Forecasting in a Changing Air Quality Regime

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Outline

• A brief look back at the last two summer seasons (2009 and 2010).
• Changes in regional and local air quality over the past decade.
• Effect of these changes on air quality forecasting skill and methods.
• Adaption of forecast methods to these changes and sources of uncertainty in current forecast methods.
Both Ends of the Weather Spectrum: 2009 – Cool and Wet, 2010 – Hot and Dry

Temperature anomalies for JJA 2009 (left) and 2010 (right) vs. recent (1993-2007) average
Philadelphia Metropolitan Area

Closest Comparisons to 2010 are 1999 and 2002, both prior to “NO_x SIP Call”
All Three Recent Warm Summers Featured Similar Large Scale Weather Pattern

Plots are geopotential height at 925 mb (~800 m). Winds are roughly parallel to gradients. Strong westward extension of the Bermuda High.
Comparison of Three “Warm” Summers

Number of Days (JJA)

- T>=90F
- Days Rain
- Orange
- Red

8-h Ozone Color Codes

- 1999
- 2002
- 2010
Note Similar Effect for Set of “Cool” Summers

2009 Not Remarkably Different from 2000 and 2004 Except for Frequency of Bad Air Days
The frequency of Code Orange cases has been reduced by 43% since 2002 and Code Red cases reduced by 76%.
Effect on Regional Scale O₃: Big Meadows, Shenandoah National Park

Frequency of Days with Peak 8-hour O₃ ≥ 70 ppbv at SNP reduced by 68%
Shenandoah NP PM$_{2.5}$ Daily Average Concentrations (May-August, 2004-2010)

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Median (µg/m$^3$)</th>
<th>Mean ± 1 σ (µg/m$^3$)</th>
<th>Ratio (Days &gt; 20 µg/m$^3$)</th>
<th>Ratio (Days &gt; 30µg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004-2008</td>
<td>487</td>
<td>14.2</td>
<td>15.1 ± 7.8</td>
<td>0.23</td>
<td>0.04</td>
</tr>
<tr>
<td>2009</td>
<td>116</td>
<td>9.5</td>
<td>9.8 ± 4.3</td>
<td>0.02</td>
<td>0.00</td>
</tr>
<tr>
<td>2010</td>
<td>121</td>
<td>10.7</td>
<td>11.4 ± 5.4</td>
<td>0.07</td>
<td>0.004</td>
</tr>
</tbody>
</table>

PM$_{2.5}$ is, on seasonal scale, less sensitive to temperature and rainfall (cloud cover) than O$_3$. However, summer season high PM$_{2.5}$ episodes are nearly always coincident with high O$_3$ episodes.

In 2009, 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. 2010 had only 1 day ≥ 30 µg/m$^3$. 
Frequency of High PM$_{2.5}$ Cases in Philadelphia

Peak 24-hour average PM$_{2.5}$ from Philadelphia metropolitan area FRM monitors
Energy Use Was Suppressed in 2009 Due to Economic Recession, Recovery in 2010

U.S. Total Electricity Consumption

Source: Short-Term Energy Outlook, December 2010
Coal Consumption Increased in 2010 Though Not Markedly Until 4\textsuperscript{th} Quarter

Effect on Air Quality Forecasting:
Hot Days are Now Less Likely to be Smoggy

Prior to 2003, half of days with $T_{\text{max}} \geq 90^\circ F$ days observed Code Red $\text{O}_3$. Since then, only 16% of hot days reach Code Red and only 65% reach Code Orange.
Statistical Model Forecasts, Trained on Historical Data, Have Become Increasingly Biased

Forecast Skill in Philadelphia: Median Absolute Error for Peak 8-h O$_3$

MAE for the NOAA numerical forecast model (NAQC) rivals the “Expert” forecast.
Temperature-Ozone Relationship Frayed

- Variance in peak $O_3$ “explained” by $T_{\text{max}}$ now only 44% (a 25% reduction from pre-$\text{NO}_x$ SIP Call years).

All statistical models depend on this relationship and, for near future, there will be no stable historical database to support new statistical models.

Numerical models can quickly adjust to EGU emissions changes, not so quickly to other precursor sources.

Numerical models are now the most reliable forecast guidance for much of the mid-Atlantic – though skill varies by location.
Steep Coastal O$_3$ Gradients, Driven by Sea/Bay Breezes, Are Observed in Some Cases

In this case (August 11, 2010) sea breeze circulations developed north of a frontal boundary and re-circulated the previous day’s polluted air mass.
We Blew the Forecast Because a Cold Front was Forecast to Cross through PHL

High O₃ in B-W Corridor on Prior Day (August 10)

In fact, front crossed Delaware by 1800 UTC on August 11th.
Aqua Polar Orbiting Satellite Visible Image Shows Sea Breeze and Haze

MODIS/Aqua
~ 1730 UTC
August 11, 2010
NOAA Forecast Model Did Forecast High O₃

Daily Peak Ozone AQI
Wednesday, August 11, 2010

Observed Color Coded AQI

NOAA Ozone Model Forecast,
Maximum 8-h Ozone (ppbv)

(prd) 12Z 25H–48H 2 day 8h max sf O₃ (ppbv) Valid 11 AUG 2010
Why? Met Model Picked Up Sea Breeze Front Forming *Behind* Frontal Boundary

Winds speeds (shaded) and streamlines from the high resolution WRF weather forecast model for 1800 UTC (left) and 2100 UTC (right) (Figure courtesy: Penn State eWall, [http://www.meteo.psu.edu/~gadomski/ewall.html](http://www.meteo.psu.edu/~gadomski/ewall.html))
Using Numerical Ozone Forecast Models

• Can post-process NOAA model guidance to filter the effect of land-sea $O_3$ gradients.
  – In PHL: Simplest case, can reduce false alarms of high $O_3$ by more than half.
  – In CT: Can improve on expert forecast skill by use of $O_3$ forecast magnitude and range in forecast concentrations.
  – In Baltimore: Most difficult case, but can improve skill.

• Details and further discussion, see:
  – http://www.meteo.psu.edu/~wfryan/quebec/iwaqf-2010.pptx
The public forecast (blue) is compared to the post-processed NOAA model (red) and the current statistical model guidance (green). For more details on skill scores, see: http://www.meteo.psu.edu/~wfryan/skill-score-appendix-2010.docx
O$_3$ Forecast Model Guidance Issues (2): Weekday/Weekend Effects

Prior to the NO$_x$ SIP Call emissions reductions, high O$_3$ cases (75$^{th}$%ile shown here) had no day of week pattern - not the case since 2003.
This Has Been a Recent Problem for Human Forecasters

False Alarm rate for Code Orange (≥ 76 ppbv) forecasts in PHL 2003-2010
NOAA-EPA forecast model guidance bias, peak O₃ by day of week (2007-2010)
O₃ Forecast Model Guidance Issues (3): Seasonal Bias Drift

![Graph showing seasonal bias drift in peak 8-h ozone forecast bias (ppbv). The x-axis represents different periods, such as May 1-4, June 1-7, etc., and the y-axis shows the forecast bias in ppbv. The graph includes bars for median and mean values.]
• Significant, and continuing, reductions in $\text{NO}_x$ emissions on a regional scale since 2003 have contributed to lower $\text{O}_3$ concentrations in the mid-Atlantic.

• Skill of statistical $\text{O}_3$ forecast model guidance depends on a training data base that is “quasi-static”. Precursor emissions and $\text{O}_3$ concentrations not static since 2003 and not likely to be in the near future.
The key relationship that powers statistical forecast model guidance skill, $O_3$ and $T_{\text{max}}$, has weakened as well so that statistical models, a mainstay of air quality forecast guidance, are rapidly becoming less useful.

Forecasters must now rely on numerical forecast models, updated with EGU emissions data yearly, for forecast guidance.
• Numerical O$_3$ models in the mid-Atlantic are reasonably accurate, but:
  – Models produce steep land-sea gradients in O$_3$.
  – Weekend/Weekday differences are now apparent and only partly addressed by the models.
  – Seasonal bias in NOAA model forecast is present but not well understood.

• Forecast research should be directed to post-processing of model forecasts. However, the emissions, chemistry and meteorology sub-models will not be “frozen” any time soon so that post-processing must be of the “updateable” form (e.g., UMOS (Environment Canada)).
Acknowledgements

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