Ground-level ozone in Phoenix: its sensitivity to emissions through numerical modeling with WRF-Chem

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Motivation and Objectives

Improved understanding of elevated $[O_3]$, its locally produced versus transported portions, and its attribution to various local emission sources.

Develop effective air quality management strategies to achieve ever more stringent US air quality standards.
Achievements

1) We developed an advanced modeling system based on WRF-Chem and applied it at high-resolution to the Phoenix metropolitan area
   a. Novel technique for downscaling of emissions inventory was developed and used.
   b. Comparisons with observations of ozone demonstrate excellent agreement.
2) Land cover and land use experiments: Investigate impacts of urbanization and urban/agricultural irrigation on air quality
   a. Urban land modification results in ground-level ozone increases up to 10 ppb during nighttime.
   b. Urban irrigation increases DMA8 [O₃] within the urban area.
3) Emission scenario experiments: Investigate the relative contributions of different emission sources on Phoenix DMA8 [O₃]
   a. Anthropogenic emissions from southern California affect the DMA8 [O₃] in Phoenix from a few ppb to up to 30 ppb.
   b. Local anthropogenic emissions in Central Arizona dominate Phoenix DMA8 [O₃].
   c. Biogenic emissions play a key role, despite the arid climate.
STATE OF THE SCIENCE: OUR RECENT PUBLICATIONS IN TOP JOURNALS


‘Regional-scale transport of air pollutants: Impacts of southern California emissions on Phoenix ground-level ozone concentrations’, Atmospheric Chemistry and Physics, 2015, accepted for publication.

We developed an advanced modeling system based on WRF-Chem and applied it at high-resolution to the Phoenix metropolitan area. WRF-Chem is the Weather Research and Forecasting (WRF) model coupled with Chemistry. The model simulates the emission, transport, mixing, and chemical transformation of trace gases and aerosols simultaneously with the meteorology. The model is used for investigation of regional-scale air quality, field program analysis, and cloud-scale interactions between clouds and chemistry.
EPA: Ozone Non-Attainment Counties

Figure from EPA web, updated on February 1, 2013
How is ozone transported to inland CA and Central AZ?

Ozone difference integrated fluxes \( \int \overline{H} (O_3^{(ctrl)} - O_3^{(noCA)}) V dz \)

Daytime mean wind vectors at 30m-agl

Pass Chanel Effect and Mountain Chimney Effect (Li et al., 2015)
Validation and Verification: O₃, CO, and NOx at sites

New emission interpolation method (MCI) improved O₃, CO and NOx at observation sites, comparing with default method.
Ozone in the troposphere

1) Presents as the 3rd most important greenhouse gas (IPCC AR4)

2) Acts as a strong oxidant in atmosphere

3) Adversely affects human health (Anderson, 2009; Smith et al., 2009)

4) Reduces crop yields (Avnery et al., 2011; Chameides et al., 1999)

5) Damages natural ecosystems (Ashmore, 2005; Mauzeral and Wang, 2001)

6) Affects hydrological cycle (Su et al. 2011, Lombardoozzi et al., 2015)
Ozone attainment status in greater Phoenix

As of January 30, 2015, Phoenix-Mesa is classified as a marginal non-attainment area based on the 2008 EPA Federal standard (i.e., daily maximum 8-hr average (DMA8) ozone concentrations \([\text{O}_3\text{]}\), <75 ppb) (http://www.epa.gov/airquality/greenbook/hnc.html)

Changes of a few ppb may change the attainment status

The Federal standard is proposed to change to 65-70 ppb (EPA 2014) sometime this year
Ozone observation sites
14 MCAQ sites + others
Mean 8-hr maximum ozone concentration for May - August at eastern sites

**ID2005: Pinnacle peak**
- Trend (ppb yr\(^{-1}\)) = -0.01, -0.44
- Corr. Coeff. = -0.02, -0.80

**ID9704: FOUNTAIN Hills**
- Trend (ppb yr\(^{-1}\)) = -0.50
- Corr. Coeff. = -0.89

**ID1010: Falcon Field**
- Trend (ppb yr\(^{-1}\)) = -0.54
- Corr. Coeff. = -0.92

**ID9508: HUMBOLDT Mountain**
- Trend (ppb yr\(^{-1}\)) = -0.61
- Corr. Coeff. = -0.79

R > 0.482 for 15 years R > 0.349 for 30 years (p < 0.05)
Mean 8-hr maximum ozone concentration for May – August at central sites

- **ID0019: W. PHX**
  - Trend (ppb yr\(^{-1}\)) = 0.09, -0.22, -0.15
  - Corr. Coeff. = 0.26, -0.54, -0.18

- **ID1004: N. PHX**
  - Trend (ppb yr\(^{-1}\)) = 0.25, -0.32, 0.26
  - Corr. Coeff. = 0.57, -0.78, 0.31

- **ID2001: Glendale**
  - Trend (ppb yr\(^{-1}\)) = 0.10, -0.33, 0.09
  - Corr. Coeff. = 0.66, -0.79, 0.22

- **ID3003: S. PHX**
  - Trend (ppb yr\(^{-1}\)) = 0.30, -0.03, 0.84
  - Corr. Coeff. = 0.80, -0.10, 0.88

Note: not all sites begin with the same year

R > 0.482 for 15 years R > 0.349 for 30 years (p < 0.05)
Ozone Case Studies and What-If Mitigation Scenarios

1) Nested simulation: The inner-most domain has a resolution of 1-km.

2) Emissions inventory: Downscaling to 1-km resolution from EPA-2005 4-km emission inventory (NEI05) using shape preserving interpolation.

3) Validation and verification: Assess WRF-Chem performance during elevated ozone events.

4) Sensitivity studies: Investigate impacts of urban land cover, ozone regional transport, and urban/agricultural irrigation on air-quality.
Anthropogenic emissions preparation

4-km resolution National Emissions Inventories (2005) data (NEI05)

(NOx)

4-km resolution National Emissions Inventories (2005) data (NEI05)

(NOx)

Downscaled to 1-km resolution

Default

New method (Li et al. 2014)

NOx emissions at 12Z (moles per hour)
Sensitivity Studies: impact of urban/agricultural irrigation on DMA8 [O₃]

- Lowers PBL height -> constrains vertical diffusion
- Decreases Temp. -> weakens photochemical reactions
- Increases water vapor -> increases HO and HO₂ in atmosphere

Treat urban greenness cover as mixed forest and grassland

Irrigation starts: when the root zone’s relative available soil-water (SW) content is less than the maximum allowable water depletion (SWₘ), where SWₘ depends on the crop (vegetation) type (Hanson et al., 2004)

Irrigation stops: when root-zone soil moisture reaches its capacity

July 18, 2005

Urban irrigation increases DMA8 [O₃] in urban area
Sensitivity Studies: Contributions of emission sources to DMA8 [O₃] in Phoenix

Emission scenarios

CTRL: run WRF/Chem as usual

noCA: same as CTRL but zero out anthropogenic emissions in S. CA

noAZ: same as CTRL but zero out anthropogenic emissions in AZ

BEO: same as CTRL but zero out all anthropogenic emissions (Biogenic Emissions Only)
Emissions from S. CA contributed up to 30 ppb, depending on time and location. Local emissions dominate DMA8 [O$_3$] (70%), but biogenic emissions alone contribute 40%.
Conclusions

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