Trends in Hourly Ozone and Ozone Health Metrics across the United States and the European Union

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Photochemical modeling analysis predicts that future NOx reductions will lead to changes in spatial and temporal patterns of ozone:

- Decreased frequency of high and low O$_3$ concentrations: “compression” of O$_3$ distribution
- Shift in seasonal pattern: peaks occur earlier in the year

**All days and census tracts**

**Philadelphia site 42101004 (urban)**

Simon et al., 2016 *Environmental Health Perspectives*
Photochemical modeling analysis predicts that future NOx reductions will lead to changes in spatial and temporal patterns of ozone.

- **Annual 4th high MDA8** decreases at in all Philadelphia census tracts:
  - Highest pop density areas (low starting O₃) see less benefit
- **Most of population lives in** areas with decreasing 5-month seasonal mean:
  - A small portion of the population in the highest pop density areas see a small O₃ increase

**Motivation: Philadelphia Modeling Case Study**

Simon et al., 2016 *Environmental Health Perspectives*
Emissions changes impact the ozone distribution and these changes can in turn be related to changes in important ozone regulatory and health metrics.

- **Hourly O\textsubscript{3}**
- **8-hour daily maximum O\textsubscript{3} (MDA8) - human health**
  - Seasonal MDA8 mean (May-September)
  - Annual 4\textsuperscript{th} high MDA8
- **MDA8 Percentiles: 5\textsuperscript{th}, 25\textsuperscript{th}, 50\textsuperscript{th}, 75\textsuperscript{th}, 95\textsuperscript{th}**
  - Annual SOMO35 – MDA8 sum for days $\geq 35$ ppb
  - Annual SOMO10 – MDA8 sum for days $\geq 10$ ppb
- **W126 - vegetation**
- **AOT40 - vegetation**
- **6-month average of 12-hr (0800-1959h) O\textsubscript{3} concentrations - vegetation and climate and global atmospheric chemistry model evaluation**
What Can Ambient Data Tell Us About These Trends?

- Extensive ground-based ozone monitoring network with data dating back at least 20 years in the EU and US

- Long-term data from Chinese monitoring sites are more limited
  - Not discussed today

- The past ~25 years provide a “natural experiment” to look at ambient ozone trends over a period of dramatically changing NOx and VOC emissions
  - U.S. NOx emissions dropped by 52% from 1990 to 2015
  - EU NOx emissions dropped by 54% from 1990-2013

Satellite-Derived NO$_2$ Trends

- Duncan et al (2016) show OMI satellite column NO$_2$ changes from 2005-2014 for different regions

- Broad NO$_2$ decreases across US and W. Europe are consistent with reported decreases in NOx emissions
Trends in Hourly $\text{O}_3$ Concentrations in EU & US

- Changes in hourly $\text{O}_3$ distributions at US and EU sites categorized into trend types
- By far the most common trend was a compression of the $\text{O}_3$ distribution – shift of high and low $\text{O}_3$ values towards mid-range

Lefohn et al., 2018, *in review*
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Relationship between Hourly \(O_3\) Trends and Trends in \(O_3\) Health and Vegetation Metrics

Common Trend Pattern in US and EU

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Lefohn et al., 2017, Atmos. Environ.
The same pattern of change in hourly O₃ distributions can result in different trend directions for various health metrics.

Suffolk, NY presents an example of a site where monthly mean values have increased while regulatory metrics have decreased.
What about Urban/Rural Differences?
Closer Look at MDA8 O₃ in the US 1998-2013

- We separated trends in MDA8 O₃ at US sites by
  - Season
  - Urban class
  - MDA8 percentile
What about Urban/Rural Differences?
Closer Look at MDA8 $\text{O}_3$ in the US 1998-2013

- Most sites with statistically significant trends in 95\textsuperscript{th} percentile MDA8 showed decreasing $\text{O}_3$

- Decreases in 95\textsuperscript{th} percentile were more frequent during summer than during winter

- Decreasing trends in 95\textsuperscript{th} percentile were most common at rural sites

Simon et al., 2015 *Environmental Science & Technology*

- Most sites with statistically significant trends in 5\(^{th}\) percentile MDA8 showed increasing \( \text{O}_3 \) except for rural sites in summer.
- Increases in 5\(^{th}\) percentile were more frequent during winter than during summer.
- Increasing trends in 5\(^{th}\) percentile were most common at urban sites.

Simon et al., 2015 *Environmental Science & Technology*

• Most sites with statistically significant trends in 50th percentile MDA8 showed *increasing* $O_3$ in winter and *decreasing* $O_3$ in summer

• **Increasing** trends in 50th percentile were most common at urban sites

• **Decreasing** trends in 50th percentile were most common at rural sites

Simon et al., 2015 *Environmental Science & Technology*
Conclusions

• Models predict that when NOx emissions are decreased, the frequency of low and high concentrations will decrease

• Trends in observed hourly ozone across the EU and US over a period of dramatic NOx decreases shows a compression of the ozone distribution, consistent with model predictions

• A compression of the O₃ distribution can lead to some regulatory, health and vegetation metrics increasing and others decreasing
  – High-end O₃ metrics generally decrease
  – Cumulative or mid-range O₃ metrics trend direction depends on starting O₃ concentration, season & degree of urbanization

• Health and regulatory metrics must be chosen carefully
  – Response to emissions scenarios depends on metrics chosen