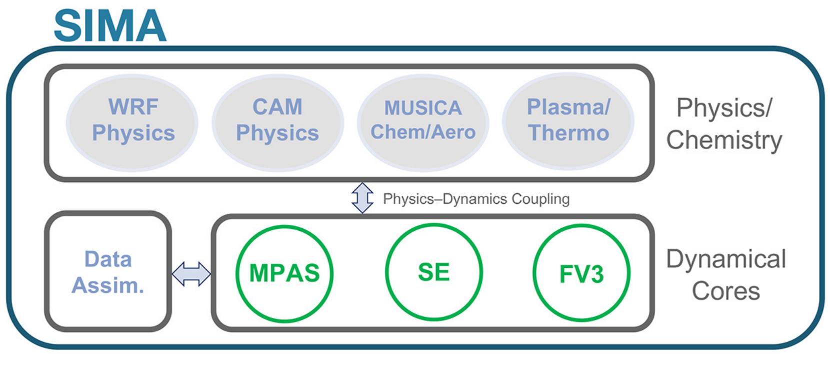
Recent advancement of EPA's global air quality modeling system: MPAS-CMAQ

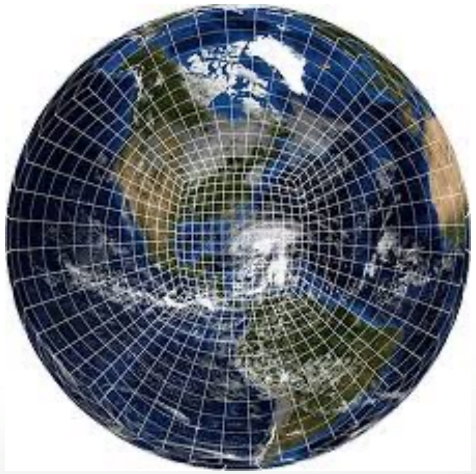
Jeff Willison, Jonathan E. Pleim, David Wong, Robert C. Gilliam, O. Russell Bullock Jr., Jerold A. Herwehe, Christian Hogrefe, George Pouliot, Golam Sarwar and Rohit Mathur

Atmospheric & Environmental Systems Modeling Division
Office of Research and Development, USEPA

MPAS-CMAQ Motivation

- Why couple the Model for Prediction Across Scales (MPAS) with Community Multiscale Air Quality (CMAQ) model when other options are available?
  - CMAQ can be used for regulatory purposes
  - MPAS is desirable for its global domain and boundary-free refinement. Natural extension of WRF-CMAQ.
  - Possible future integration of CMAQ with CESM components via SIMA





MPAS-CMAQ Design

- MPASv7.1 is coupled with the EPA's Community Multiscale Air Quality model (v5.3.3+)
- CMAQ is called as a module in MPAS with 2-way data transfer through a coupler analogous to the coupler for WRF-CMAQ
- Advection of chemical species in MPAS is identical to advection of meteorological scalars.

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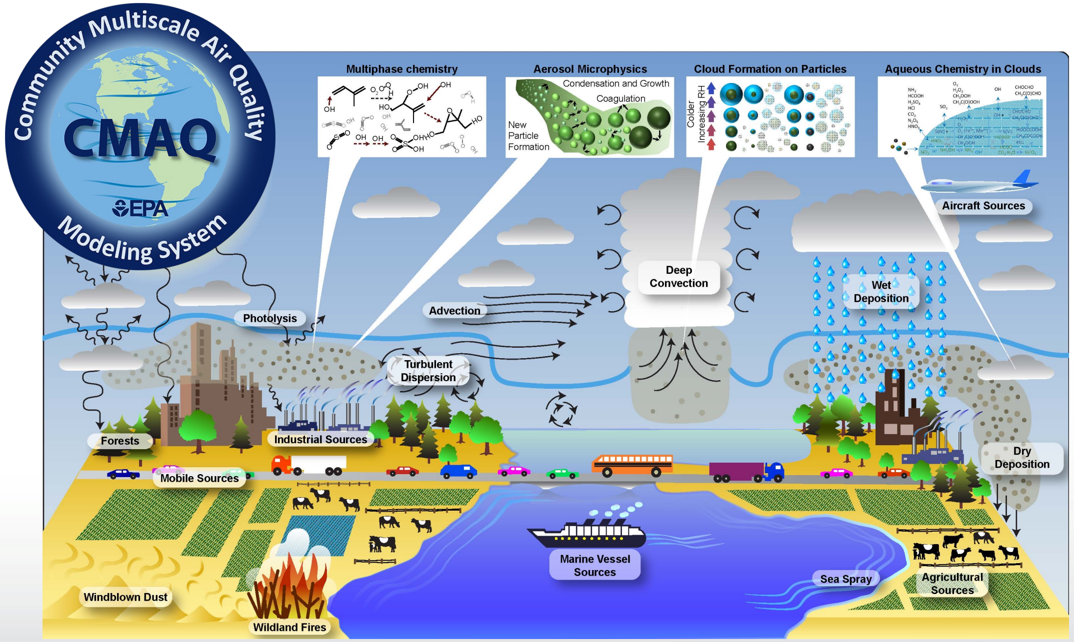
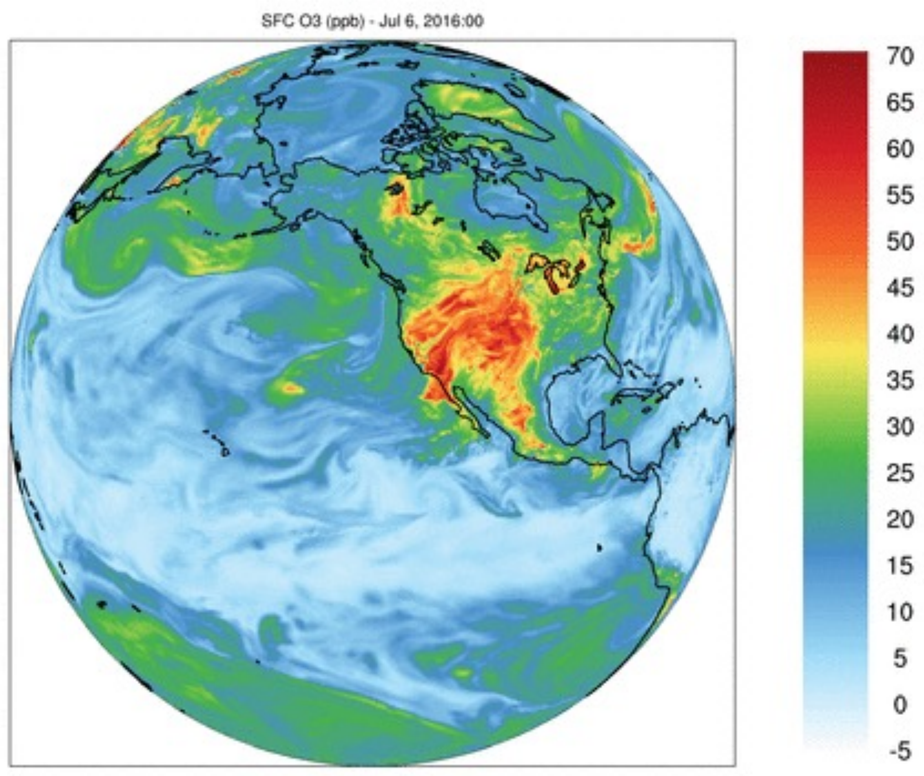


MPAS-CMAQ Updates

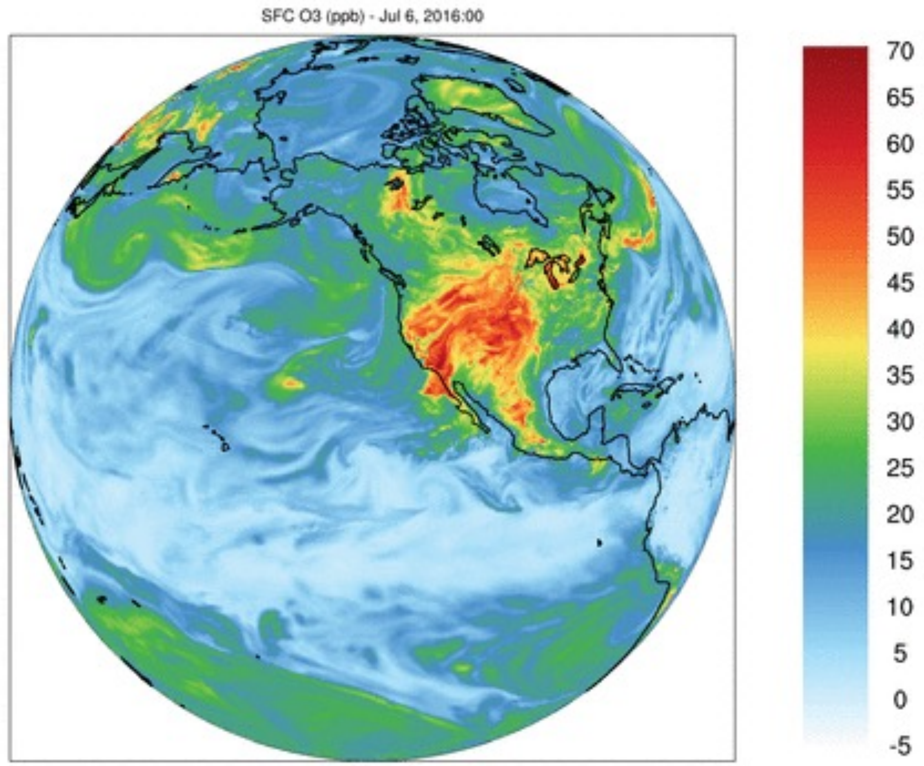
- Added US EPA physics routines to MPAS
  - ACM2 Boundary layer model
  - Pleim-Xiu Land Surface Model (PX LSM)
  - Updated Kain-Fritsch convective cloud scheme
    - including radiation feedback and dynamic lifetime
  - All modified EPA physics is consistent between WRFv4.3 and MPAS7.1
- Data Assimilation
  - Implemented analysis FDDA as in WRF (Bullock et al. 2018)
  - Implemented indirect soil moisture data assimilation in PX LSM
- Meteorological Evaluation
  - Gilliam et al. (2021) showed that the EPA configuration of MPAS performs comparably well with the EPA configuration of WRF for air quality applications.



July 2016 surface ozone (ppb)

MPAS-CMAQ Testing

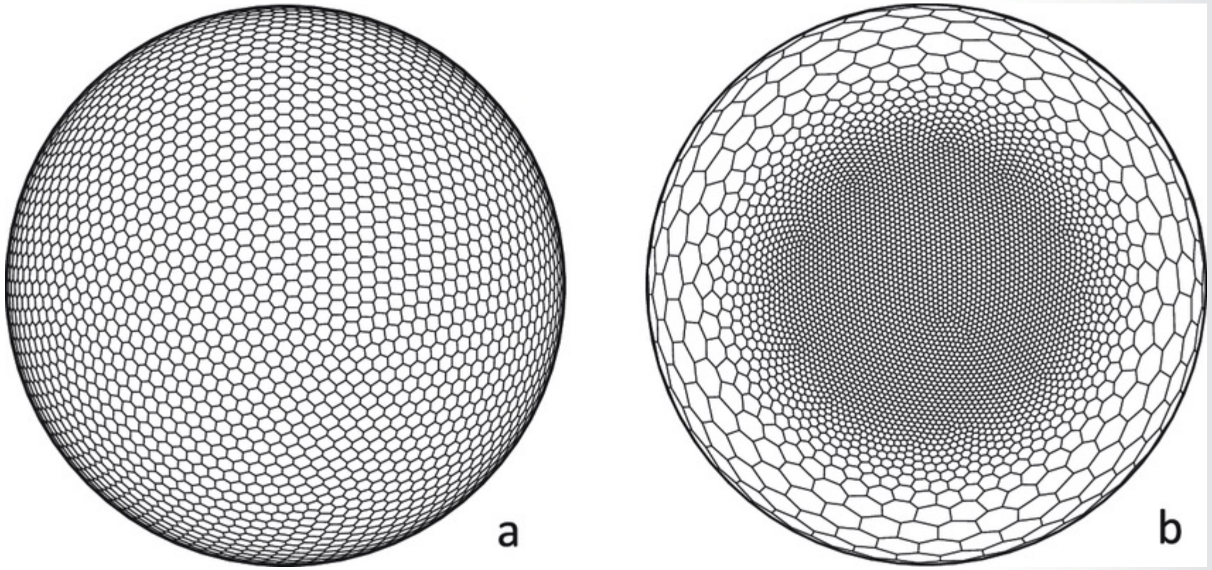
- Experimental Configuration
  - Initialize with CAMSRA ozone and maritime profile for other chemical species
  - EPA-added physics and grid nudging toward FNL winds, temperature, and moisture
  - Stratospheric O_3 continuously assimilated from 6-hourly CAMS reanalysis (Inness et al. 2019)
- Emissions
  - US anthropogenic emissions from beta 2016 USEPA National Emission Inventory (NEI)
  - Global anthropogenic emissions from the HTAP_v2.2 inventory with 2015 China emissions provided by Tsinghua University
  - Biogenic emissions from inline MEGANv3.2



July 2016 surface ozone (ppb)

MPAS-CMAQ Testing

- Results presented today:
  - 2014-2016 on uniform 120 km mesh
  - July 2016 on uniform 12 and 60-12 mesh
  - All refinements centered on CONUS



DOI:10.1175/JCLI-D-12-00154.1

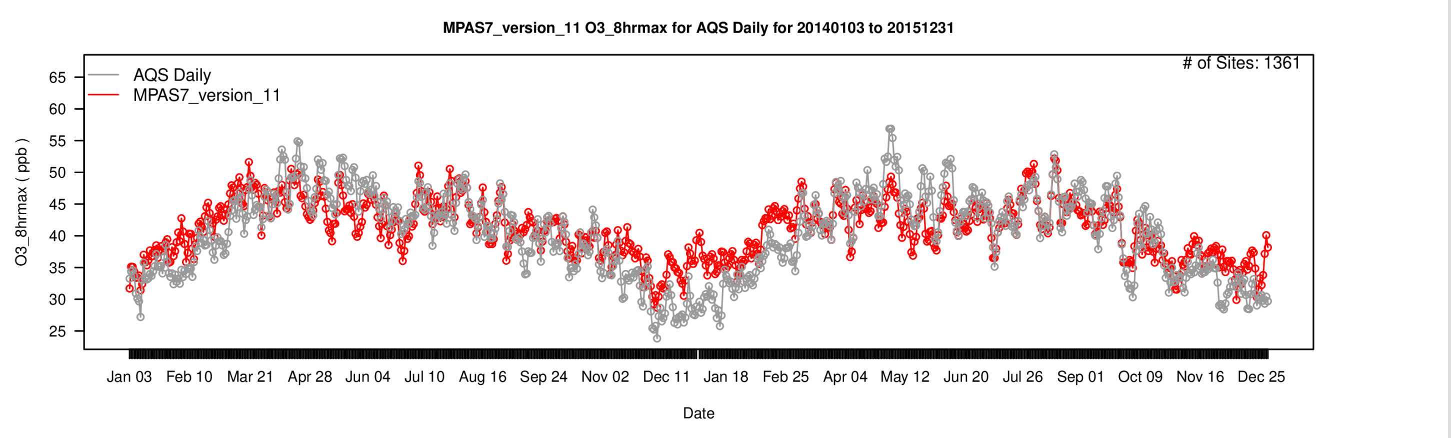
Results: Ozone on 120 km mesh

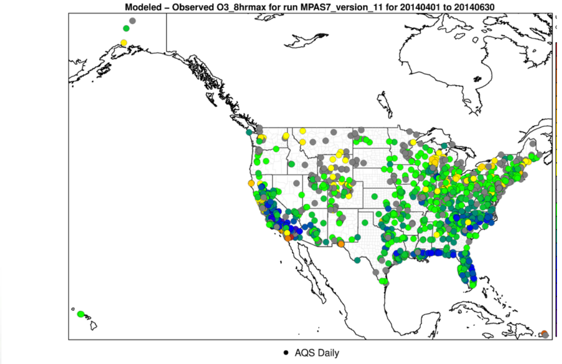
- Comparison with AQS sites indicates a seasonally-varying bias for surface 8-hr max ozone concentration over the United States

- Biased low throughout CONUS in spring

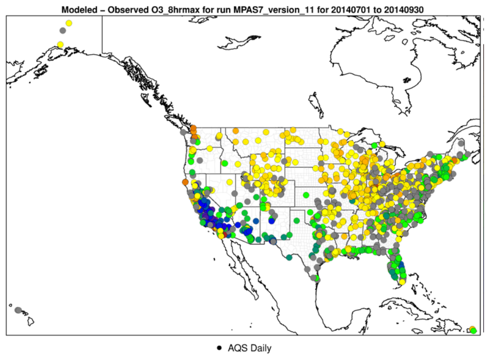
- Generally biased low along west coast and high in the continental interior during summer

- Biased low along west coast and high in eastern US through fall and winter.

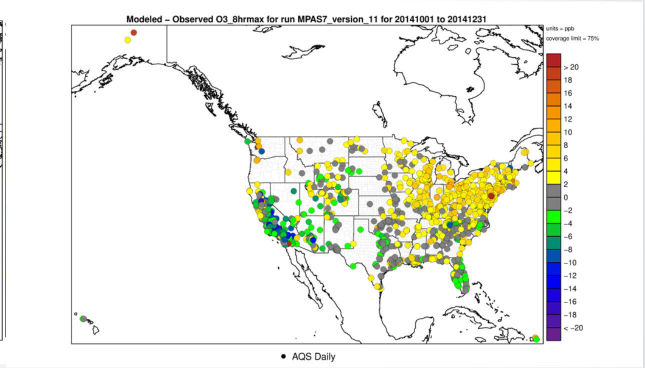




AMJ



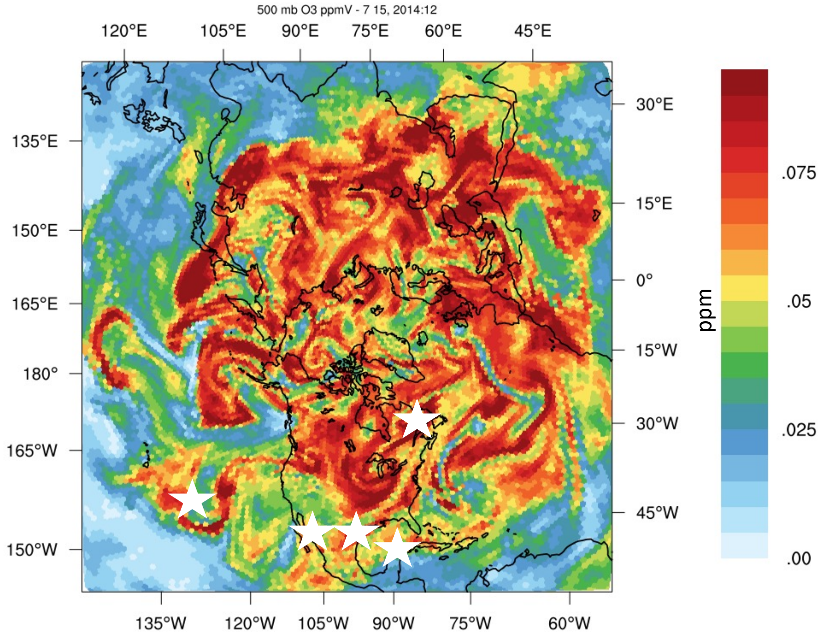
JAS



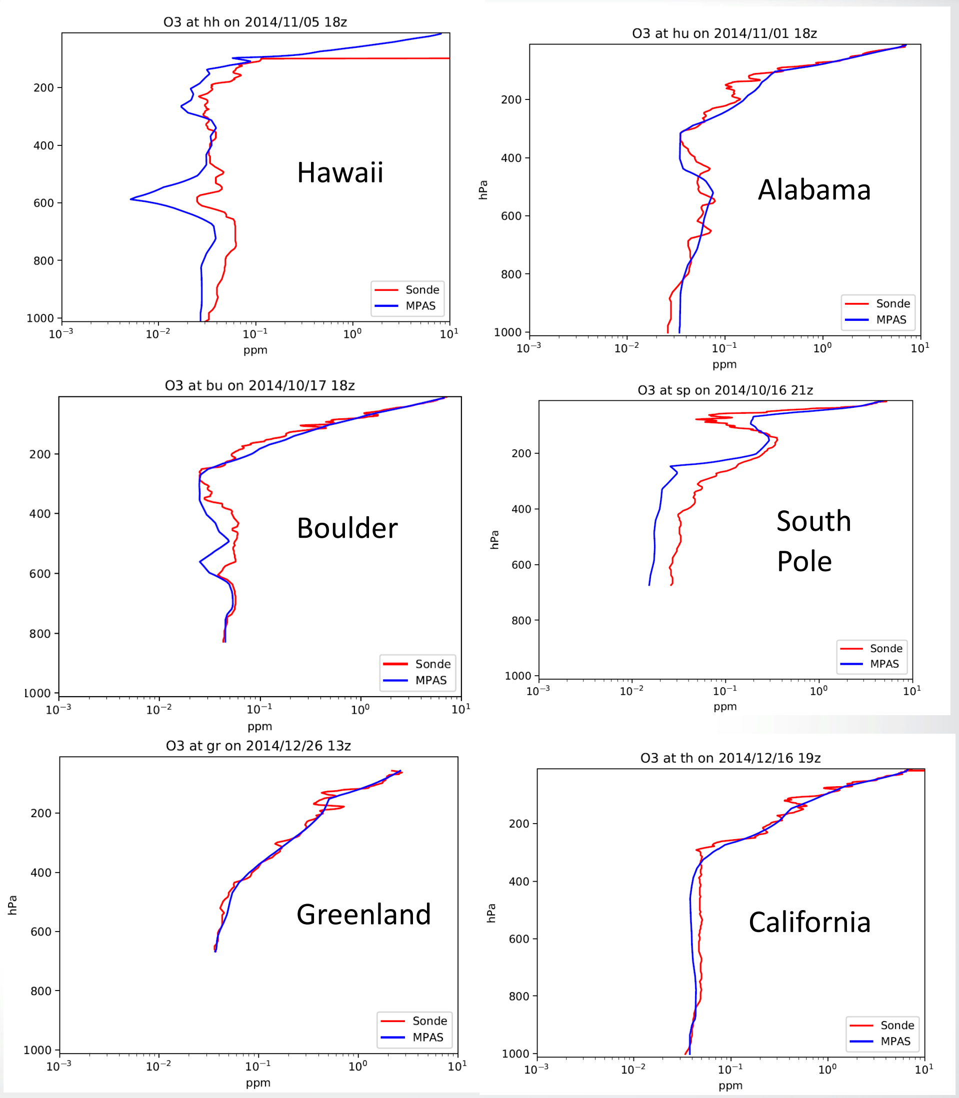
OND

Results: Ozone

- Comparing with ozonesondes shows model underprediction of ozone in mid-troposphere, especially in remote maritime environments.

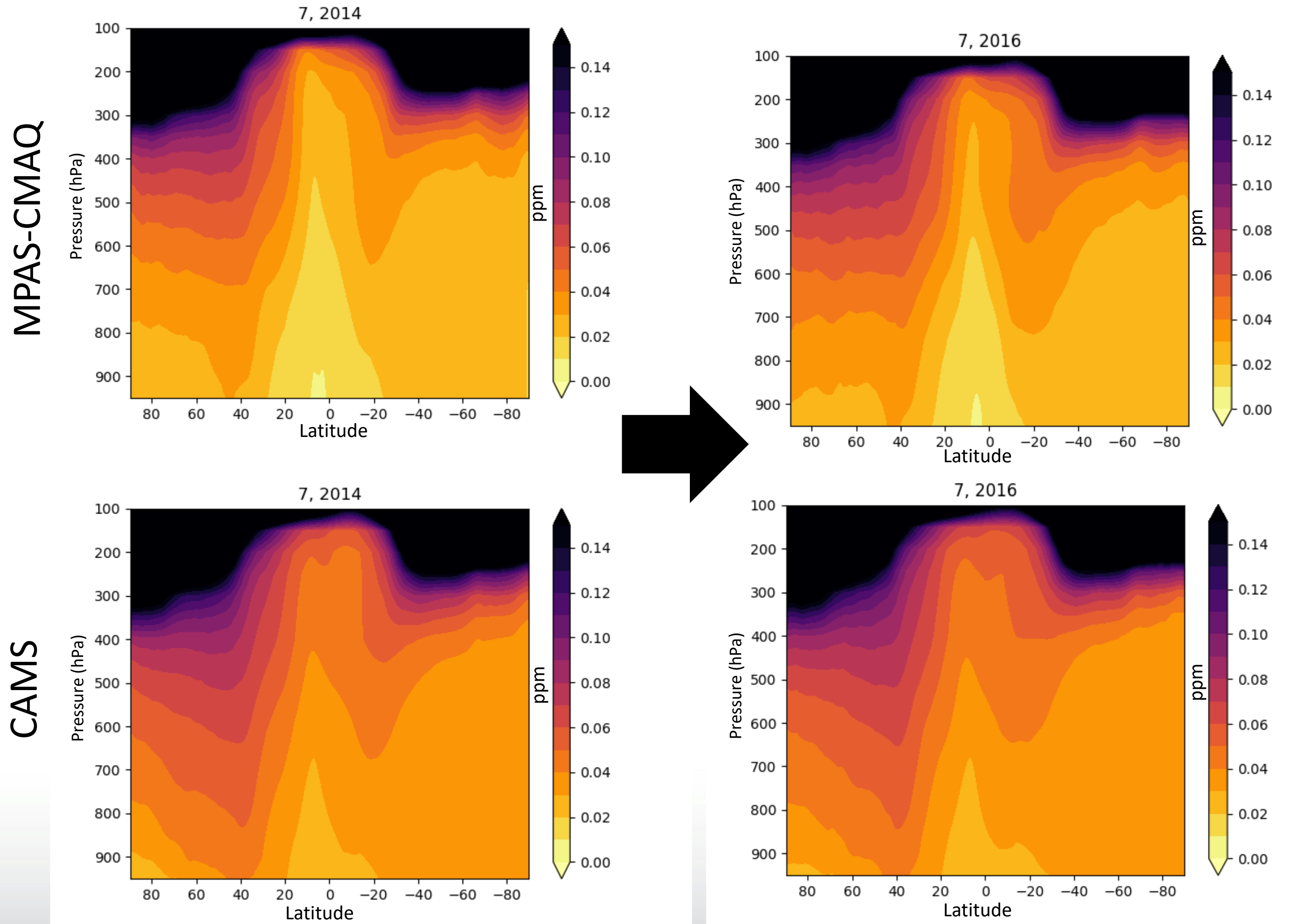


500 hPa ozone snapshot from MPAS-CMAQ



Ozone – comparison with other models

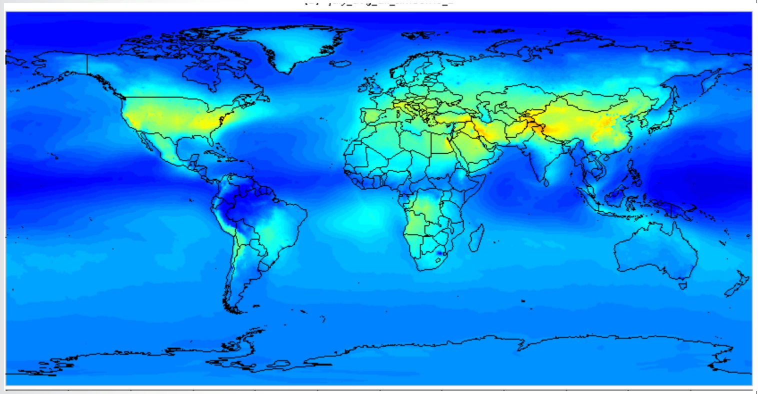
- Zonally-averaged tropospheric ozone is low relative to CAMS global reanalysis.
- Minimal change with additional years of spin up.
- Possible culprits: lightning NOx distribution, aerosol nitrate photolysis, stratospheric exchange, upper-troposphere humidity bias, vertical resolution.



Ozone – big picture

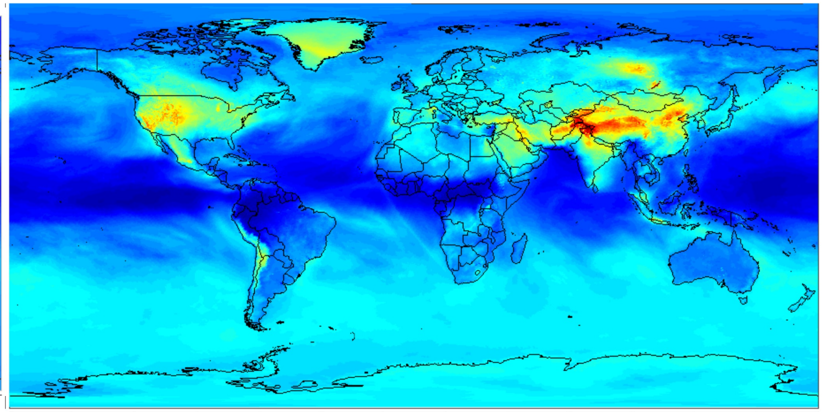
- Average July surface ozone concentration
- MPAS-CMAQ configuration on 120 km mesh is within range of other leading models

GEOS-CF (2018-2022)

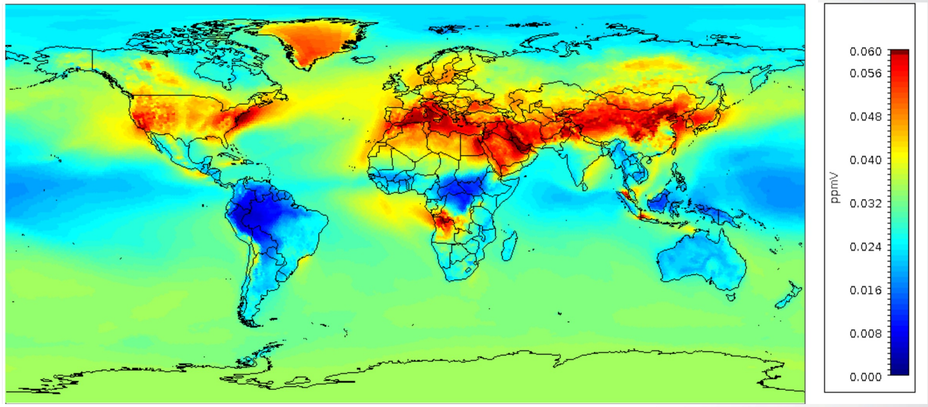


"While GEOS-CF generally captures the observed vertical structure of O3, the model tends to underestimate free tropospheric O3 (approx. 800–300 hPa) over the NH midlatitudes."[1]

MPAS-CMAQ (2014-2015)



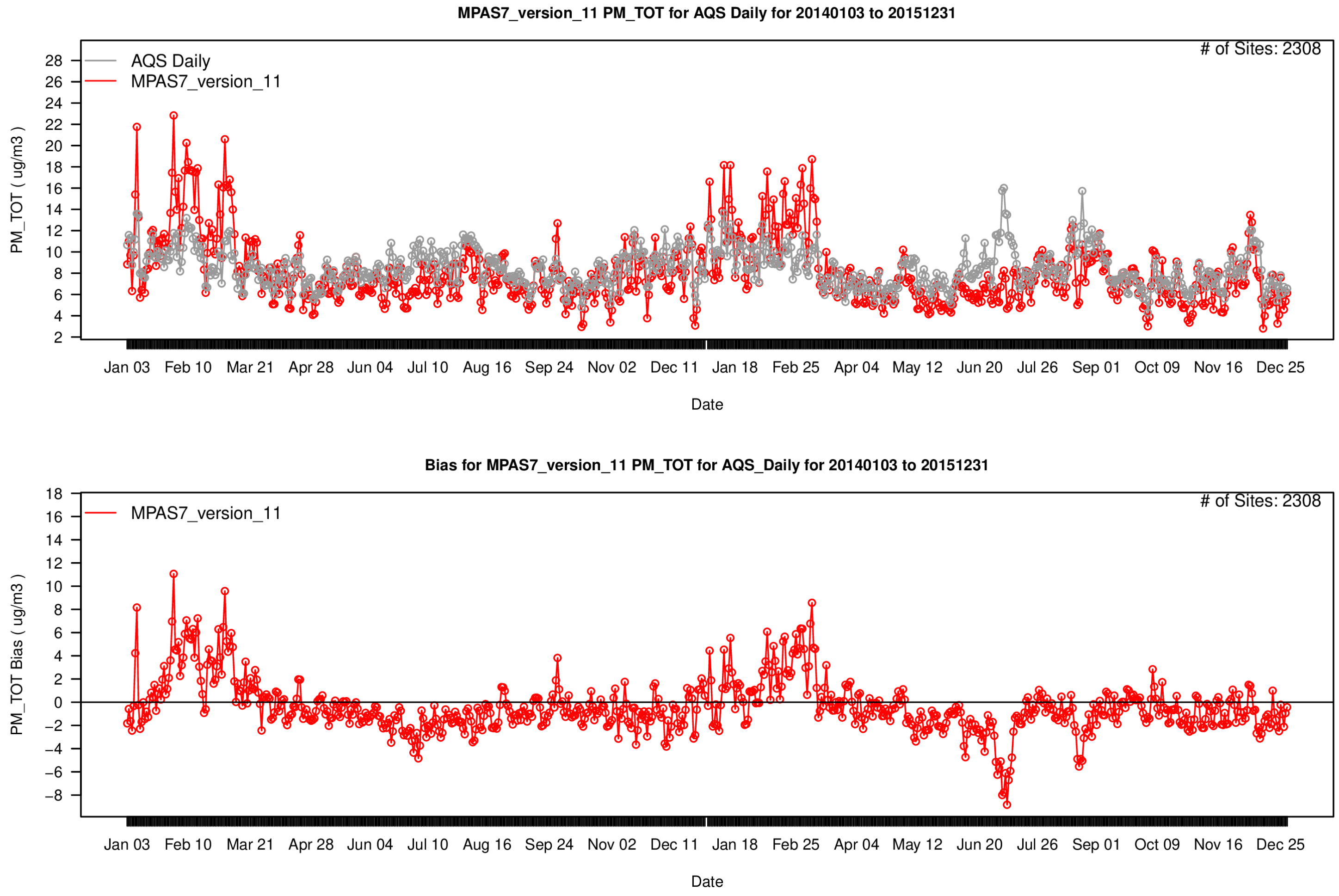
CAMS global reanalysis (2014-2016)



[1](Keller et al. 2021)

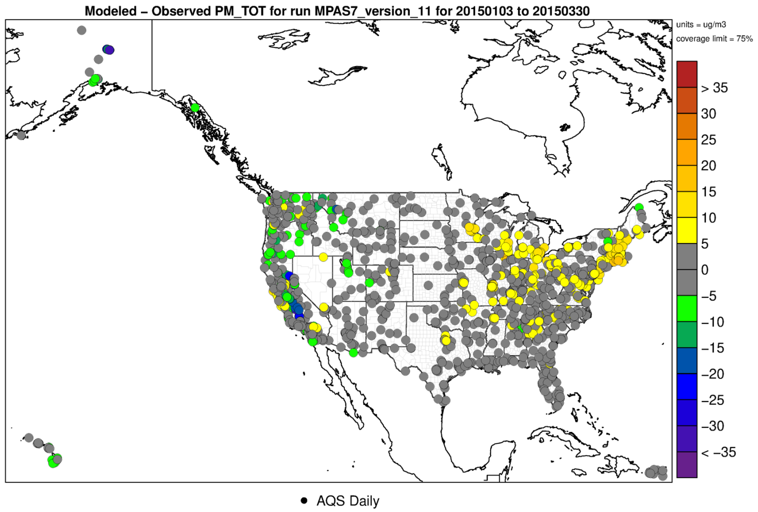
Results: $PM_{2.5}$

- Bias for 120 km mesh over two years (2014-2015)
- Overestimates mass in winter, underestimates mass in summer.

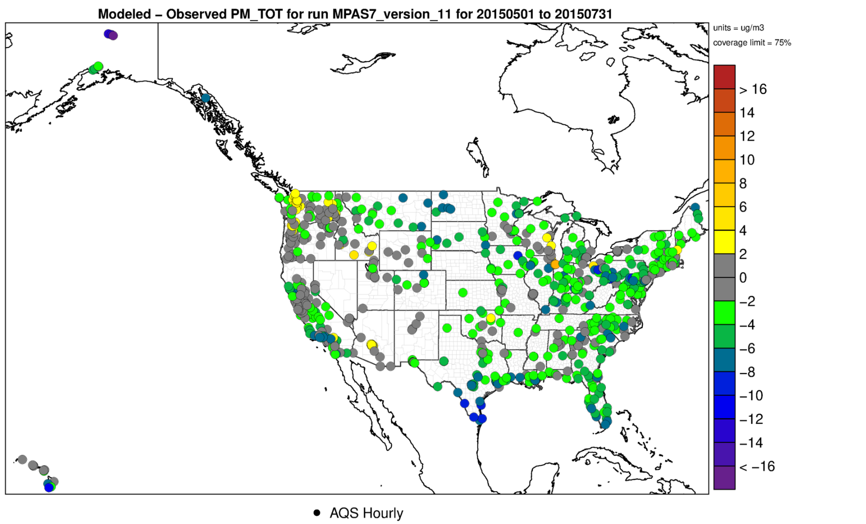


Results: $PM_{2.5}$

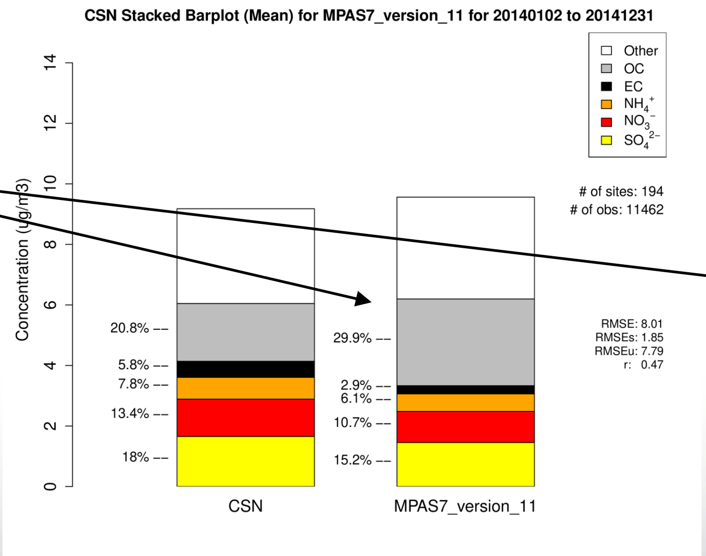
- Overestimates in winter are concentrated in the eastern US.
- Underestimates in summer are uniformly distributed.
- Annual analysis shows excessive organic carbon contribution to total $PM_{2.5}$ compared to CSN and IMPROVE surface observations.

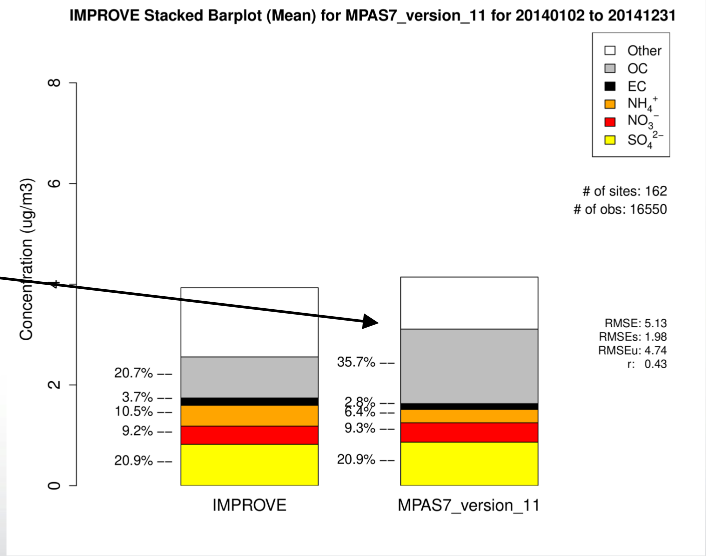


JFM bias



MJJ bias

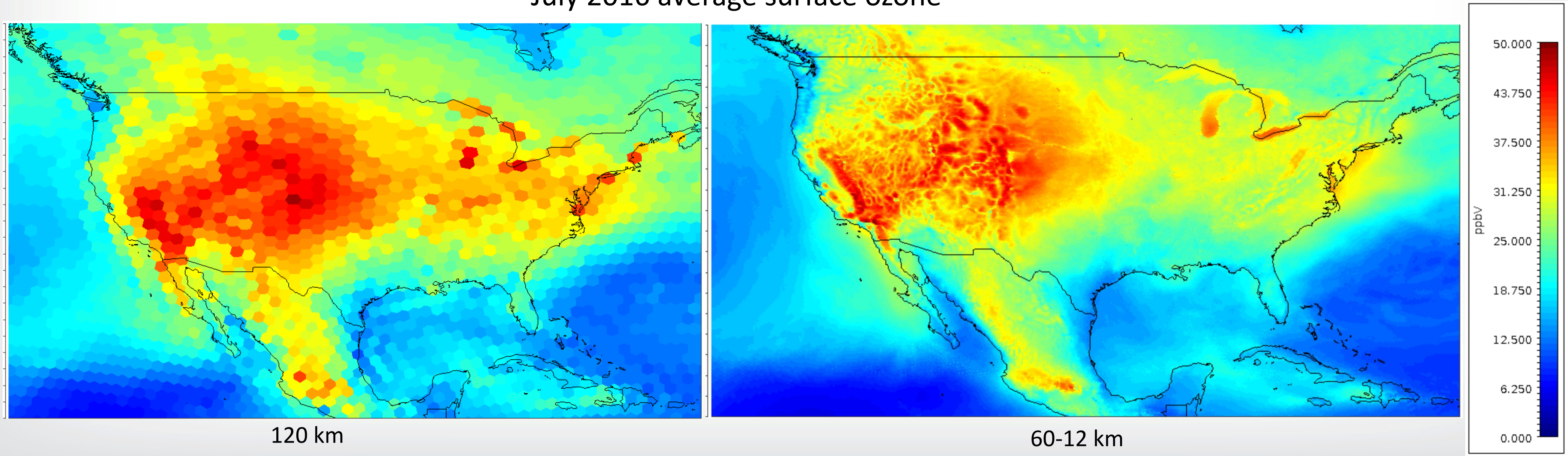




Toward higher resolution - Ozone

- July 2016 simulation with 60-12 km mesh
  - Initialized on 6/22 from a 120 km simulation that was run for 2.5 years
- Higher resolution results in reduced surface ozone

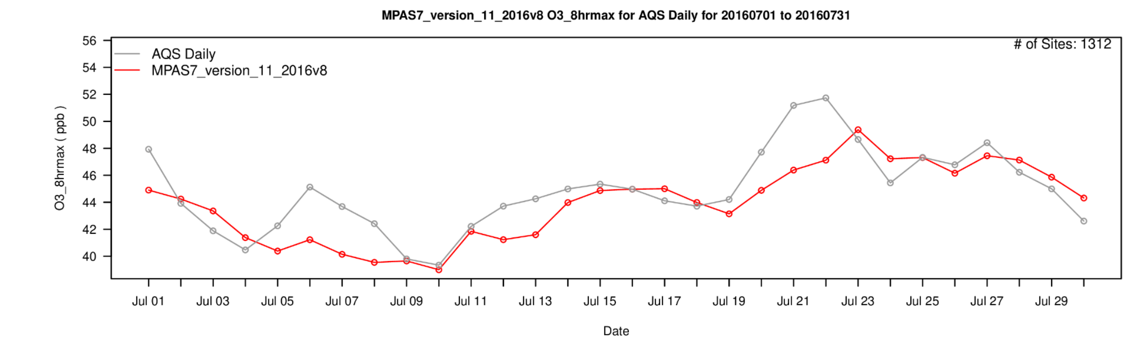
July 2016 average surface ozone



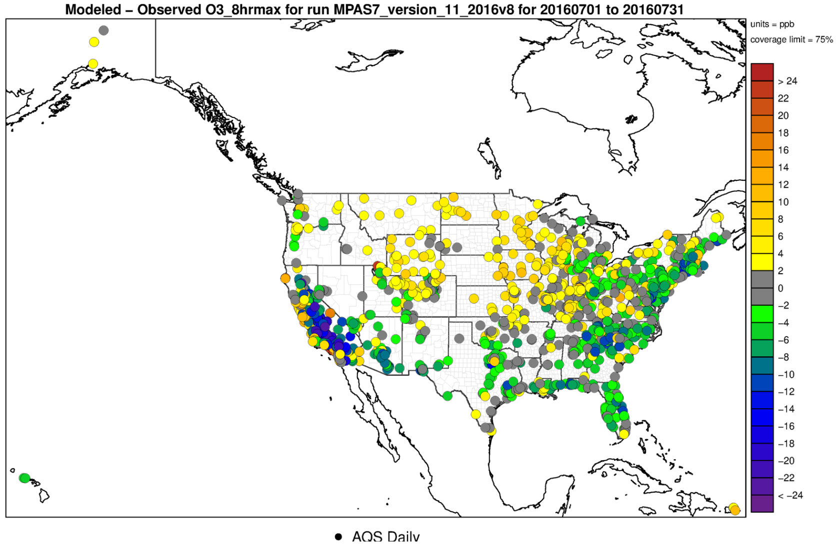
Toward higher resolution - Ozone

- Reduction of surface ozone at higher resolution is consistent across CONUS.

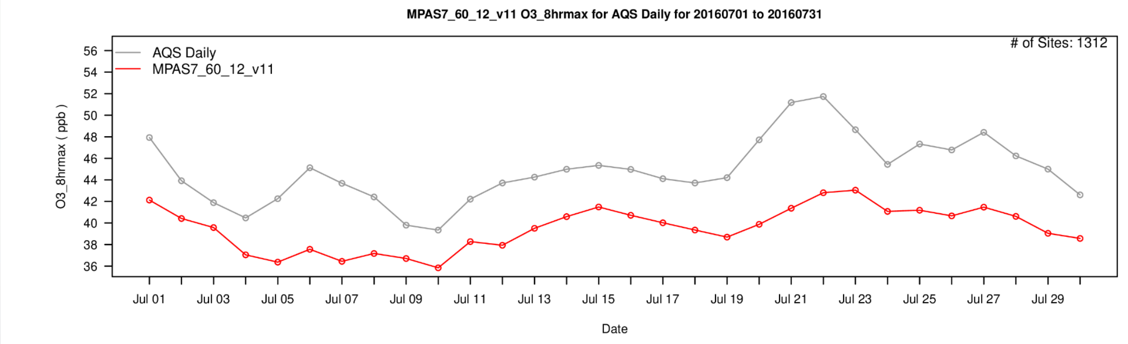
120 km



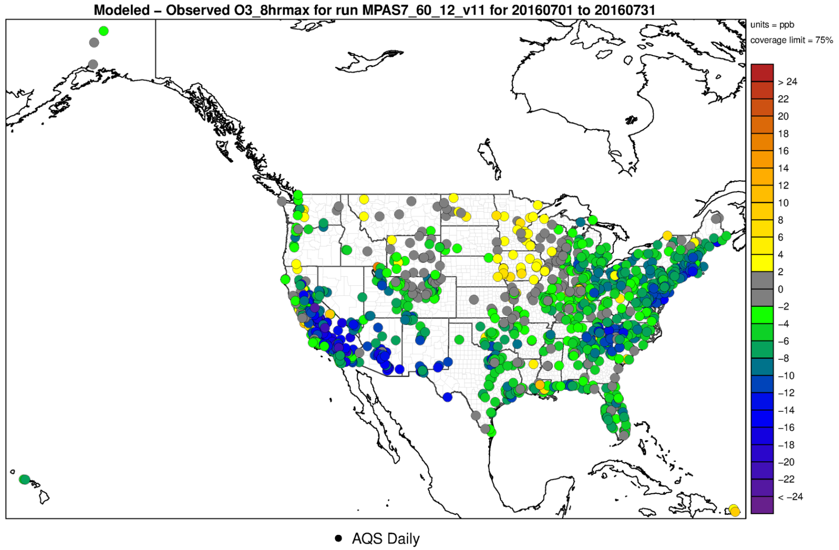
120 km



60-12 km

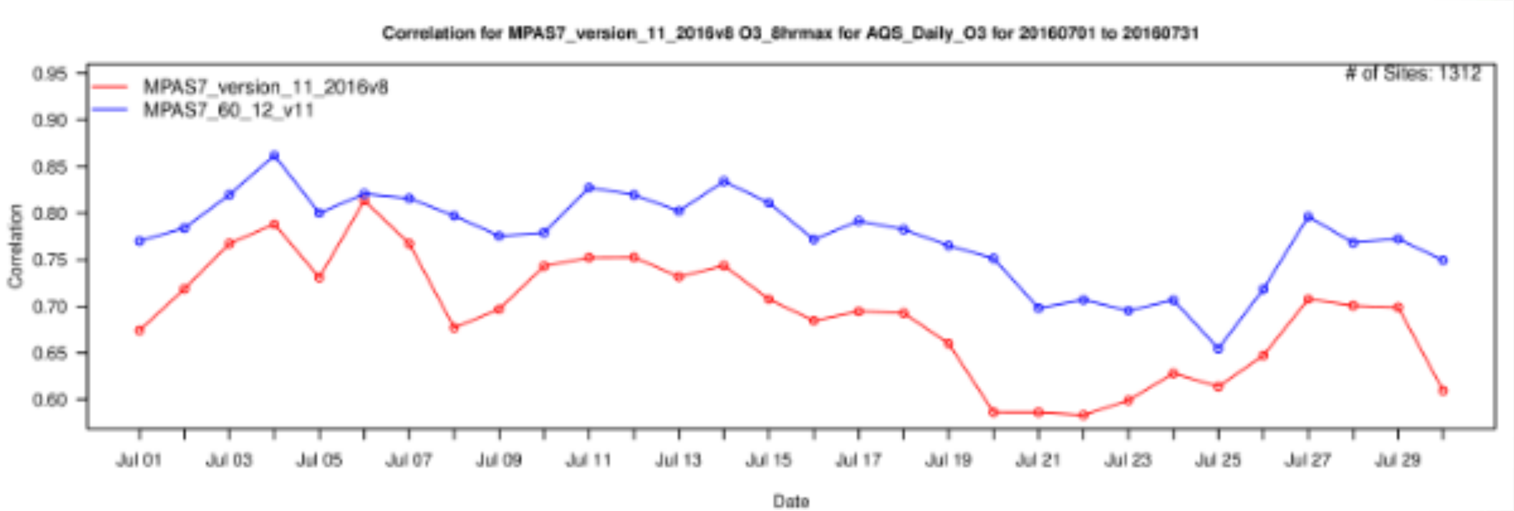


60-12 km



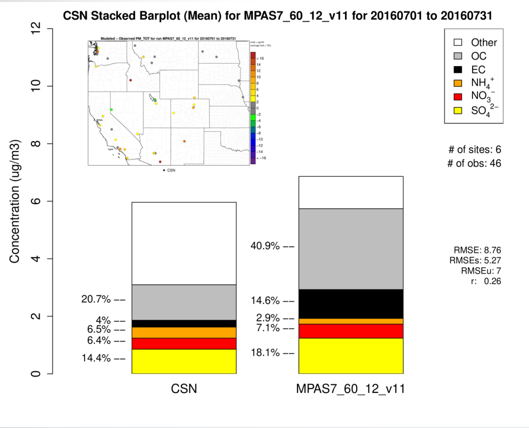
Toward higher resolution - Ozone

- Improved correlation at higher resolution

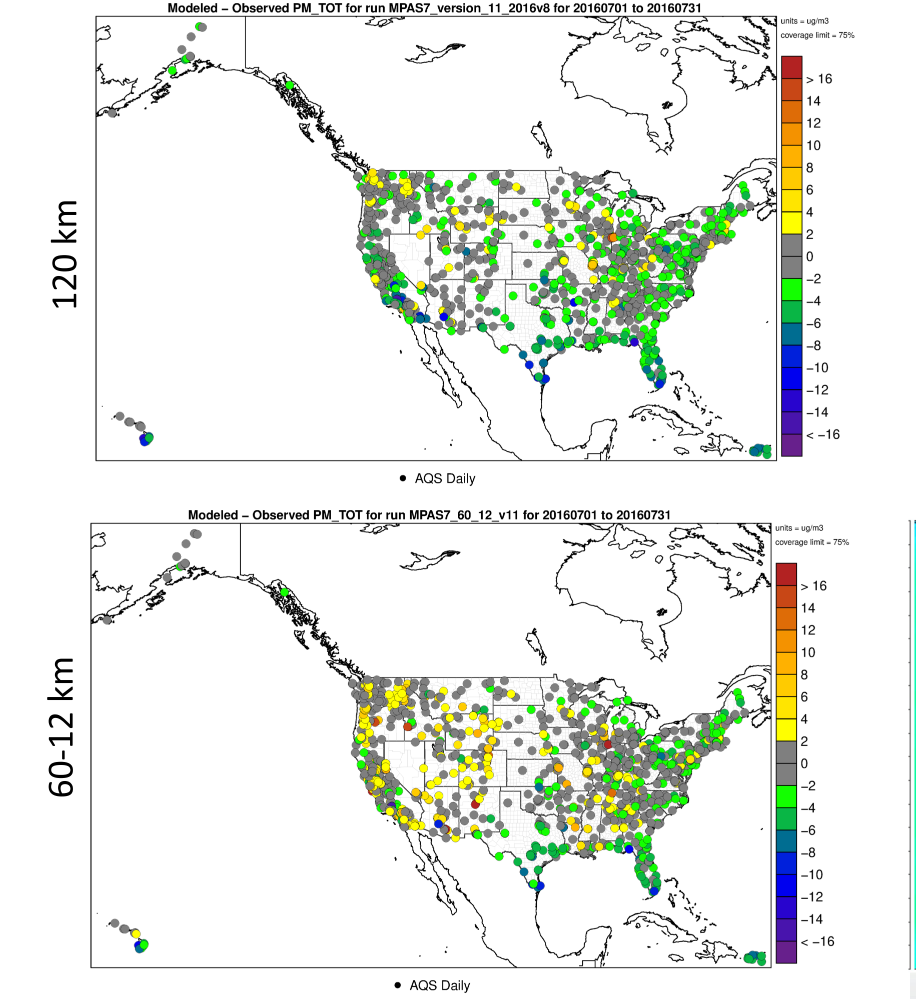


Toward higher resolution - PM

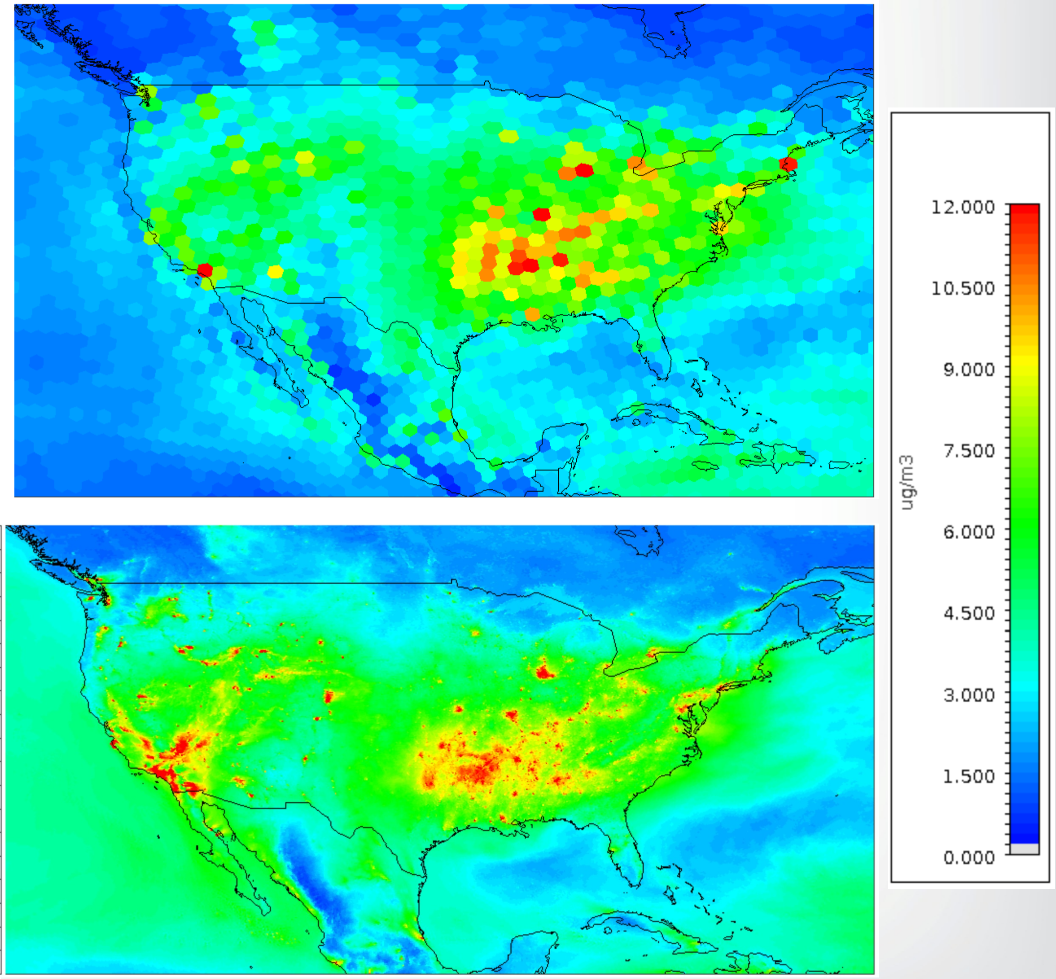
- Increased PM concentrations at higher resolution.
- Positive bias in western US.
- Too much OC and EC



July $PM_{2.5}$ bias

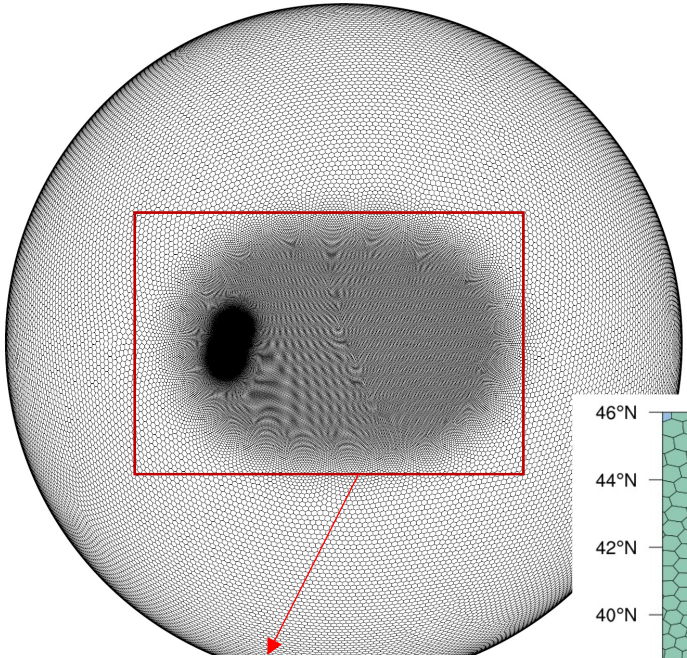


July average ATOTIJ

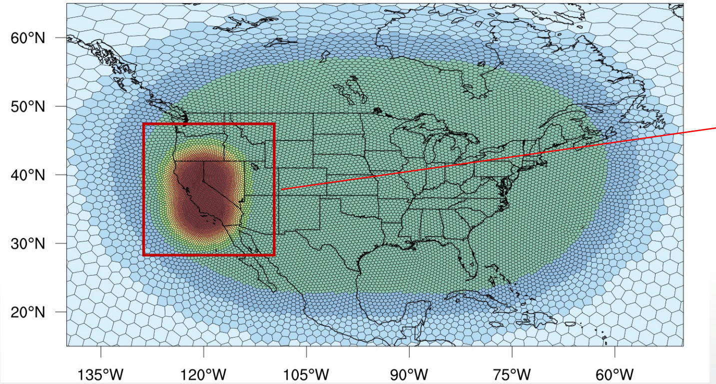


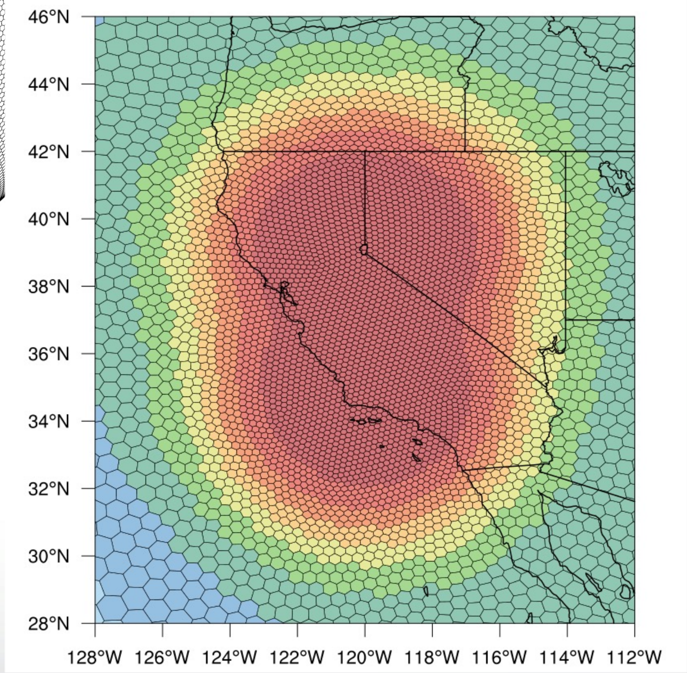
Future Developments

- Mesh generation
  - Multi-stage refinements
  - Regional drop in meshes
  - Multiple refinement zones

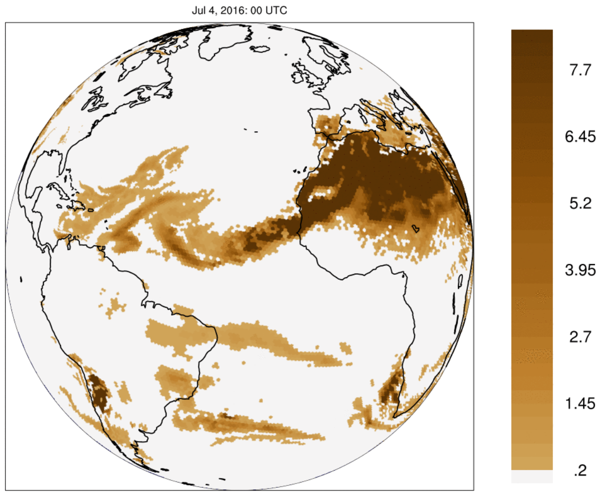


240→48→16 km

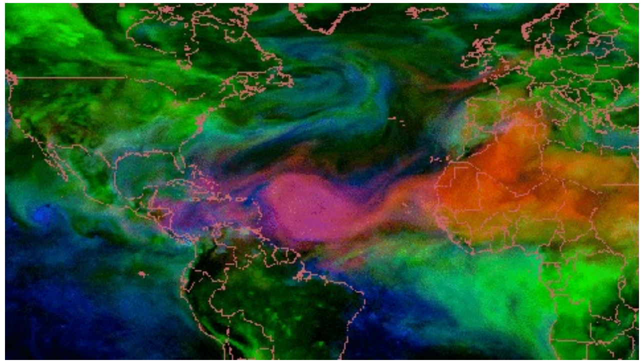




Other Applications

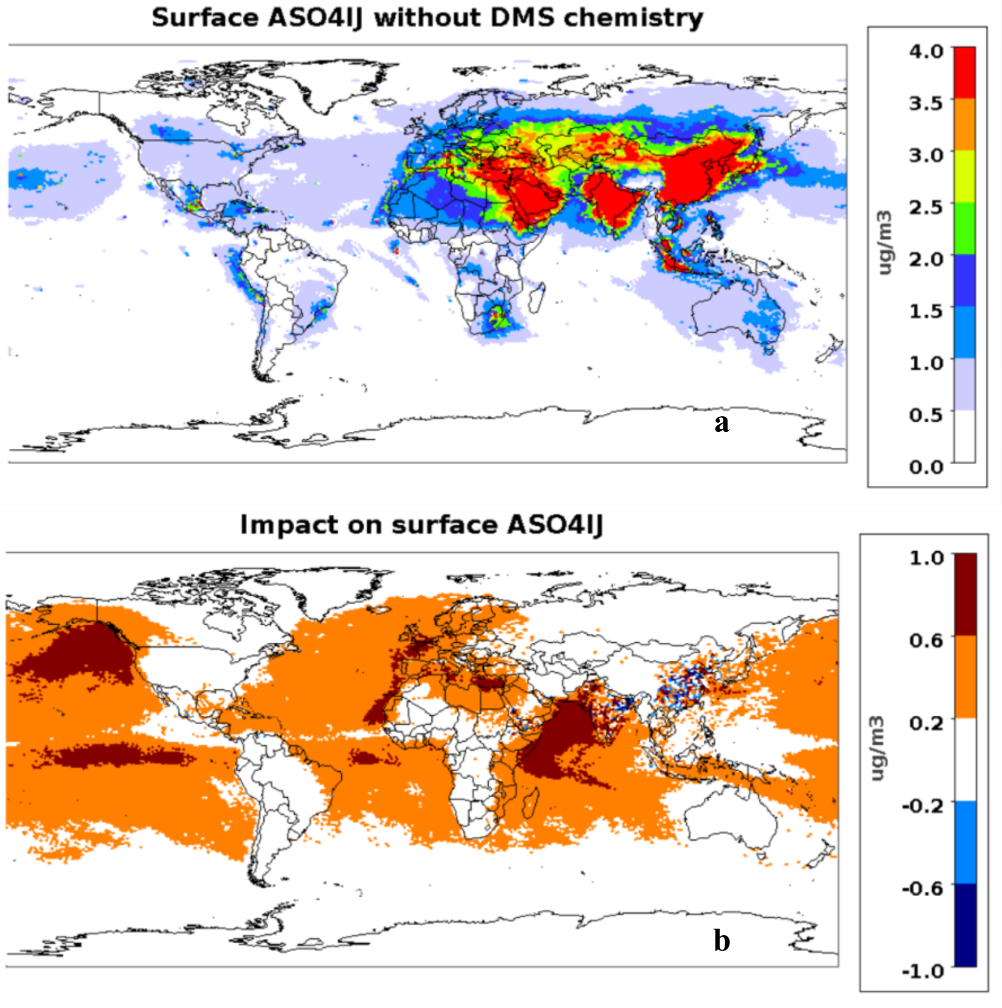


MPAS-CMAQ soil dust



NASA satellite AOD July 4-11

Long-range transport of dust



Effect of marine DMS chemistry on global scale

Summary

- MPAS-CMAQ system is an advancement of the WRF-CMAQ coupling framework.
- We have simulated several years and tested multiple mesh resolutions with MPAS-CMAQ system.
- Evaluation of multi-year simulations shows a low ozone bias in free troposphere, consistent with recent hemispheric CMAQ simulations. Surface ozone biases vary by region and season. Higher resolution is decreasing ozone.
- $PM_{2.5}$ low bias in summer on 120 km mesh, consistent with CMAQ 5.4 evaluation of 2018. High bias in western US when using higher resolution mesh.
- Future work: test direct radiative feedback from aerosols, extend simulations on high resolution meshes, complete update to CMAQ 5.4 and distribute for public use.

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