Air Quality Forecasting: Recent Advancements and Continuing Challenges

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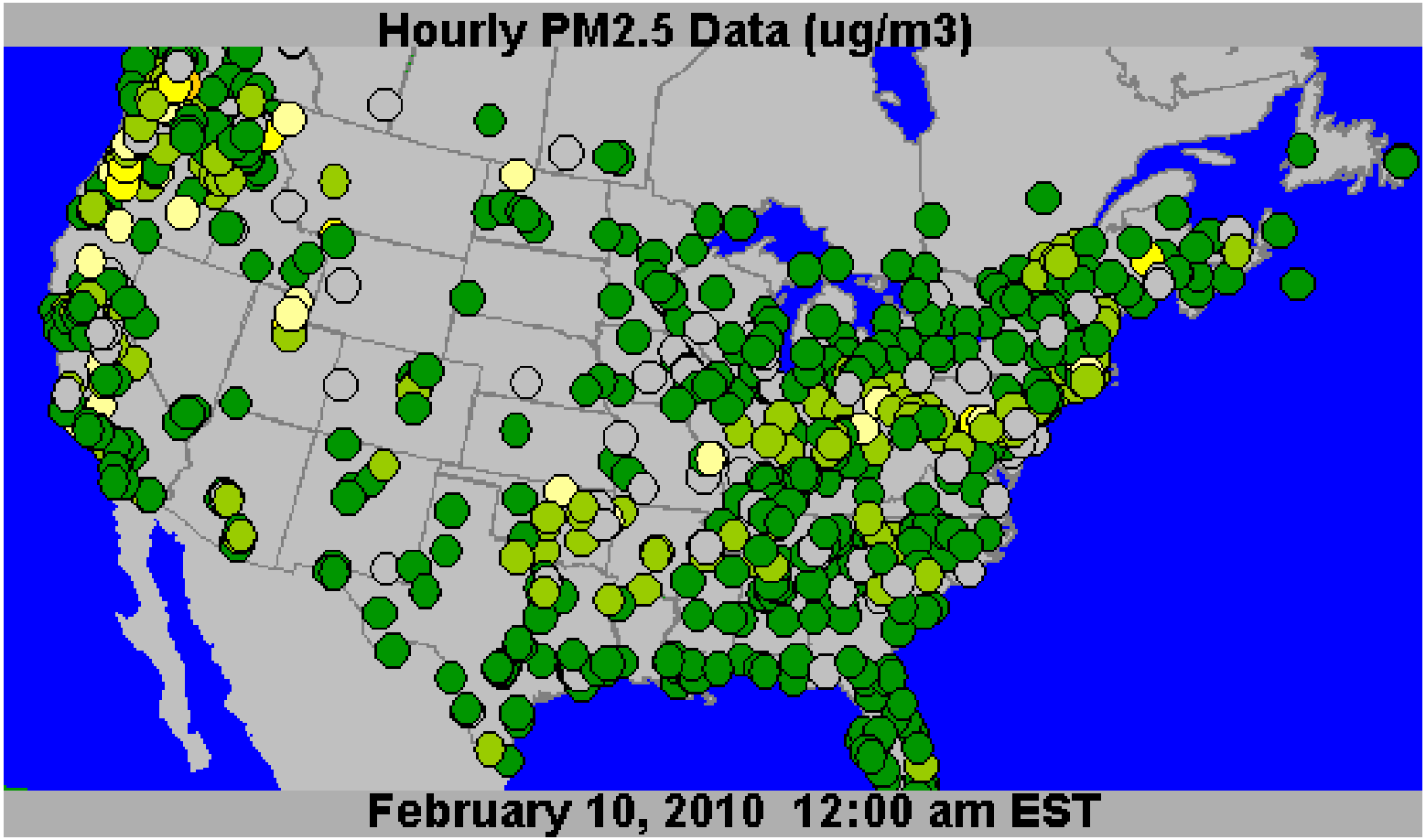
MARAMA Annual Meeting, Philadelphia, February, 2010
http://www.meteo.psu.edu/~wfryan/marama/ryan-marama-phl-2010.pptx

Key Advancements Since 2002

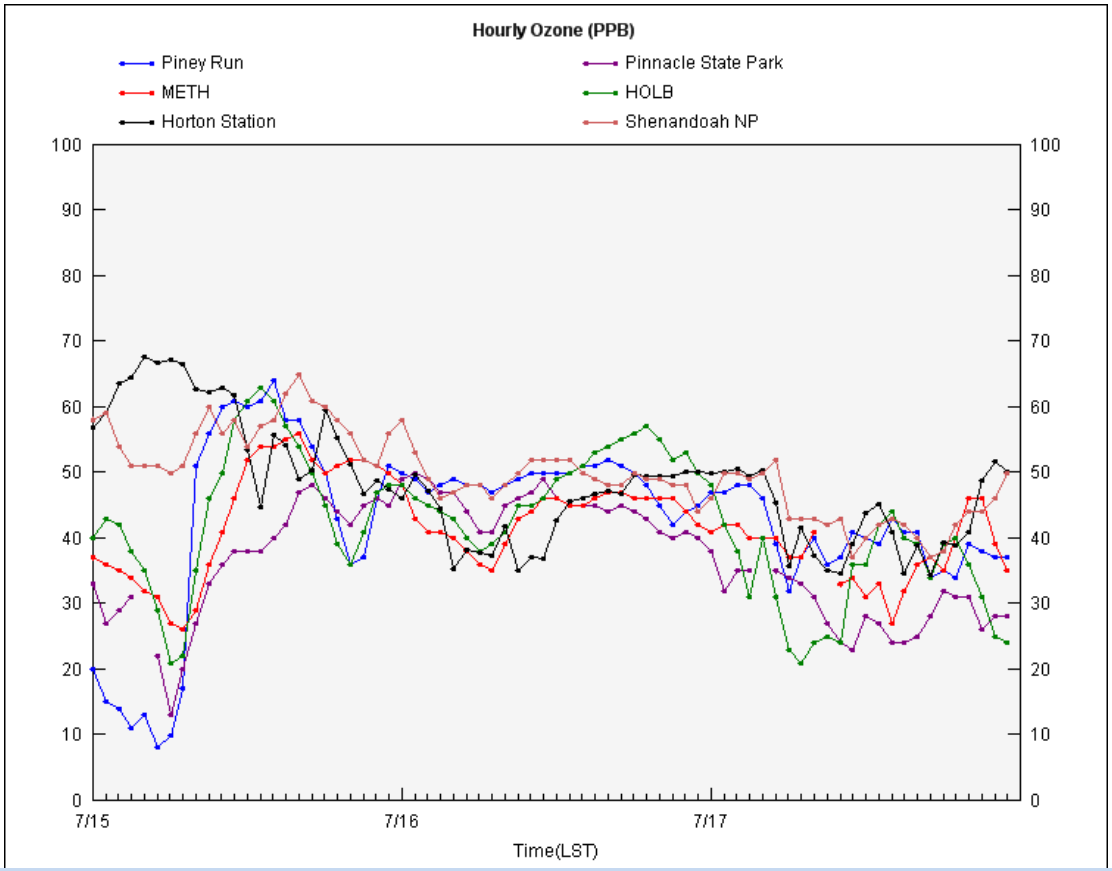
- **Timely Access to Near Real-Time Data**
  - AirNow (www.airnow.gov) and AirNowTech
- **Improvements in Weather Forecast Models**
  - Better resolution (WRF)
  - Ensembles of forecast models (SREF)
- **Specialized Numerical Forecast Models**
  - Back trajectory models (HYSPLIT)
  - Air quality models (O_3 and $PM_{2.5}$)

Near Real Time $PM_{2.5}$ Data from AirNow



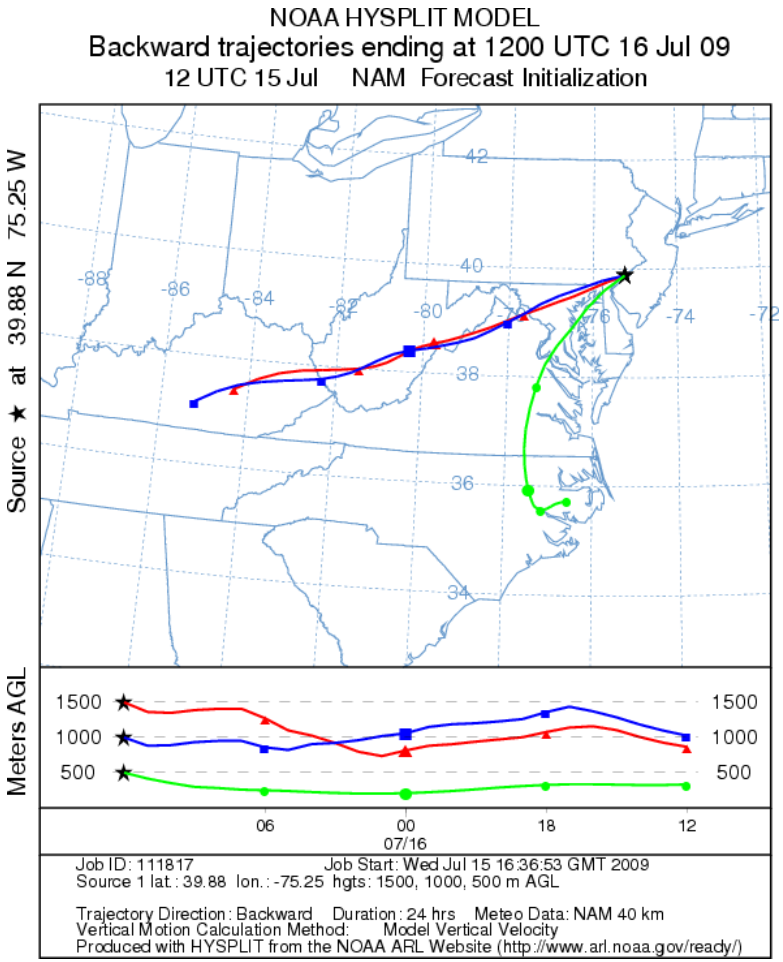
http://www.airnowdata.org/pmfine/hourly.html

Time Series of O_3 Concentrations



Hourly O_3 observations from rural, high elevation monitors. These data provide accurate information on the current regional "load" of O_3. This information is critical to forecasting tomorrow's local air quality.

Back Trajectory Forecasts Identify Source Regions for Tomorrow's Air Quality



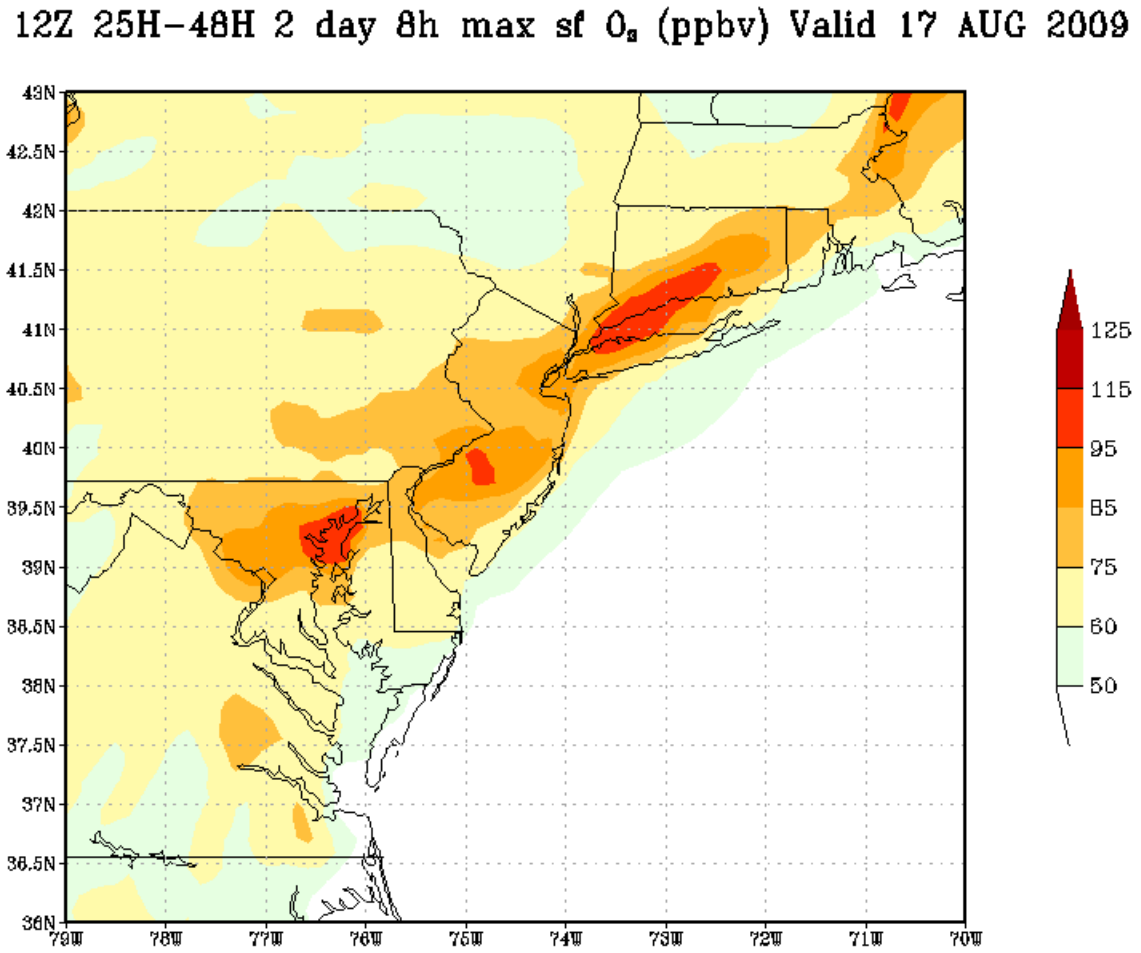
HYSPLIT Back Trajectory

Colored lines show the forecast path of air parcels that will reach PHL at 1200 UTC (8 am) on the forecast day (July 16) at three levels above the ground (500, 1000, 1500 m).

The path is 24 hours in duration with dots giving position at 6 hour intervals.

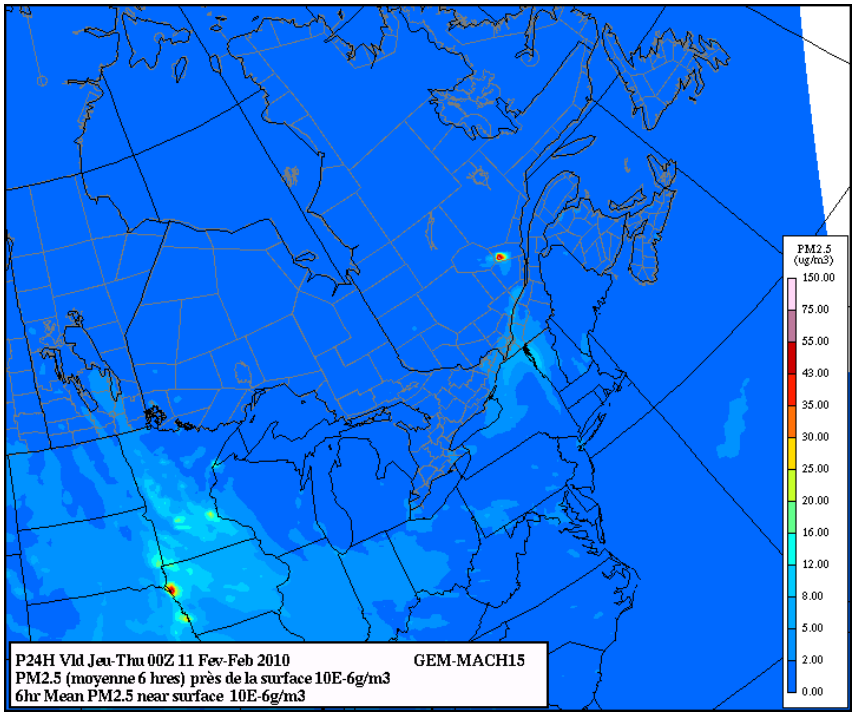
The bottom panel shows the forecast vertical motion of the parcels.

NOAA-EPA O_3 Forecast Model

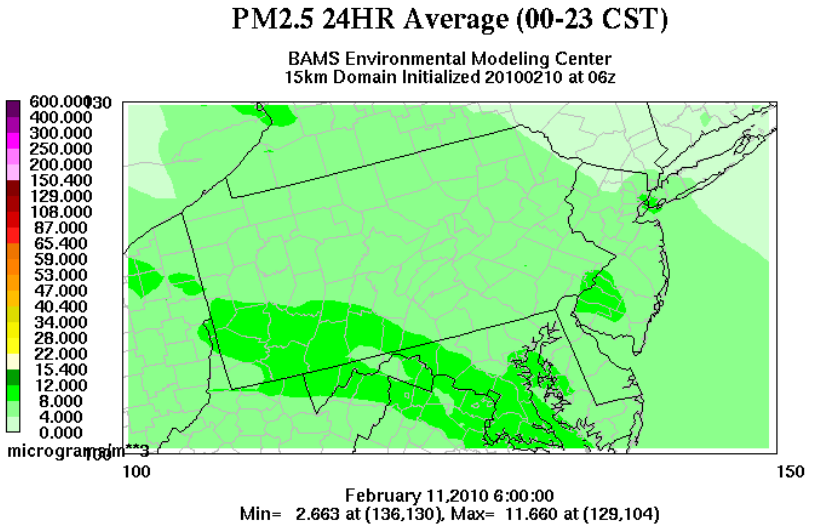


Model forecasts available twice a day, see also: http://www.weather.gov/aq/

$PM_{2.5}$ Forecast Models

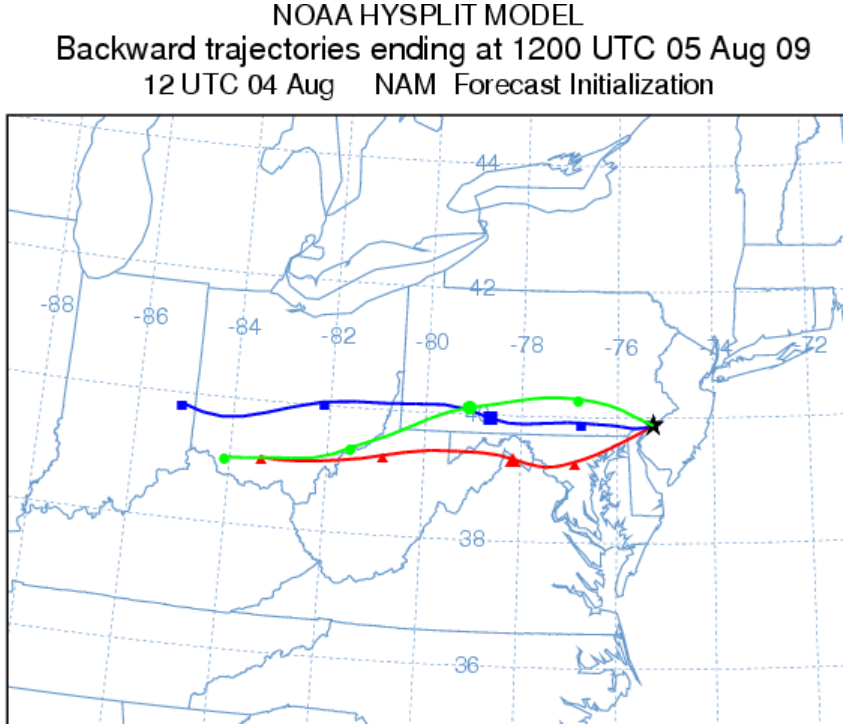


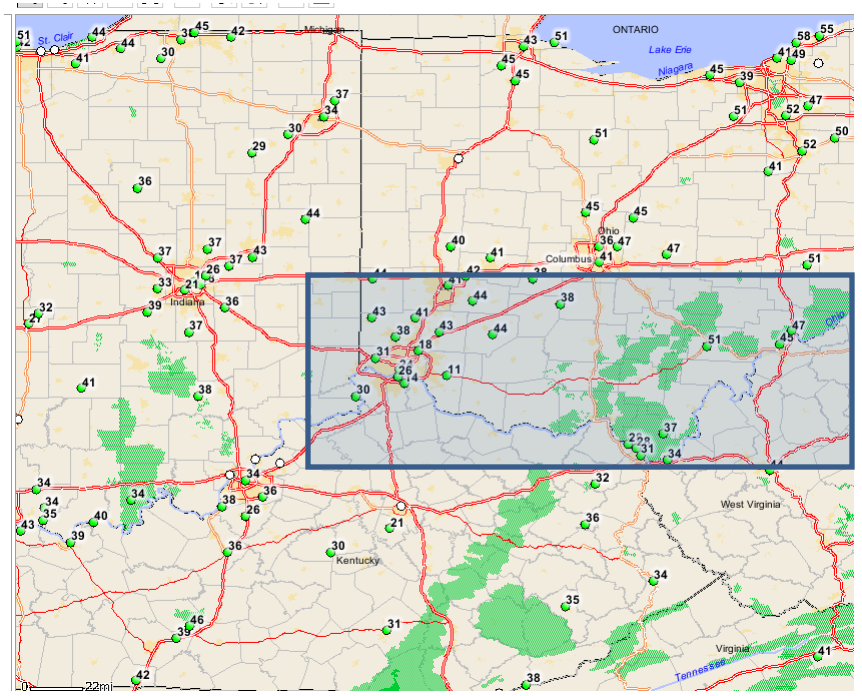
Environment Canada, GEM-MACH



Barons Advanced Meteorological Systems

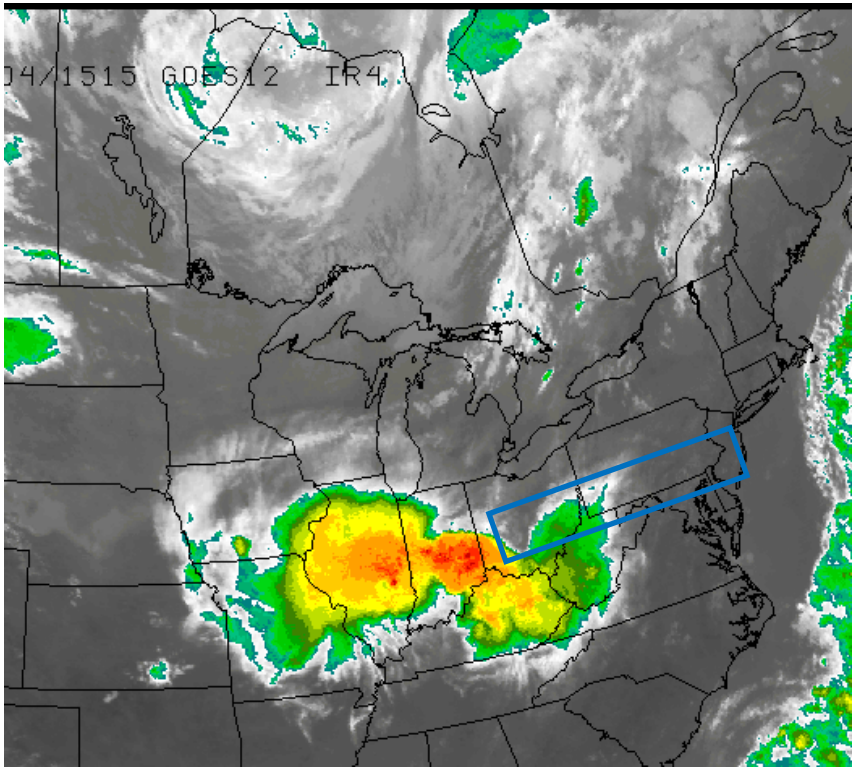
An Example of the Value of New Forecast Products

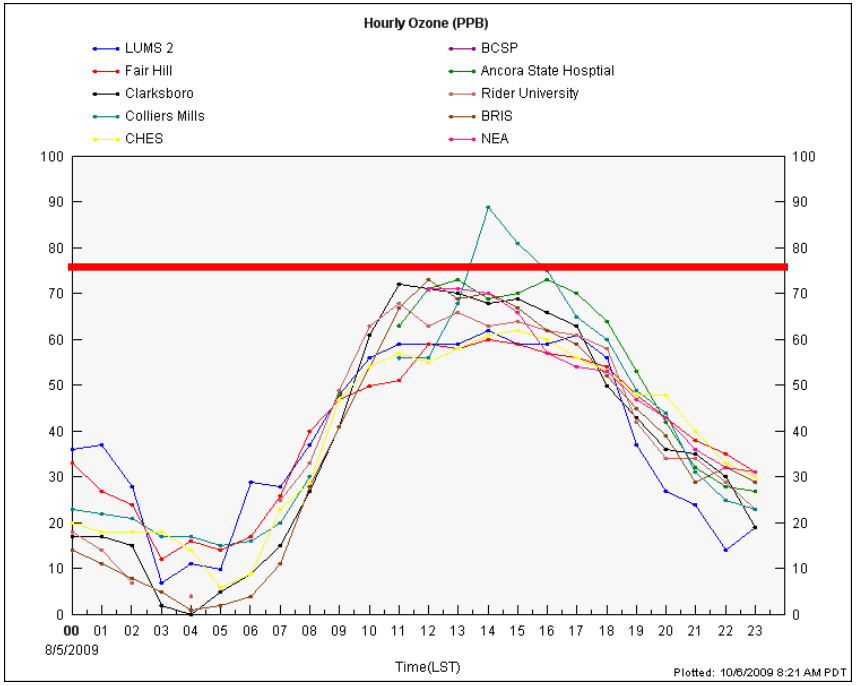




August 5th was forecast to be sunny and very warm - conducive to O_3 formation. Back trajectories are from climatologically "dirty" location. But, early afternoon O_3 concentrations along path of trajectory are relatively clean!

Low Upwind O_3 Concentrations Due to Organized Thunderstorm System (MCS) Earlier that Day

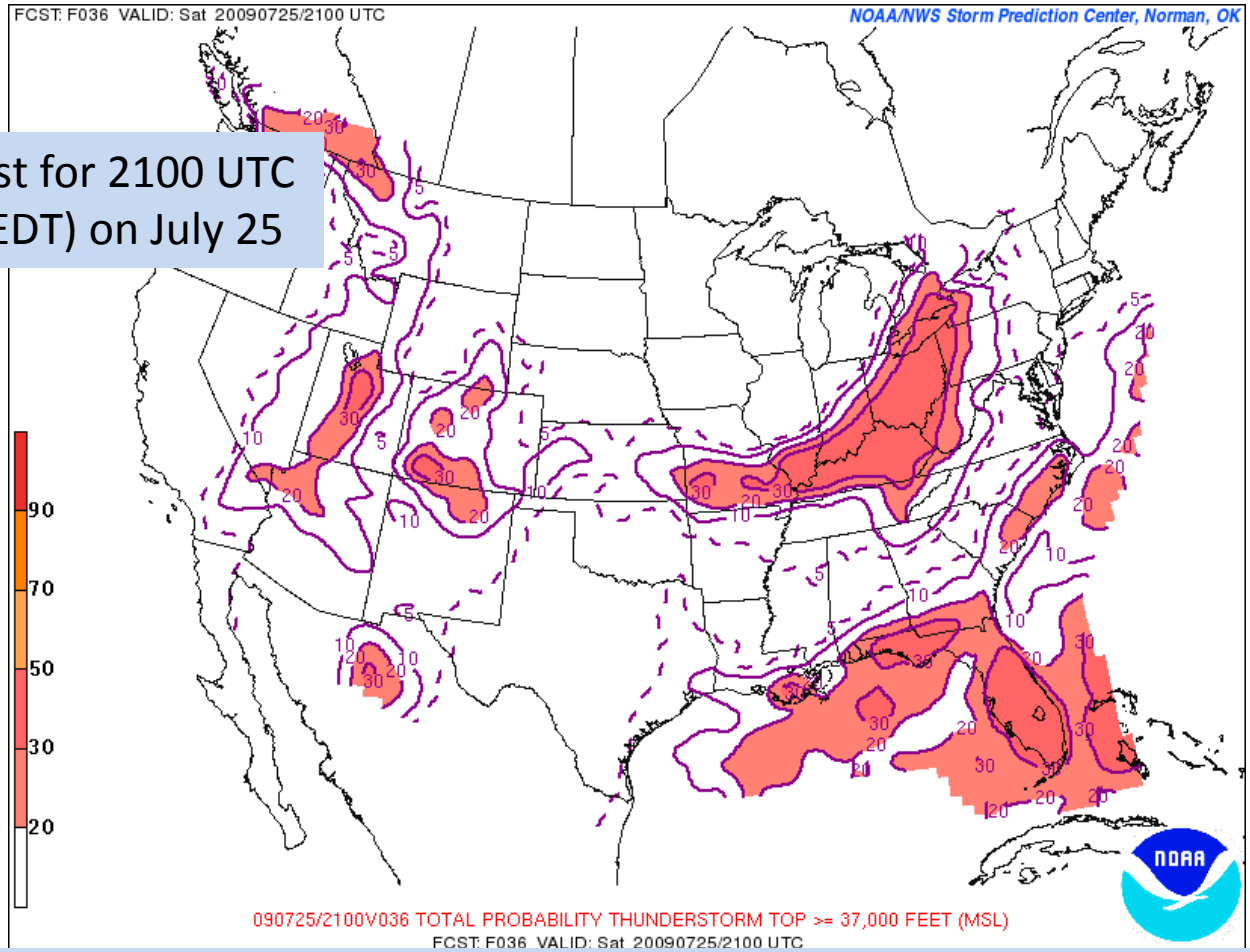




Result: While O_3 was high in PHL the following day, no locations reached the Code Orange threshold.

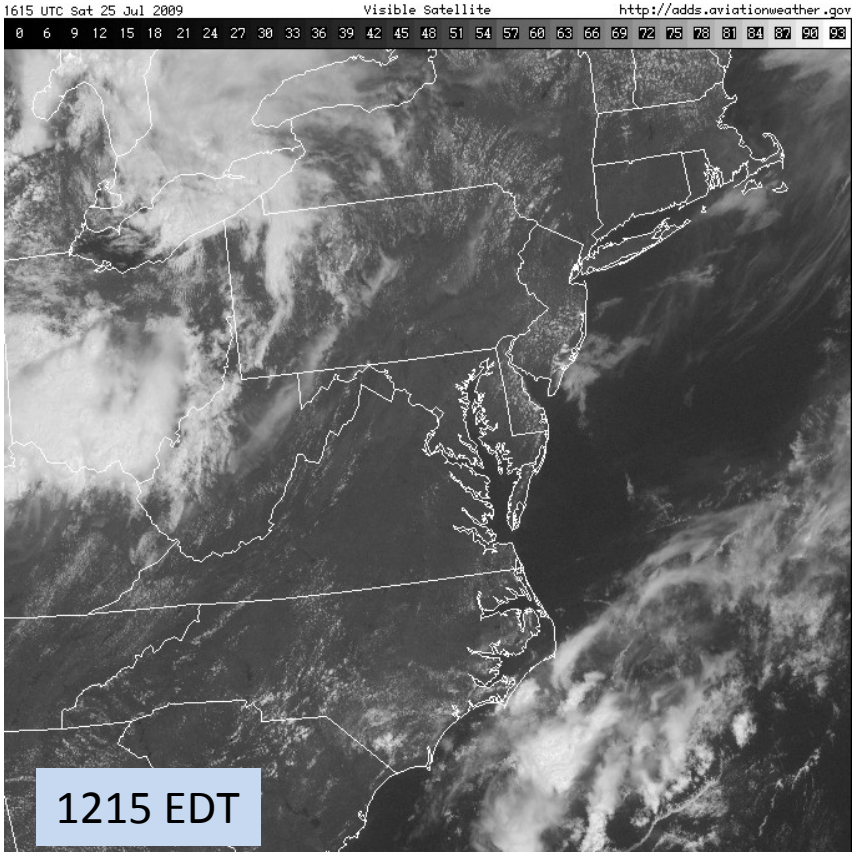
Ensembles of Models Can Give Probability of Strong Thunderstorms

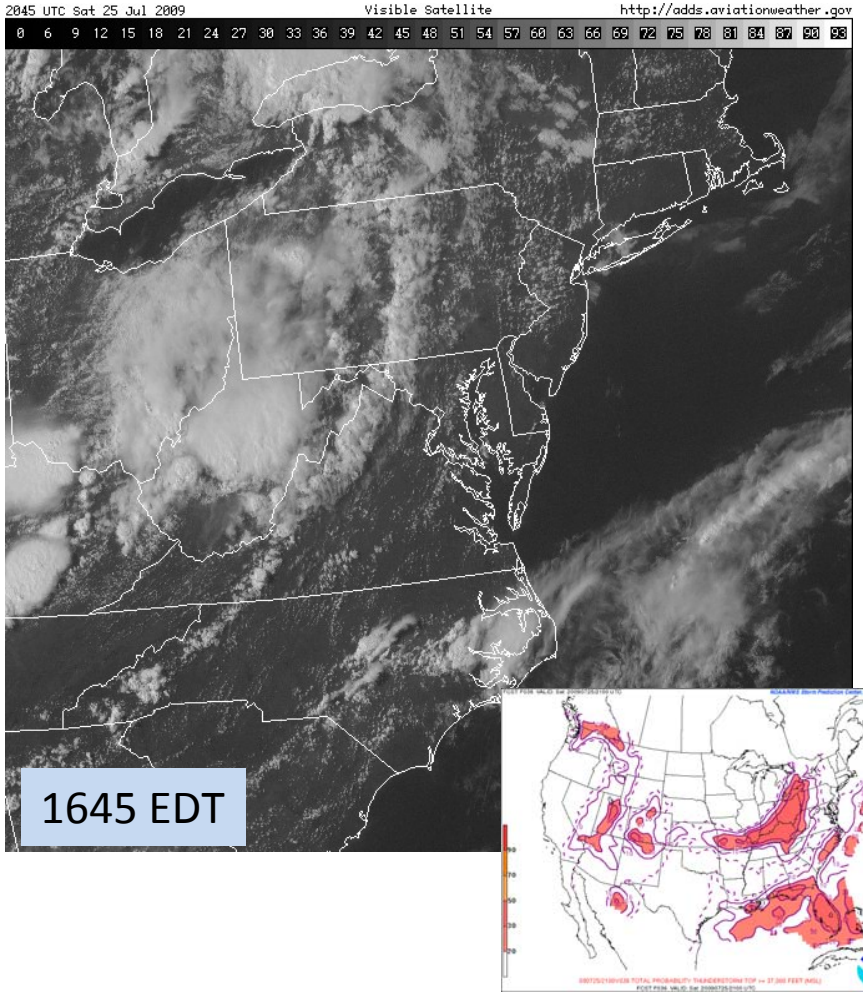
Forecast for 2100 UTC (5 pm EDT) on July 25



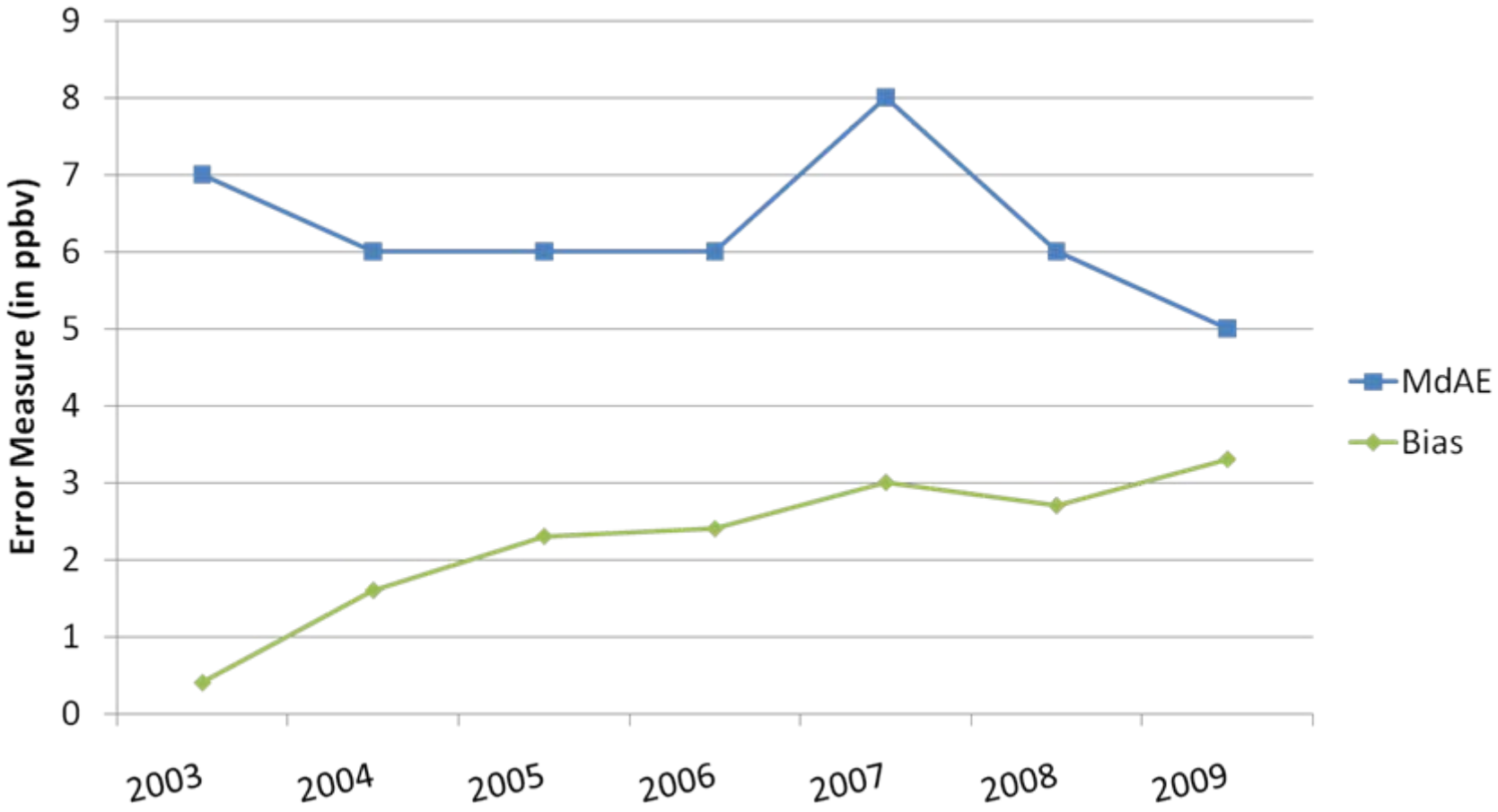
Ensembles are repeated runs of a model using slightly different initial conditions or model physics. Contours are probability (%) of thunderstorm tops > 37,000 ft.

Example: Saturday, July 25, 2009





Ozone Forecast Skill in PHL Steady Last 7 Years

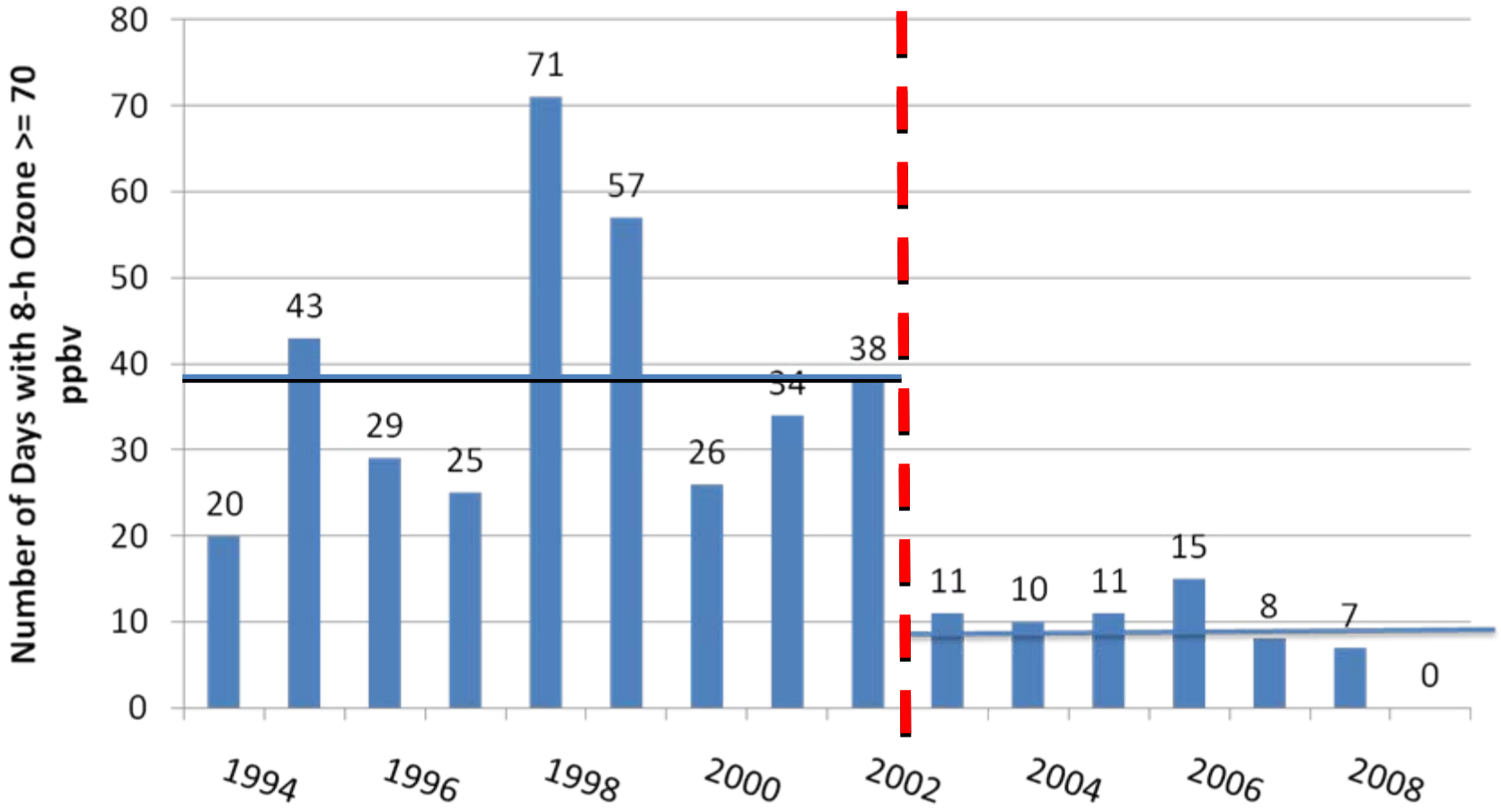


Median Absolute Error (MdAE) and Bias for PHL O_3 Forecasts

But Skill in Code Orange Cases Declined Last Two Years - Especially in 2009

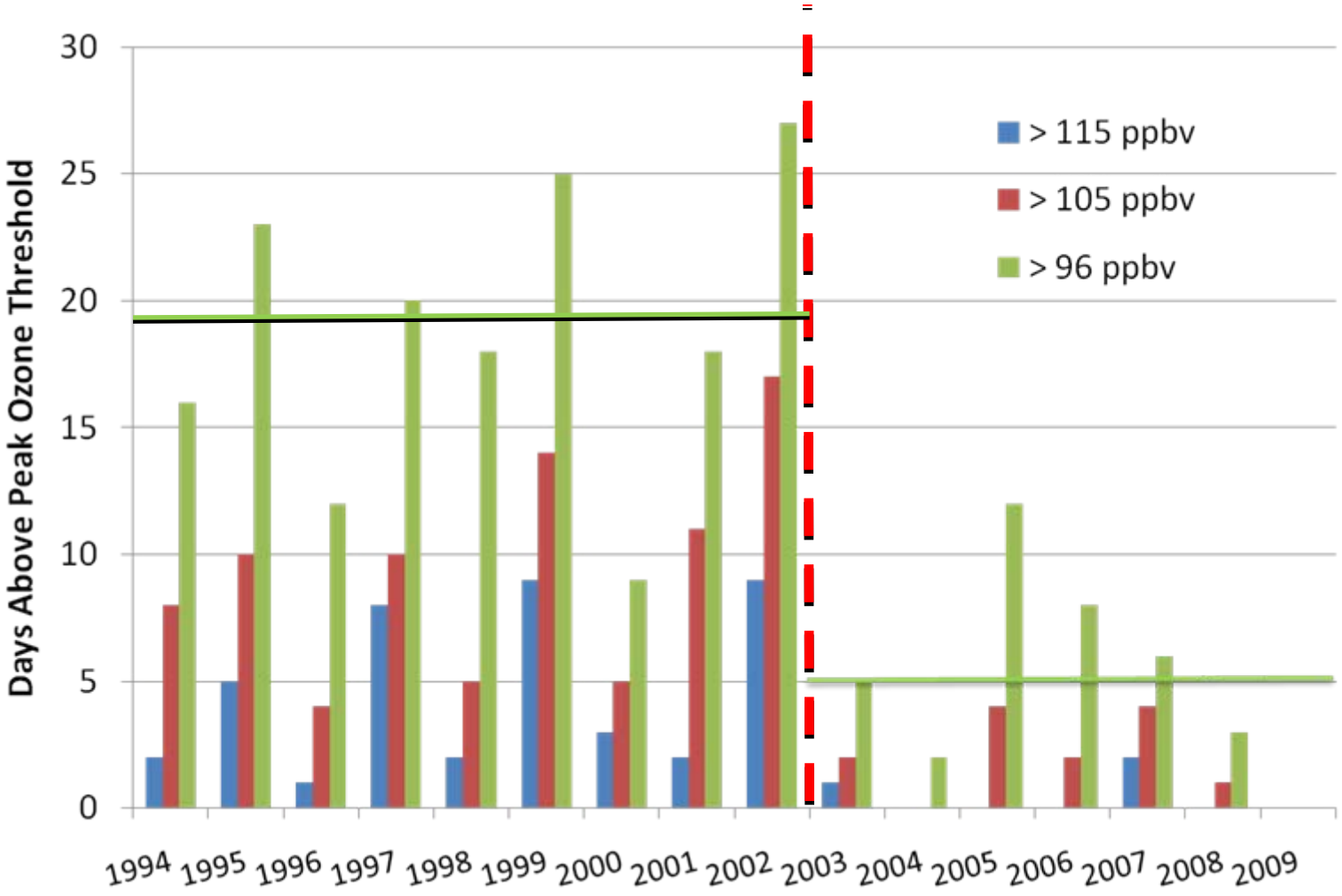
False Alarm: Code Orange forecast, not observed; Threat: Overall skill measure for threshold forecasts; Hit: Code Orange forecast and observed.

Changes in Ozone Climatology
Shenandoah National Park – Big Meadows



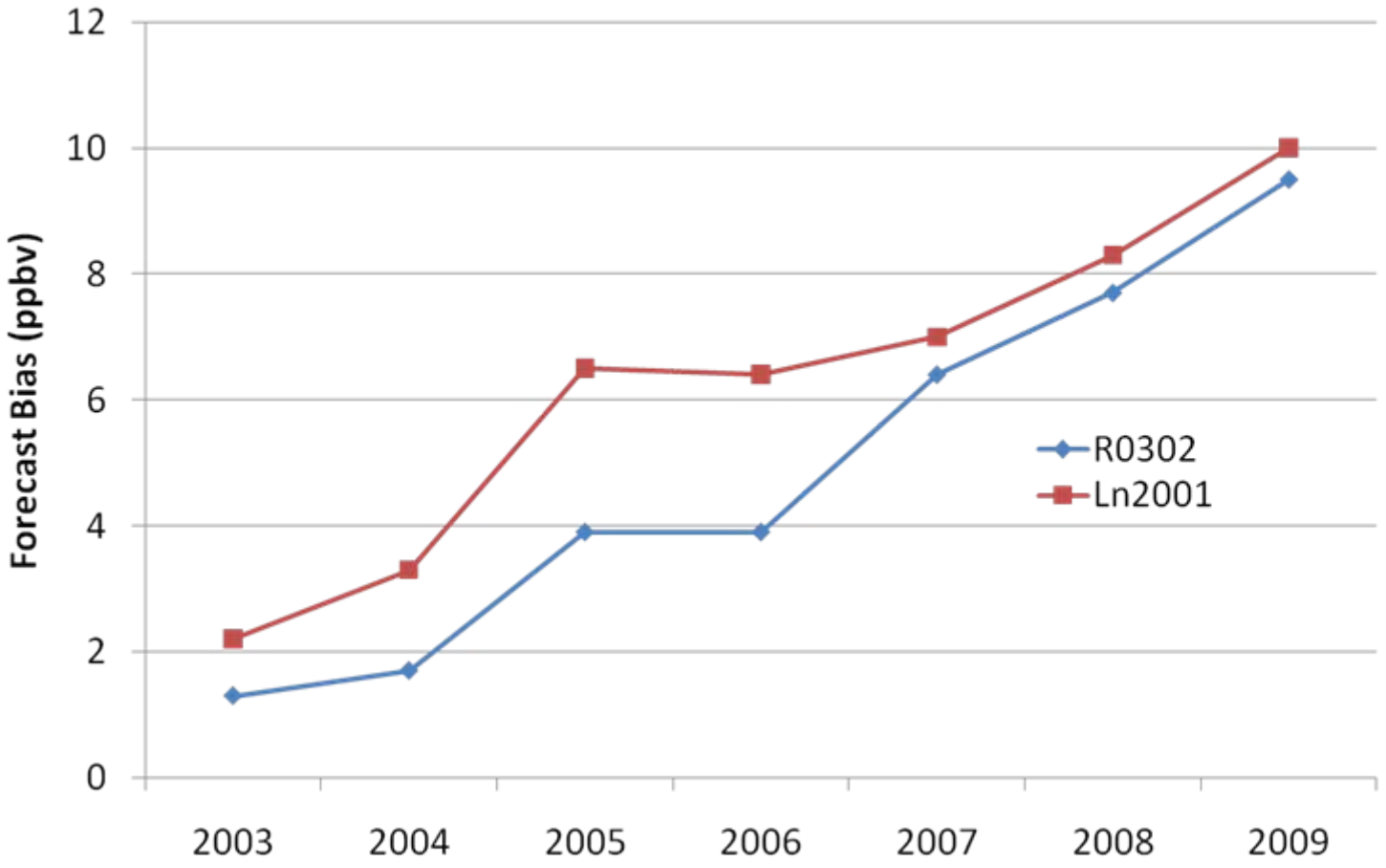
Number of Days ≥ 70 ppbv (8-hour ave). Note: No days in excess of 70 ppbv in 2009

Changes in O_3 Climatology
Frequency of Severe O_3 Cases in PHL



2009 is not blank, there just weren't any Code Red cases!

Statistical O_3 Model Bias in PHL (2003-2009)

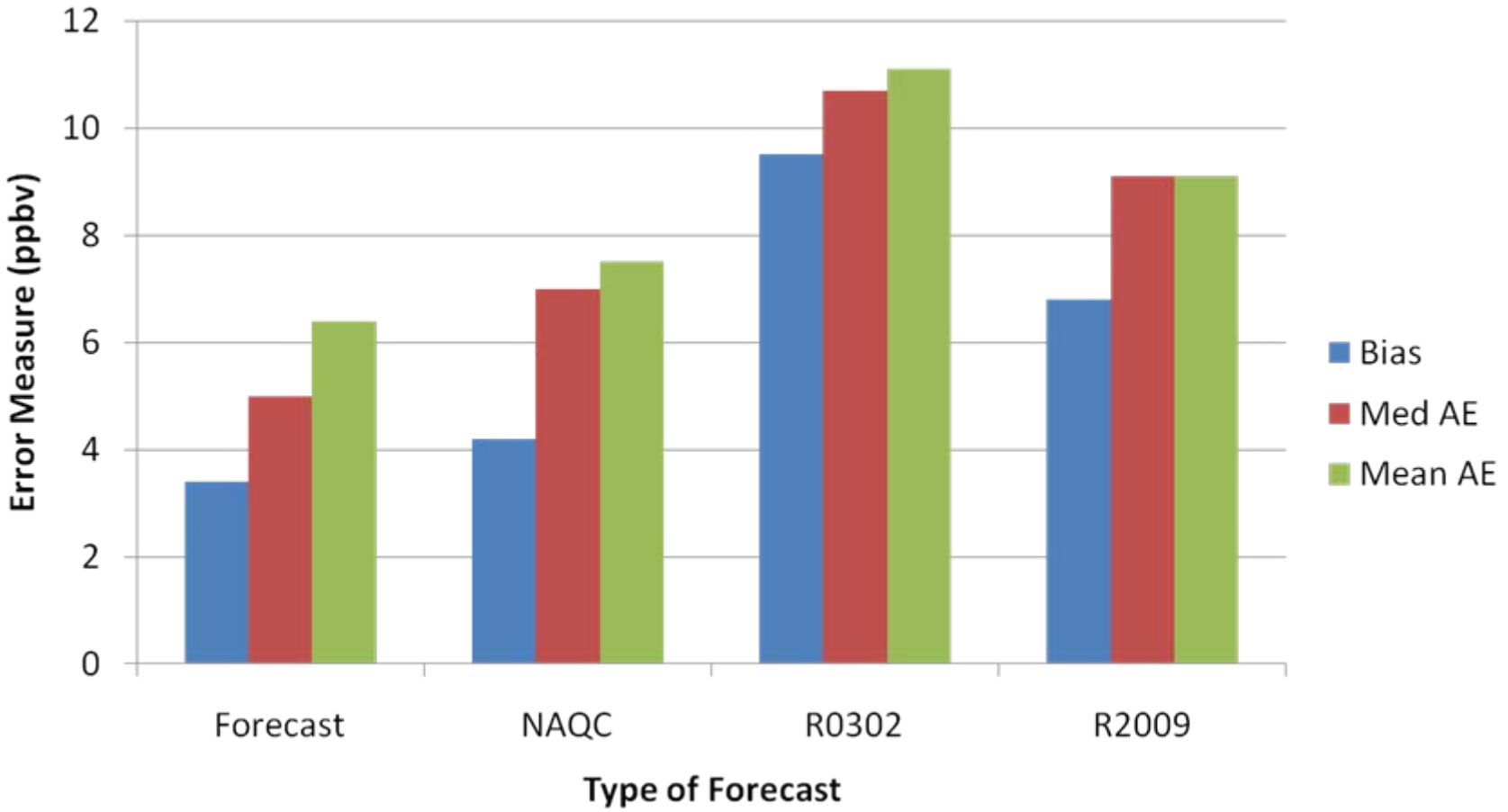


Bias in forecasts of peak domain-wide 8-hour O_3 by two MLR models used in PHL and trained on pre-NO_x SIP Rule historical data.

Shortcoming of Statistical Models

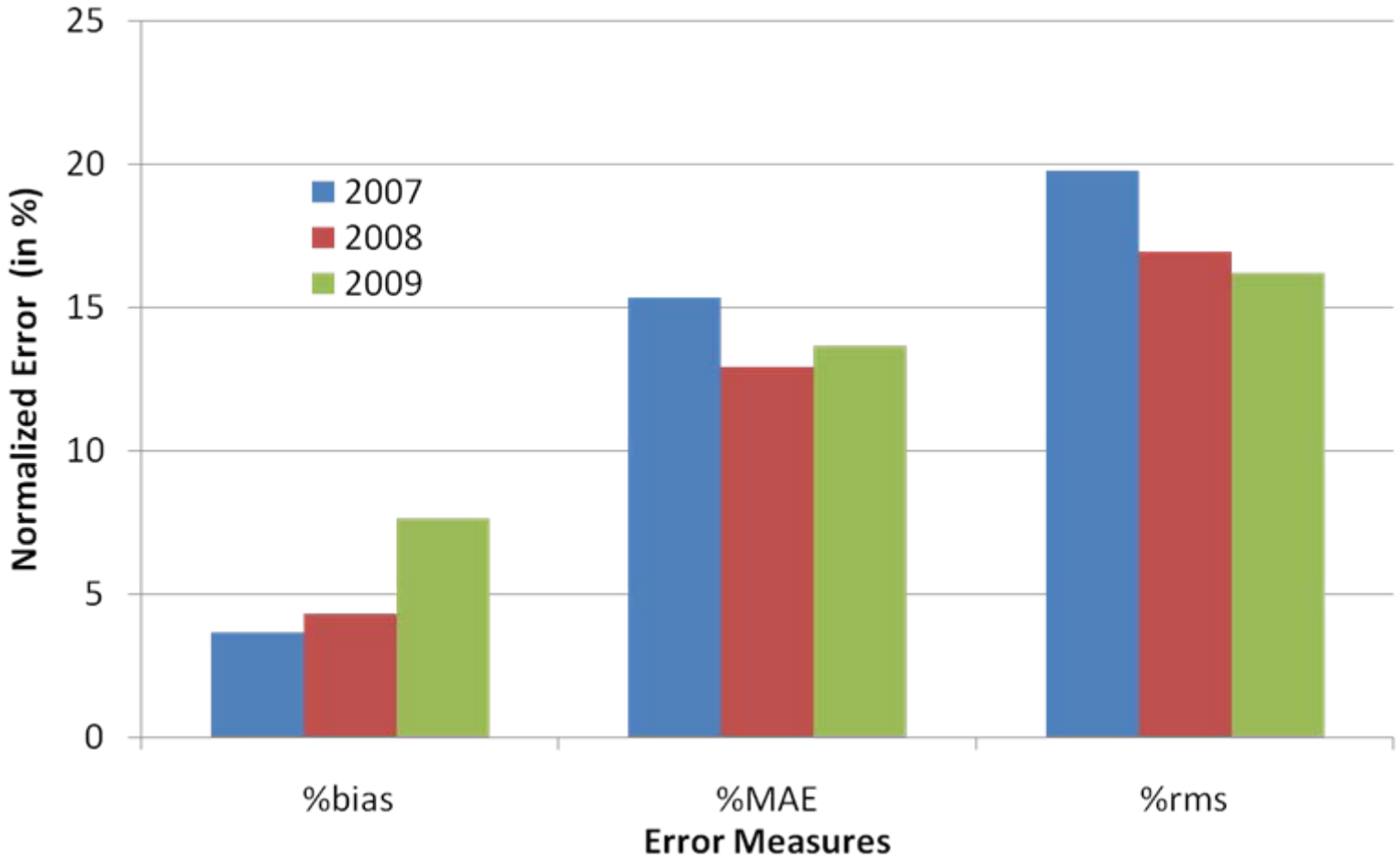
- The skill of statistical models is primarily due to the close relationship between peak O_3 and maximum surface temperature (T_{max}).
- This relationship is "frayed" in the post-NO_x SIP Rule world:
  - For 1993-2002, 58% of variance in peak O_3 in PHL is "explained" by T_{max}
  - For 2003-2009, only 44%.
  - In 2009, older statistical models showed no skill (Brier Skill Score < 0). Statistical models trained on post-NO_x SIP data showed some skill.

By 2009, Numerical O_3 Models Outperforms Traditional Statistical Models



NAQC: NOAA-EPA Model; **R0302**: MLR Model Trained on pre-NO_x SIP data; **R2009**: MLR Model Trained on post-NO_x SIP data

NAQFC Model Performance Steady in 2009

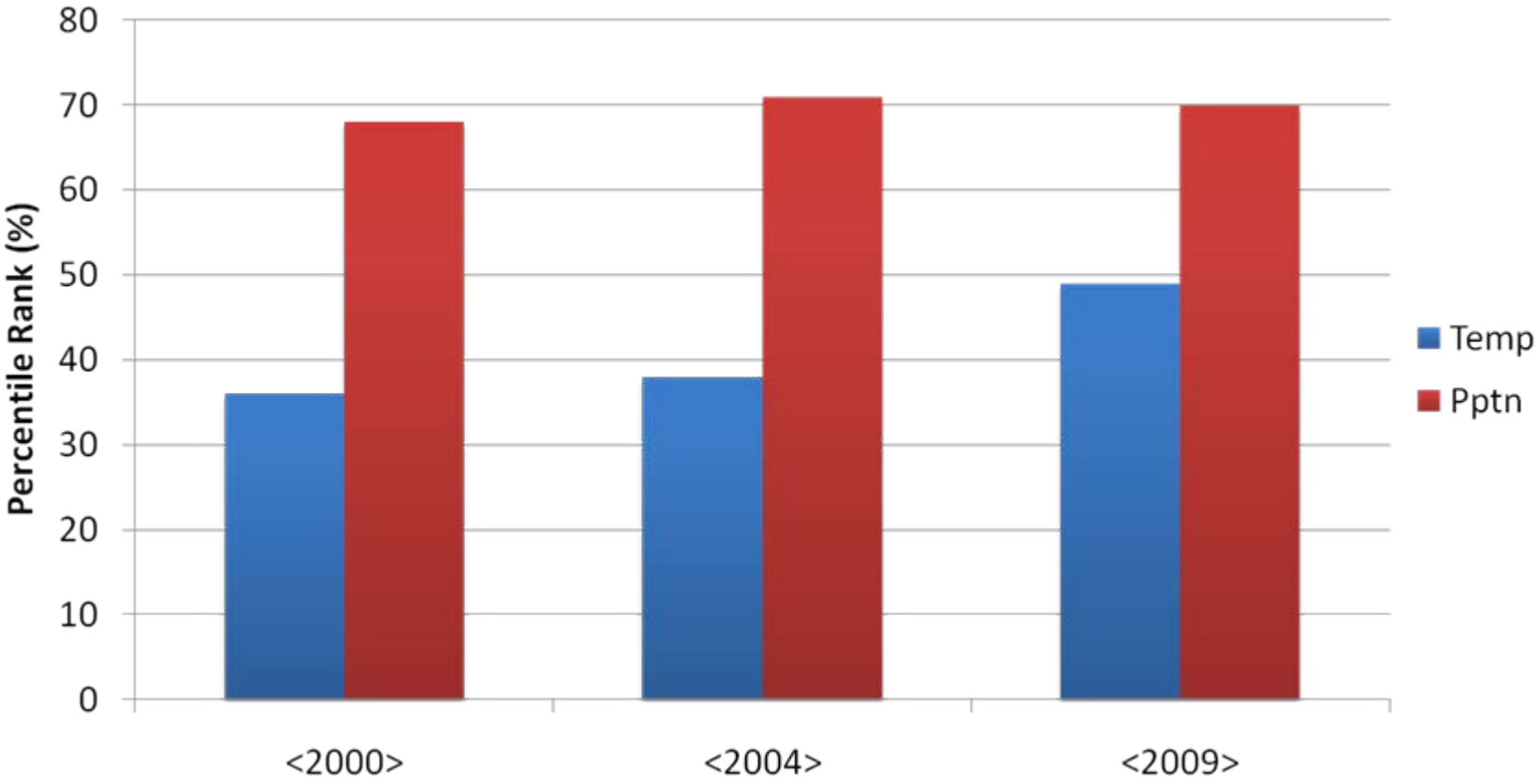


But “False Alarm” Rate in 2009 was more than double previous years

Comments on the 2009 O_3 Season

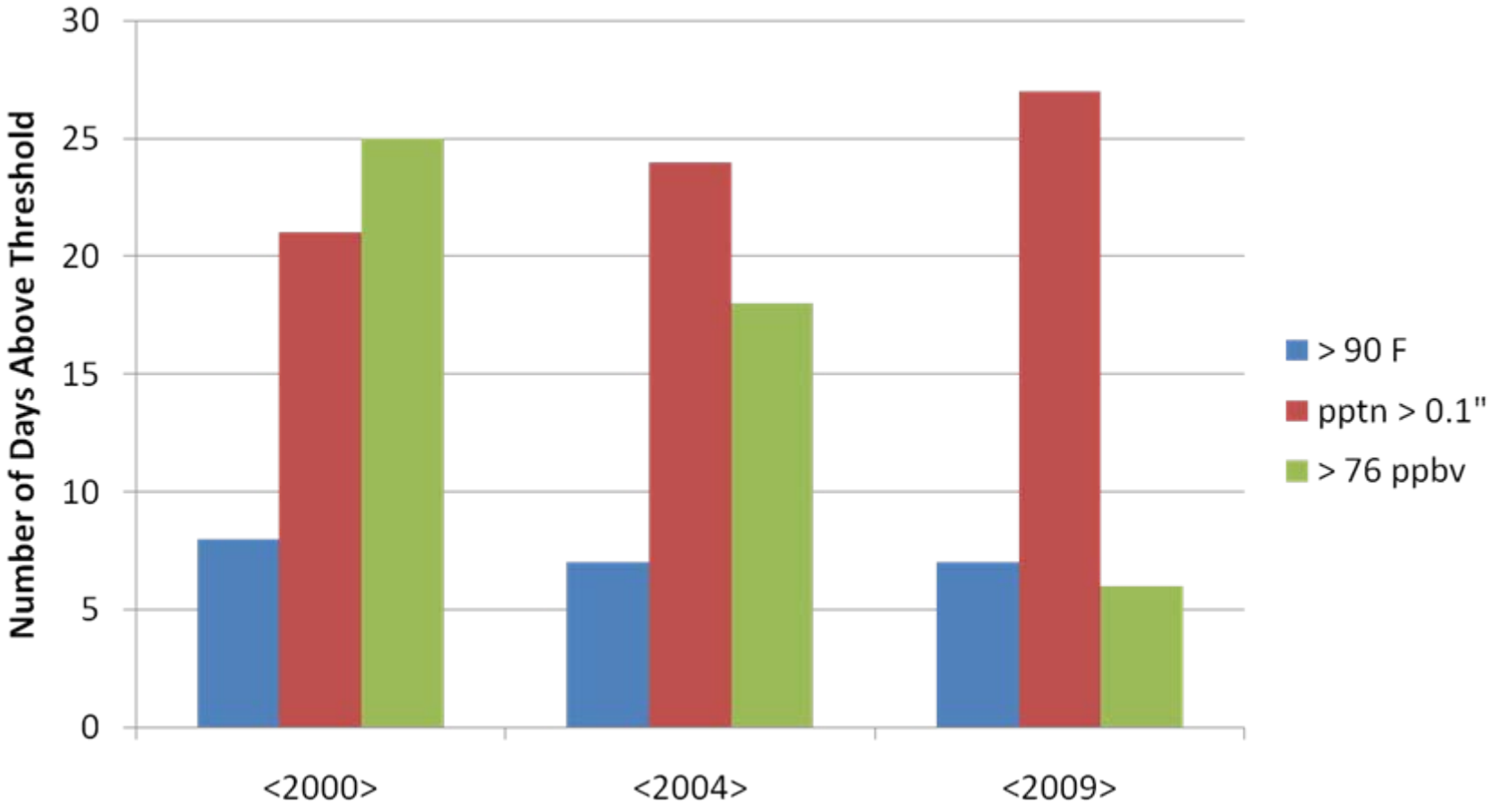
- 2009 was a cool and wet summer. Low frequency of "O_3 conducive weather" locally and regionally. Similar to 2000 and 2004.
- "Standard" high O_3 weather – westward extension of the Bermuda High, sustained westerly transport from the Ohio River Valley – was infrequent.
- This weather pattern contributed to historically low frequency of high O_3 cases but there may also have been lower emissions of O_3 precursors due to the economic recession.

Percentile Rank of Temperature and Precipitation for 3 Recent Low O_3 Summers



Average percentile rank of temperature and precipitation for PA, DE, NJ for summer months (JJA). Warmest and wettest are 100th%ile.

Weather Conditions and Code Orange O_3 in Philadelphia in Recent Cool Summers



2009 Not Remarkably Different from 2000 and 2004 Except for Frequency of Bad Air Days

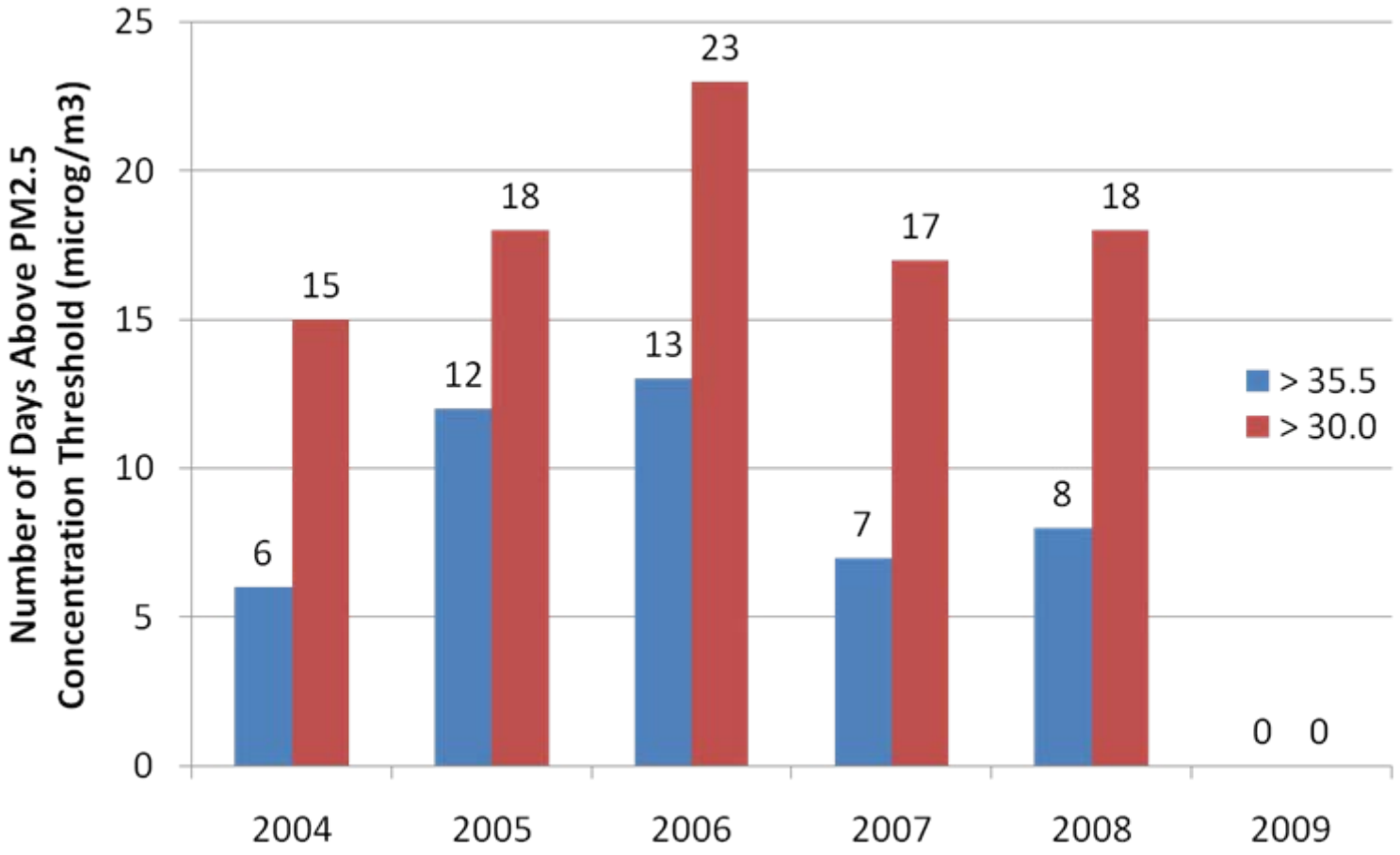
Shenandoah NP $PM_{2.5}$ Daily Average Concentrations (May-August, 2004-2009)

	N	Median ($\mu g/m^3$)	Mean ± 1 σ ($\mu g/m^3$)	Ratio (Days > 20 $\mu g/m^3$)	Ratio (Days > 30$\mu g/m^3$)
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

O_3 is very sensitive to temperature and rainfall (cloud cover) while $PM_{2.5}$ is not. $PM_{2.5}$ concentrations, on average, vary little from summer to summer.

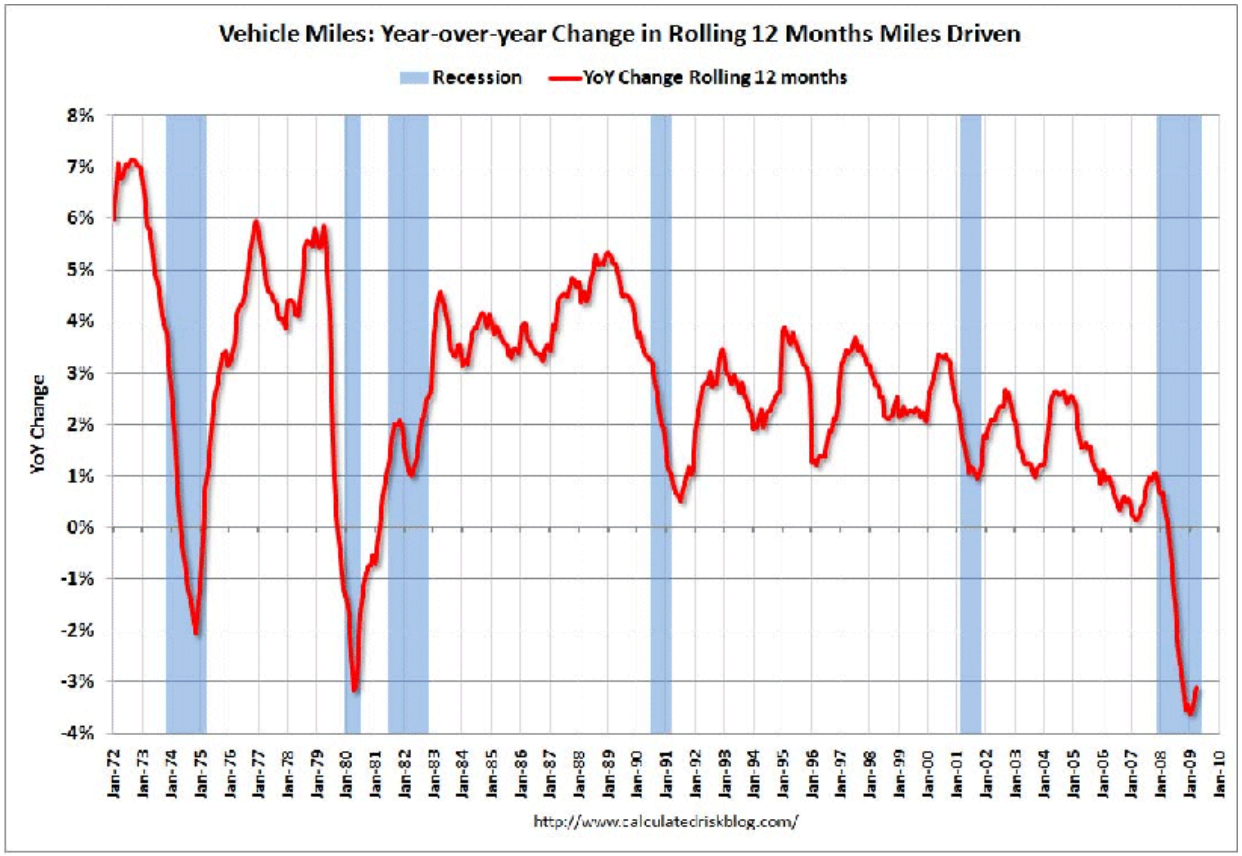
In 2009, however, mean $PM_{2.5}$ concentrations at SNP were 33% lower than the recent average and the frequency of days ≥ 20 μgm^{-3} was 90% lower.

Frequency of "Bad" $PM_{2.5}$ Days in PHL Was Remarkably Low in 2009



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

Motor Vehicle Emissions and Recessions

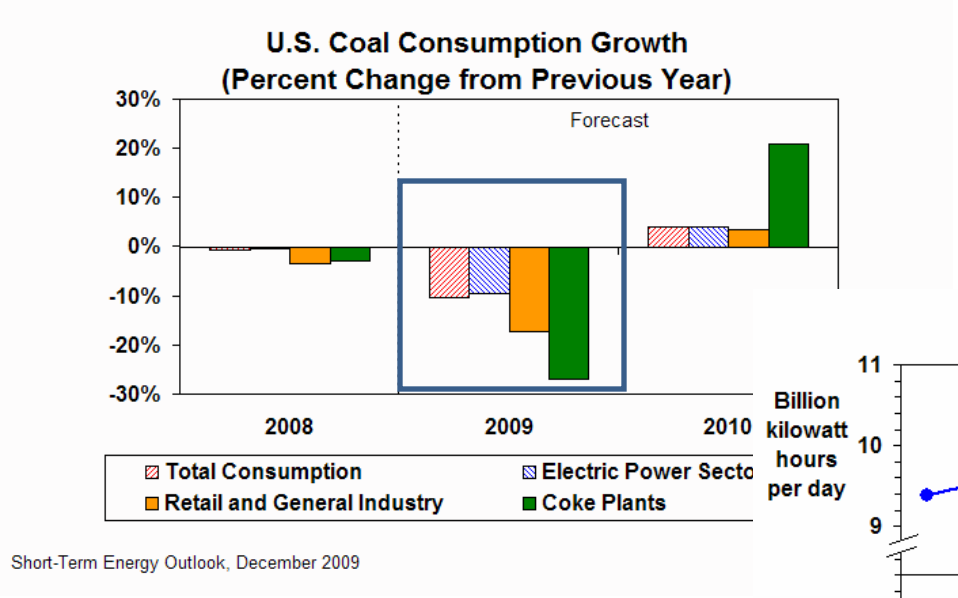


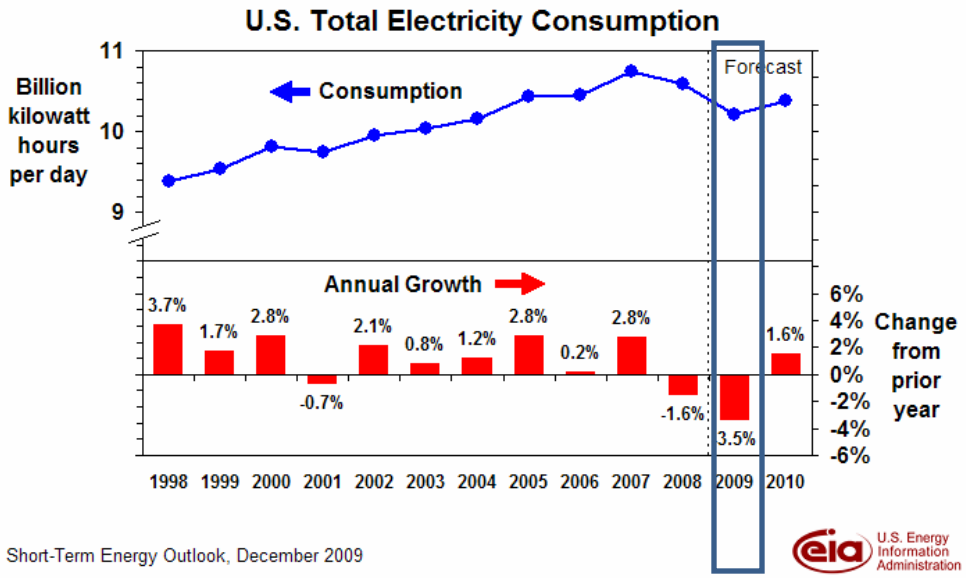
Measure is year-over-year rolling 12-month average change in vehicle miles Travelled (VMT). Periods of economic recession shaded in blue.
http://www.calculatedriskblog.com

Coal and Electricity Consumption in 2009

- ***U.S. Electricity Consumption.*** Retail sales of electricity to the industrial sector from January through September 2009 were down by about 12 percent compared with the same period last year, similar to the decline in the U.S. manufacturing production index.
- ***U.S. Coal Consumption.*** Coal consumption by the electric power sector fell nearly 12 percent for the first 9 months of 2009 in response to lower total electricity generation coupled with increases in generation from other sources, natural gas, hydropower, and wind.
- (Source: EIA, http://www.eia.doe.gov, December 8, 2009)

Coal and Electricity Consumption in 2009





Source: U.S. Energy Information Administration, December 8, 2009
http://www.eia.doe.gov/emeu/steo/pub/contents.html

Conclusions

- Air quality forecasting tools and guidance have improved over the past decade.
- Changes in O_3 precursor emissions due to the NO_x SIP Rule have lowered peak O_3 concentrations.
- Poor air quality days (Code Orange) have become much less common and, therefore, more difficult to forecast.
- Numerical forecast models have adapted better than traditional statistical methods to the change in emissions.
- The summer of 2009 was anomalous in terms of both weather conditions and precursor emissions.

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 Pennsylvania, New Jersey and Delaware.
- 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).