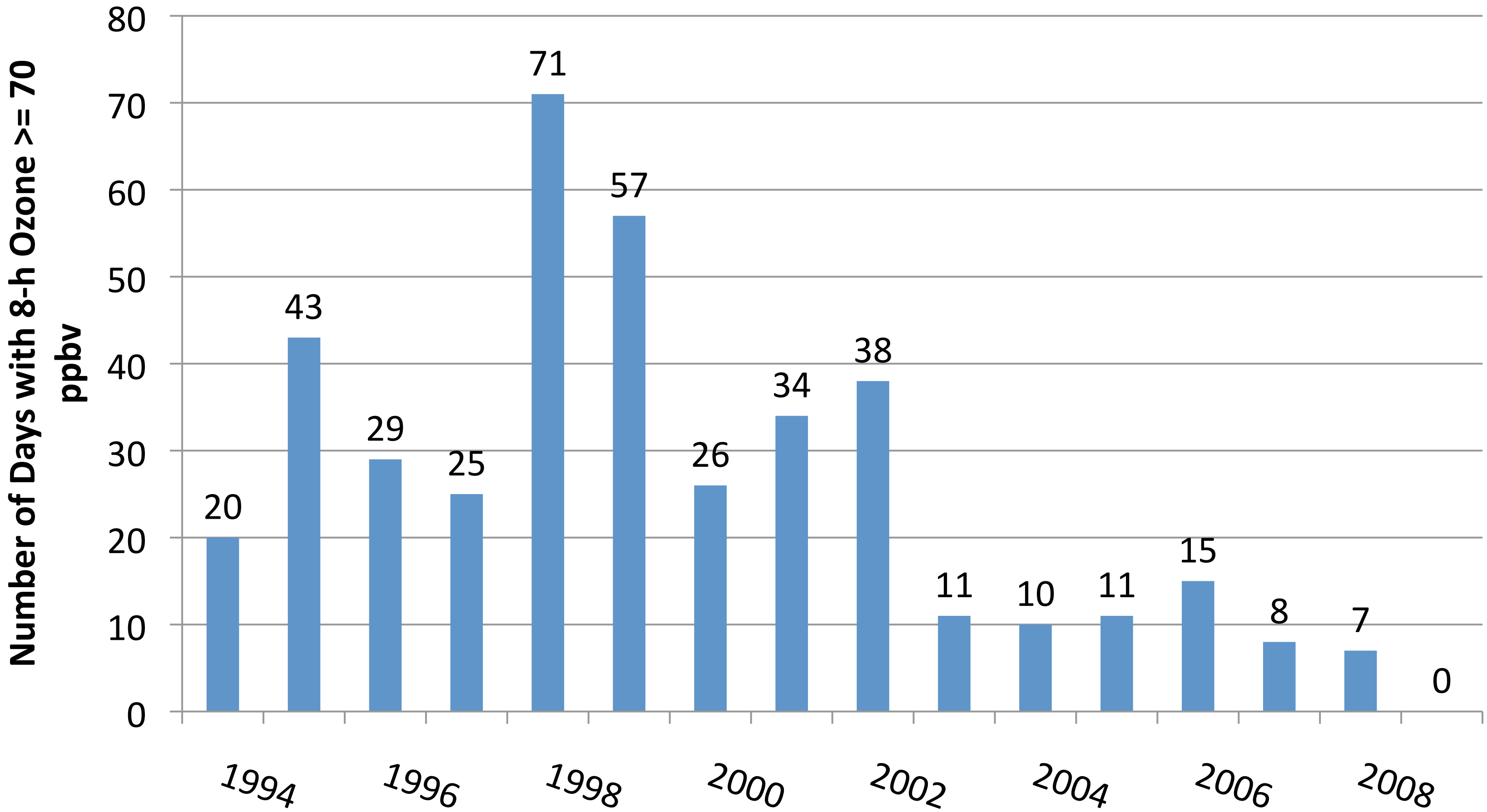
Philadelphia: Frequency of High O_3 Days
(Peak 8-Hour O_3 in the Metropolitan Area)



Shenandoah National Park
Number of Days with 8-Hour O_3 Above Thresholds

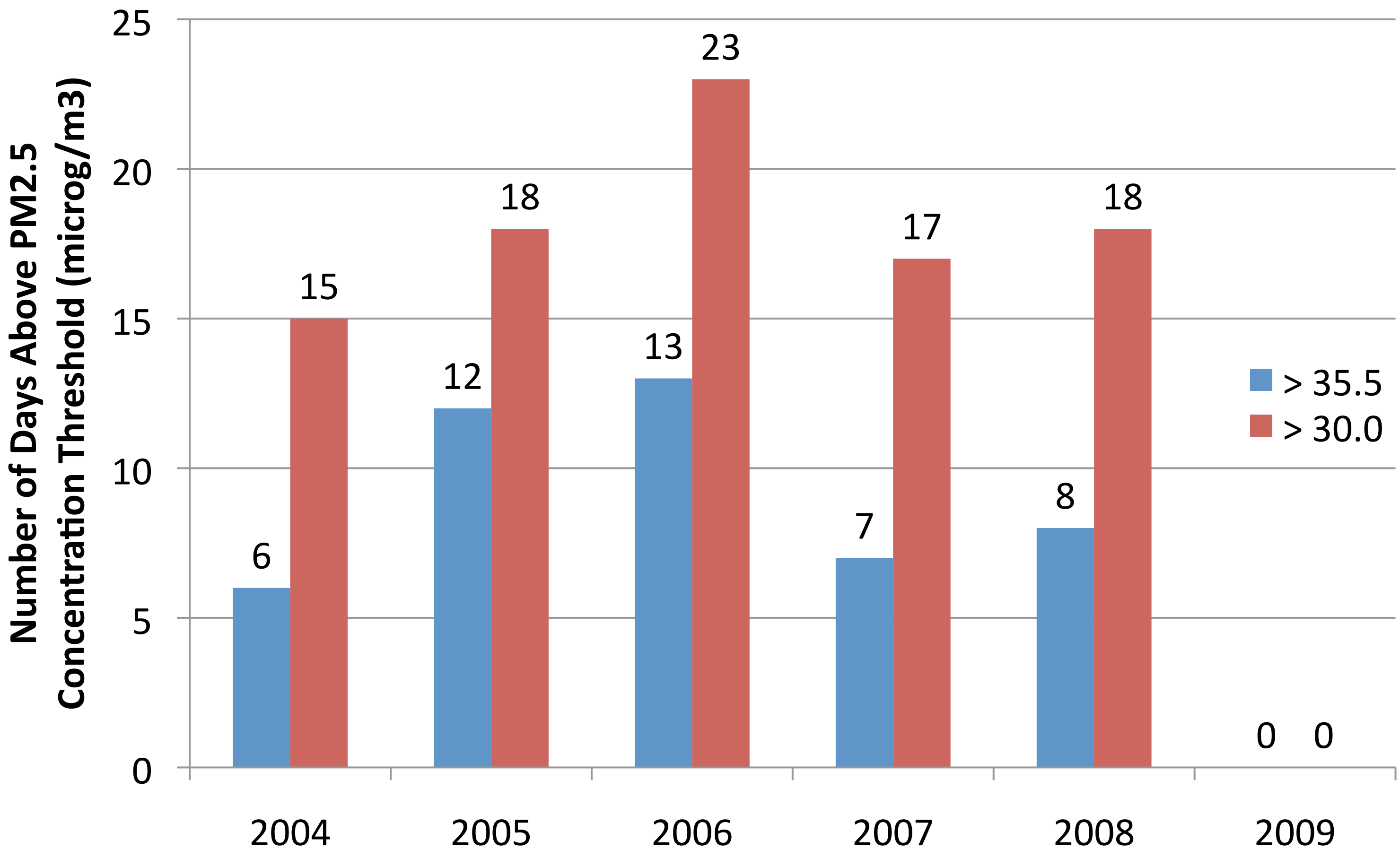


Shenandoah National Park – Big Meadows Regional Effect of NO_x Reductions



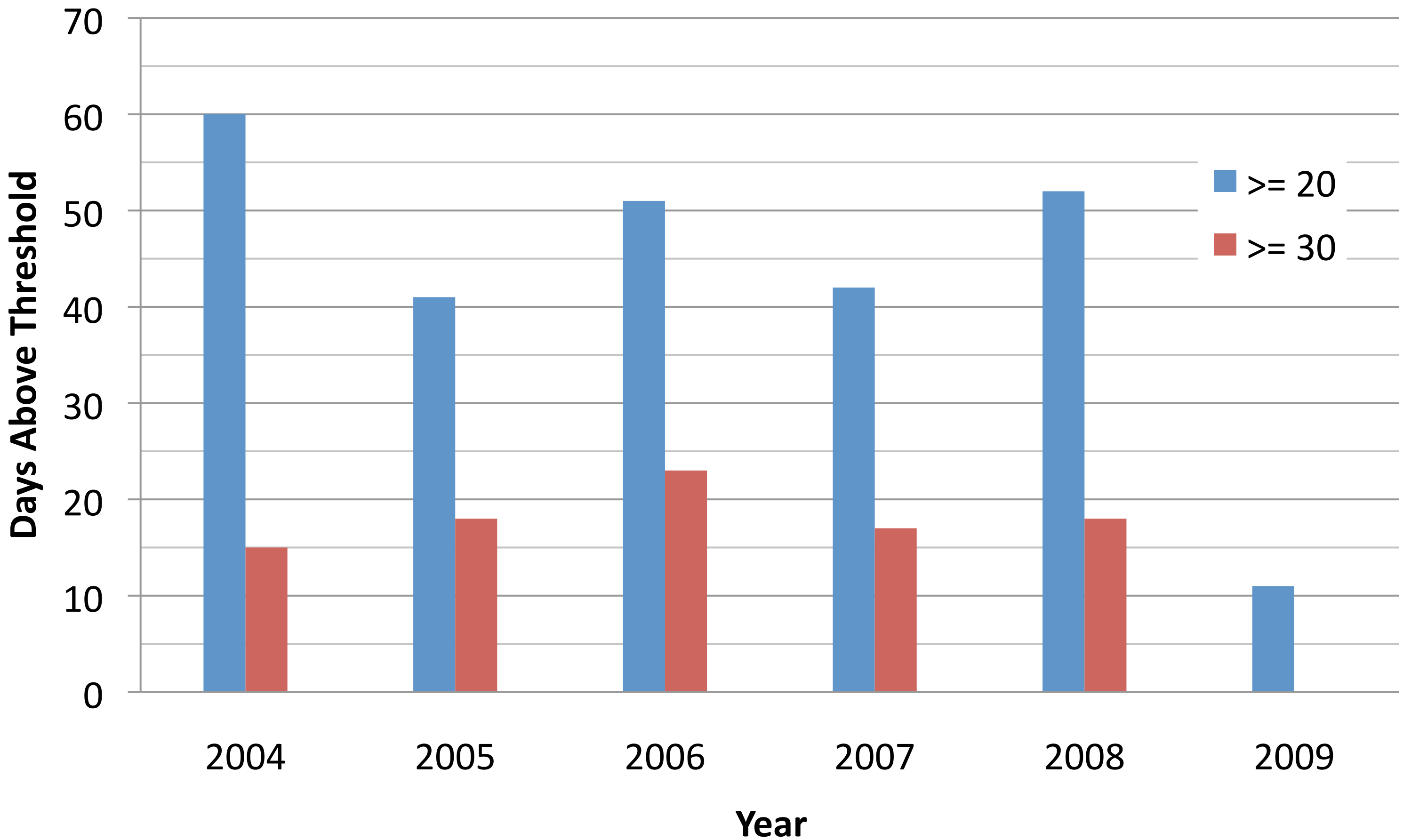
No days in excess of 70 ppbv in 2009

PHL $PM_{2.5}$ Concentrations Remarkably Low in 2009



Note: Data for 2004-2008 uses gravimetric filter monitors (FRM) while 2009 uses 24-average from continuous monitors.

Philadelphia: Number of Days with $PM_{2.5}$ (Daily Average in $\mu g m^{-3}$) Above Given Threshold



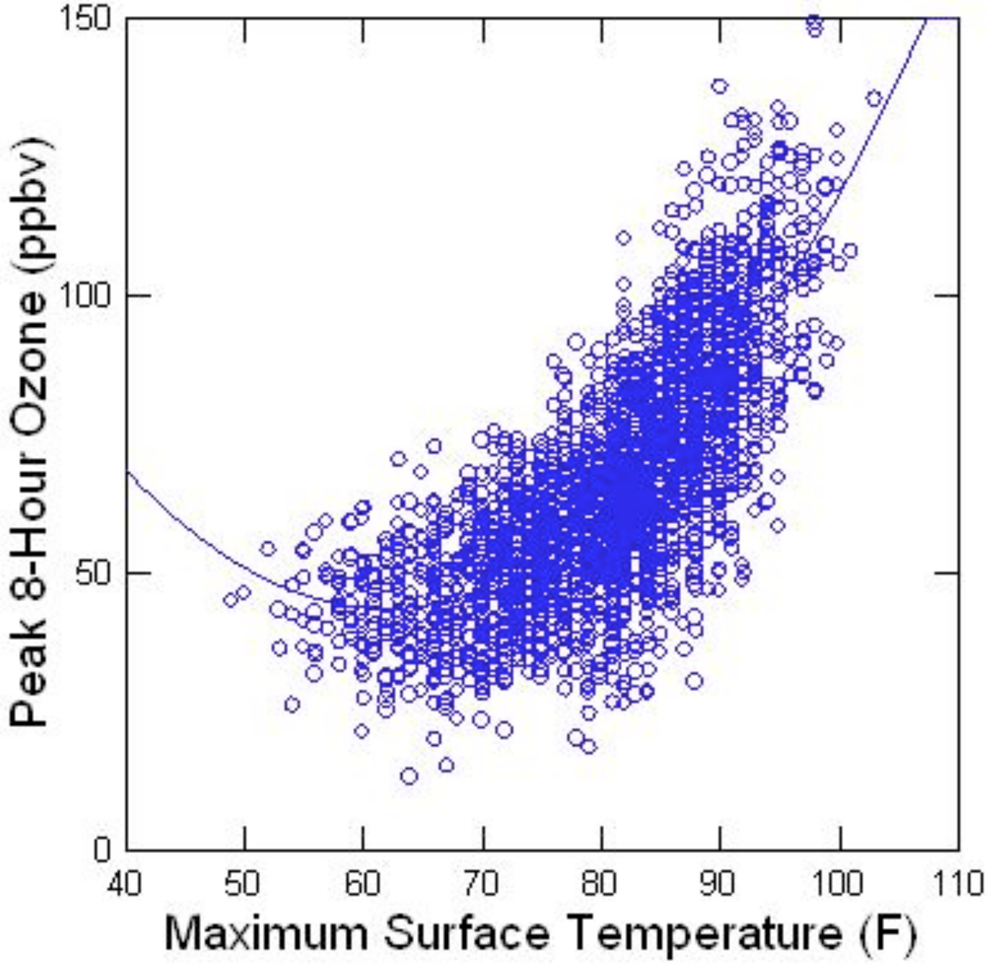
Shenandoah NP $PM_{2.5}$ Daily Average Concentrations (May-August, 2004-2009)

	N	Median (µg/m³)	Mean ± 1 σ (µg/m³)	Ratio (Days > 20 µg/m³)	Ratio (Days > 30µg/m³)
2004-2008	487	14.2	15.1 ±7.8	0.23	0.04
2009	116	9.5	9.8 ± 4.3	0.02	0.00

In Depth Slides: Topic 3
Changes in the Temperature-Ozone Relationship

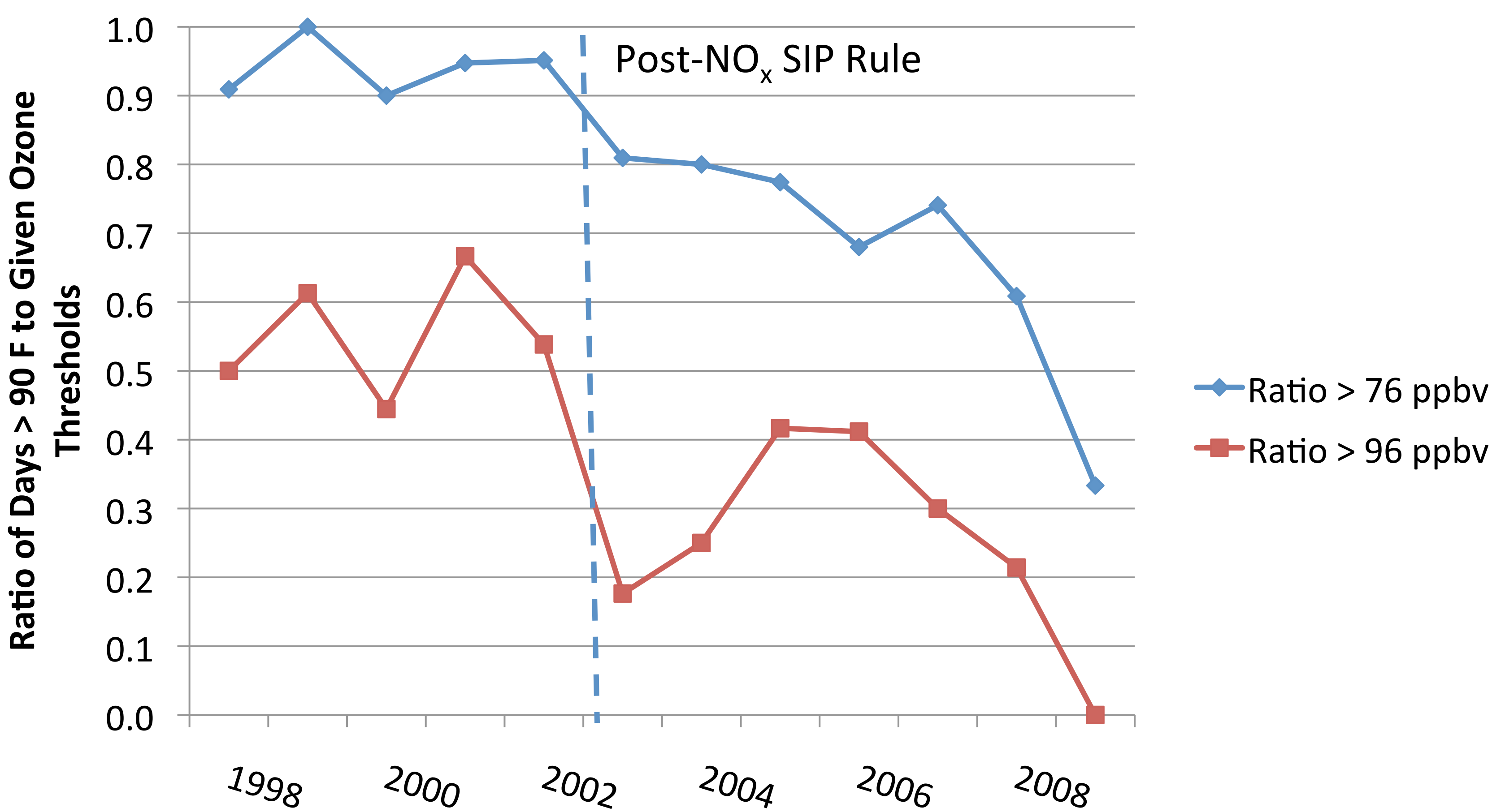
- O_3 concentrations are strongly associated with surface temperature (T_{max})
- Hot weather is necessary, but not sufficient for high O_3
- Since the implementation of the NO_x SIP Rule emissions controls, the likelihood of "bad" air given hot temperature has decreased.
- This has impacted the skill of both numerical and statistical forecast models.

Philadelphia Ozone- Temperature Relationship



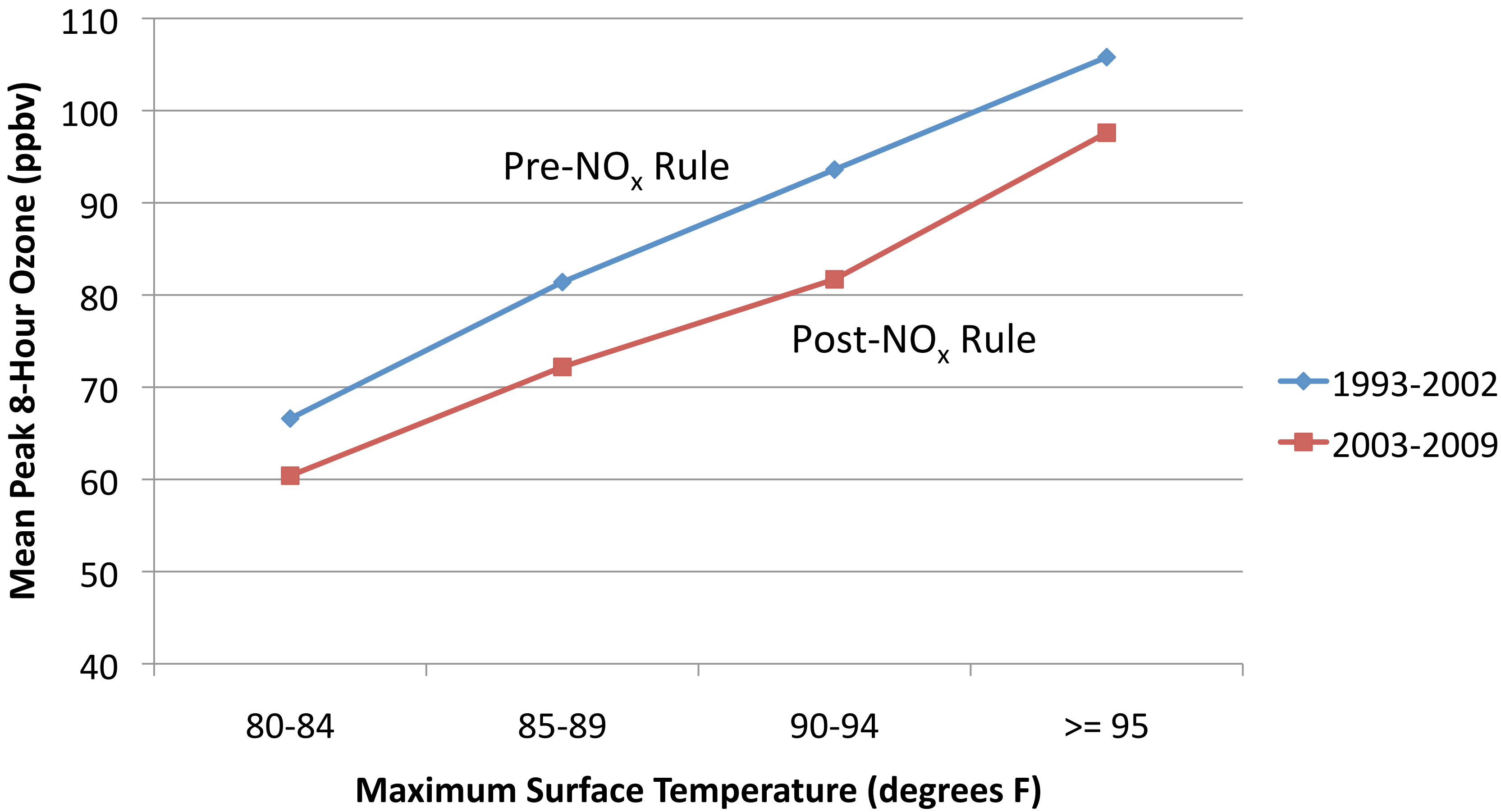
Peak 8-Hour O_3 in metropolitan PHL and T_{max} (PHL Int'l Airport) for May-Sept, 1993-2009

Hot Weather is Necessary but not Sufficient for High O_3



If T_{max} is ≥ 90^{o}F, what is the chance of Code Orange (≥ 76 ppbv) or Code Red (≥ 96 ppbv) O_3 occurring?

O_3 – Temperature Relationship in PHL: NO_x SIP Rule

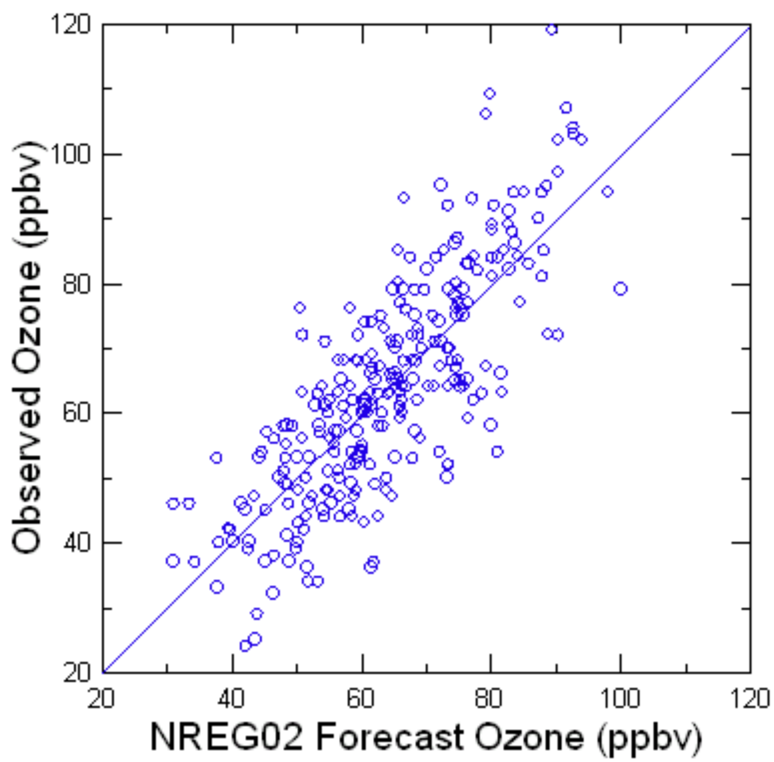


In Depth Slides: Topic 4

Using Temperature and Persistence O_3 to Post-Process NAQC Guidance

- Using 2007-2008 data, fit observed O_3 and NAQC forecast with two models:
  - NREG01: NAQC and T_{max} as predictors
  - NREG02: NAQC, T_{max} and LagO_3 as predictors
- As applied to 2009 data, both models gave an increase in skill
  - Reduced "false alarms" of high O_3 by two thirds.
  - With no reduction in probability of detection.

Simple Post-Processing Method
$[O_3]_{obs} = f([O_3]_{forecast}, [O_3]_{persistence}, T_{max})$



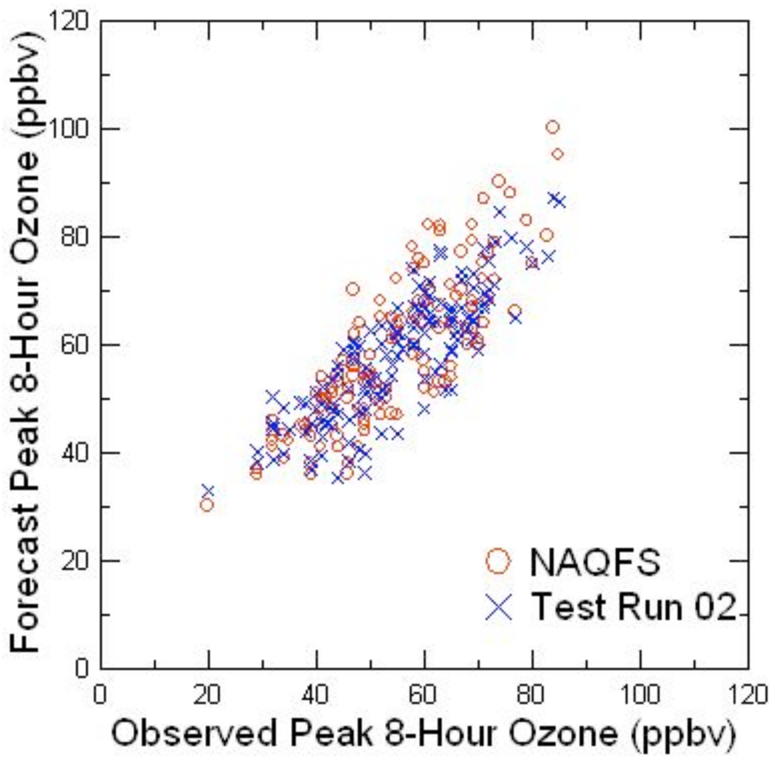
2007-2008

N = 268
r = 0.79
$r^2 = 0.62$

$[O_3]_{obs} = 0.56 * [O_3]_{NAQC} + 0.44 * T_{max} + 0.17 * [O_3]_{lag} - 20.1$

Modest improvement in explained variance and correlation

Fit to Observations in 2009



Error Statistics – 2009 (all values in ppbv)			
	Bias	MedAE	MnAE
NAQC	3.9	7.0	7.4
NREG01	3.1	6.0	6.7
NREG02	2.7	5.9	6.4

Hit Rate unchanged but number of False Alarms reduced from 14 to 5.

3 of 5 False Alarms are "near misses" with observed $O_3 \geq 71$ ppbv.