Improving ozone modeling in the Southeast US: how it affects background ozone estimates

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Models tend to overestimate surface ozone in the Southeast US in summer.

HTAP model intercomparison:

SE USA 30-36N 90-80W 0-0.8km

24-h ozone

Mean Bias = 7.2 ppb
r = 0.61

# sites = 6

We need to understand this bias and the implications for ozone background estimates

Fiore et al. [2009]
SEAC$^4$RS campaign out of Houston (Aug-Sep 2013): NASA DC-8 aircraft with full chemical payload

Ozone below 1.5 km

NO$_x$ below 1.5 km
Near-real-time GEOS-Chem simulation during SEAC⁴RS

GEOS-Chem with 0.25°x0.3125° resolution over North America
nested in global simulation with 2°x2.5° resolution
NASA GEOS-FP assimilated meteorological data
Anthropogenic US emissions from EPA NEI 2011

O₃ (ppb) in surface air - circles are aircraft data below 1 km

Karen Yu, Patrick Kim, Jenny Fisher, Katie Travis, Lei Zhu (Harvard)
Correcting model mixing depths

Model comparison to aircraft lidar observations (R. Ferrare, LaRC)

Summertime drying out in GEOS-FP causes excessive mixed layer depths

Zhu et al., submitted
Finding: NEI NO\textsubscript{x} emissions are 2x too high

Aug-Sep 2013 surface NO\textsubscript{x} emissions in Southeast US
NEI13 + soils + open fires [Gg]

Reduce mobile+industry emissions by 60%

Observations by
G. Huey, J. Dibb, T. Ryerson

SEAC\textsuperscript{4}RS median vertical profiles

Nitrate wet deposition flux (obs in circles)

-7% US bias (+80% with NEI)
Comparison to OMI NO$_2$ tropospheric columns

OMI NO$_2$ (BEHR)

OMI NO$_2$ (NASA)

GEOS-Chem with reduced NO$_x$ emissions

-18% vs. BEHR

-11% vs. NASA

Low bias in GEOS-Chem is due to lightning, not surface emissions

Travis et al., submitted
Lightning makes major contribution to OMI NO$_2$ tropospheric column in summer

Mean SEAC$^4$RS NO$_2$ profile over Southeast

GEOS-Chem low bias in upper troposphere driven by NO/NO$_2$ chemistry

Travis et al., submitted
Boundary layer NO$_x$, ozone, ozone production efficiency are well simulated after NO$_x$ emissions are decreased

Concentrations below 1.5 km

Ozone vs. NO$_x$ oxidation products

Observed slope = 18.6
Model slope = 16.7

Mean model bias for ozone is +2 ppb; before decreasing NO$_x$ emissions it was +16 ppb

*Travis et al., submitted*
Ozonesonde data in Southeast US are also well simulated.
But model is still too high by 9 ppb for surface ozone: cause is excessive boundary layer mixing

Mean MDA8 ozone (ppb)
Jun-Aug 2013

PDF of MDA8 ozone
Jun-Aug 2013

• Midday ozonesondes show 7 ppb decrease from 1.5 km to 0.2 km, not GEOS-Chem
• Excessive boundary layer mixing in GEOS-Chem caused by excessive dryness

SEACIONS ozonesondes
11am-2pm below 1.5 km

Travis et al., submitted
Ozone background over Gulf of Mexico is well simulated

Excessive ozone over the Gulf is not the problem

SEAC$^4$RS Median Vertical Profiles: Gulf of Mexico

Altitude, km

O$_3$, ppbv

NO$_X$, ppbv

Travis et al., submitted
N. American background ozone: comparison to SEAC$^4$RS

Background simulation shuts off all anthropogenic emissions in N America

Observed
GEOS-Chem (standard)
GEOS-Chem (background)

Anthropogenic emissions increase NO$_x$ only by factor 2, enough for 20 ppb increase in ozone

Travis et al., in prep.
Tropospheric ozone evaluation of current GEOS-Chem version

OMI satellite data validated with ozonesondes, reprocessed with uniform prior

OMI 700-400 hPa
– 3.6 ppb bias

GEOS-Chem
with OMI averaging kernels

difference

Hu et al., in prep.
N. American ozone background estimated with GEOS-Chem

Simulation shutting off all anthropogenic N American emissions

Mean MDA8 ozone background for summer (JJA)

Current model

Zhang et al. [2011]

- Northward shift in western US maximum (updated lightning)
- Ring of elevated values along Gulf Coast is gone
- Otherwise not much difference – despite lots of change in model
- Need to worry about soil moisture!

Travis et al., in prep.
Why is PBL mxing excessive in GEOS-Chem?

Normalized ozone profiles at Huntsville, AL in August 2013

Model underestimates cloudiness, probably due to soil drying out over summer

*Katie Travis, in prep.*
Model of SEAC$^4$RS period shows little sensitivity to grid resolution: implies that 2°x2.5° is acceptable for calculations of background ozone

Yu et al. [2016]