The GFDL Variable-Resolution Global Chemistry-Climate Model for Research at the Nexus of US Climate and Air Quality Extremes

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A cross-division development effort at GFDL started in 2021

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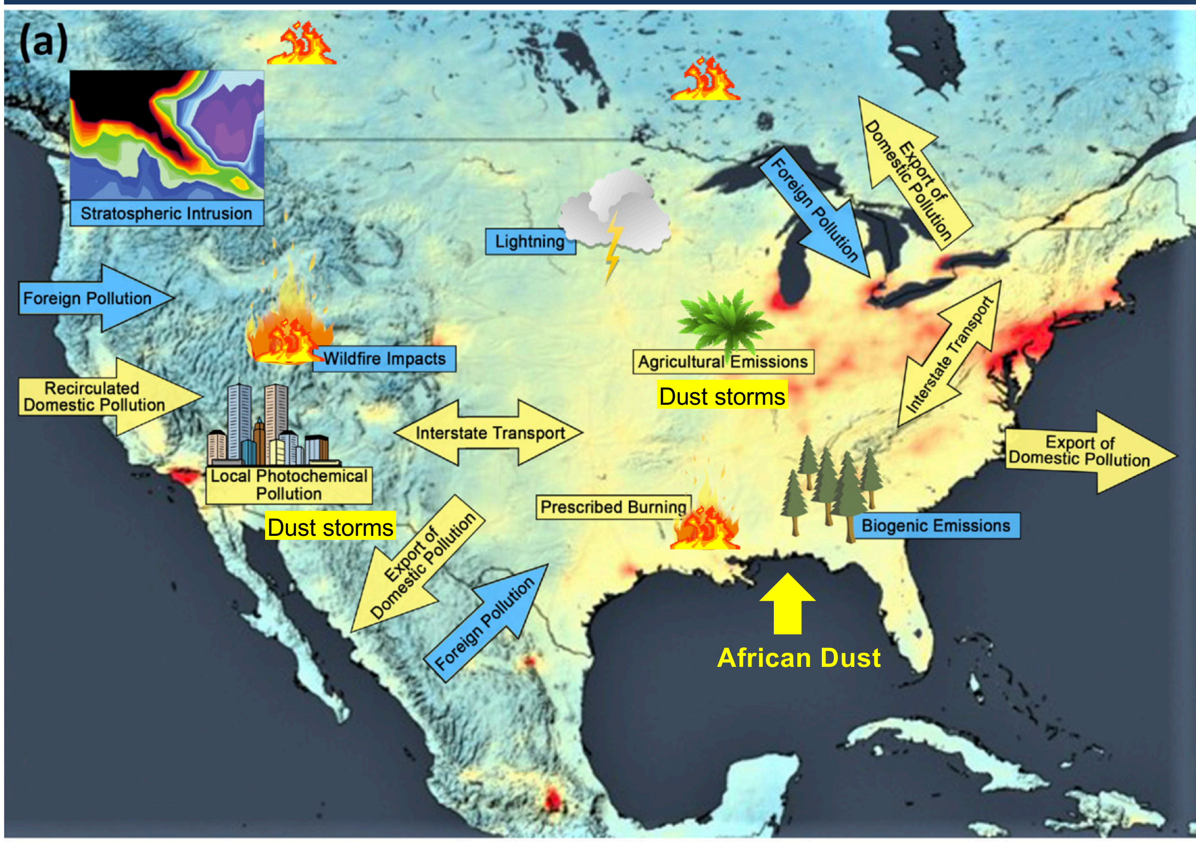
W Division: M. Zhao, L. Harris, S. Garner, L. Zhou
Modeling S: N. Zadeh and many others
DOE/PNNL: S. J. Smith and H. Ahsan

Paper: J. of Advances in Modeling Earth Systems, 2023MS003984

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

Challenges in Predicting U.S. Air Quality in a Changing Climate



Challenges:

- More frequent hot & dry weather
- Large land-biosphere feedbacks
- Transported plus local pollution
- Diverse air basins & complex terrain

Limitations in current tools:

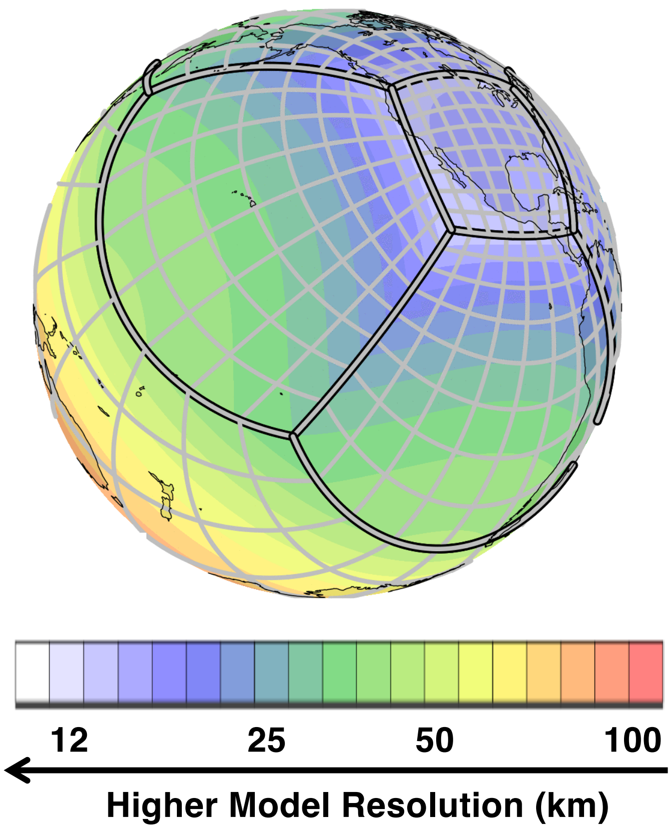
X Prescribed vegetation characteristics
X Issues with imposing global model BCs on regional models
X The "stationarity" assumption in statistical downscaling

Future:

✓ Need a seamless modeling system that can provide detailed info over a targeted region, while still integrating global Earth system components
✓ Increased coupling of atmospheric composition with dynamic vegetation

Lin et al. (2012ab, 2015ab, 2017, 2019, 2020); Jaffe et al. (2018, 2020); Ginoux et al. (2012); Xie et al. (2022)

The GFDL Variable-Resolution Global Chemistry-Climate Model (AM4VR) for Research at the Nexus of U.S. Climate and Air Quality Extremes



Illustrated by Linjiong Zhou

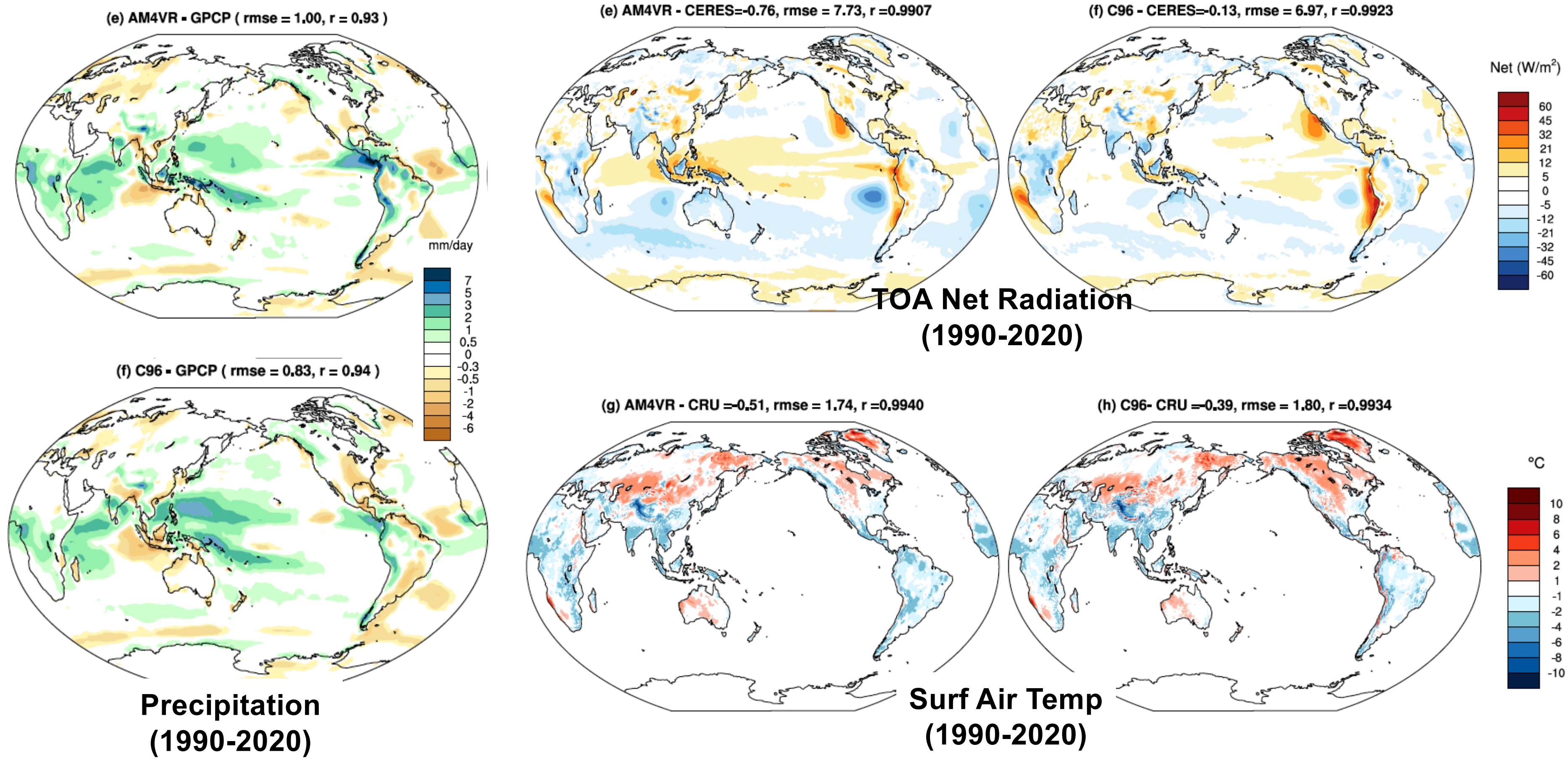
Key Features:

- GFDL FV3 Dynamical Core with regional grid refinement to 13 km over CONUS; sub-grid tiles for land surface heterogeneity
- Retuned moist physics from GFDL AM4.0
- **Comprehensive gas-phase & aerosol chemistry** from AM4.1
- High-resolution anthropogenic emissions from CEDS-2021-04-21 (0.1^{o}x0.1^{o}), 1980-2020
- **Interactive dust emissions** from a dynamic vegetation land model (LM4.0), with retuned params
- **Interactive dry deposition** of gases, responding to hydroclimate, land cover, and photosynthesis in a **dynamic vegetation** model
- Revised interactive BVOC emissions (MEGAN2.1), with revised hi-res emission potential maps and land cover data
- Revised biomass burning emissions from GFED4s (0.25^{o}x0.25^{o}), with reactive nitrogen partitioning, increased OVOCs, and MISR injection height

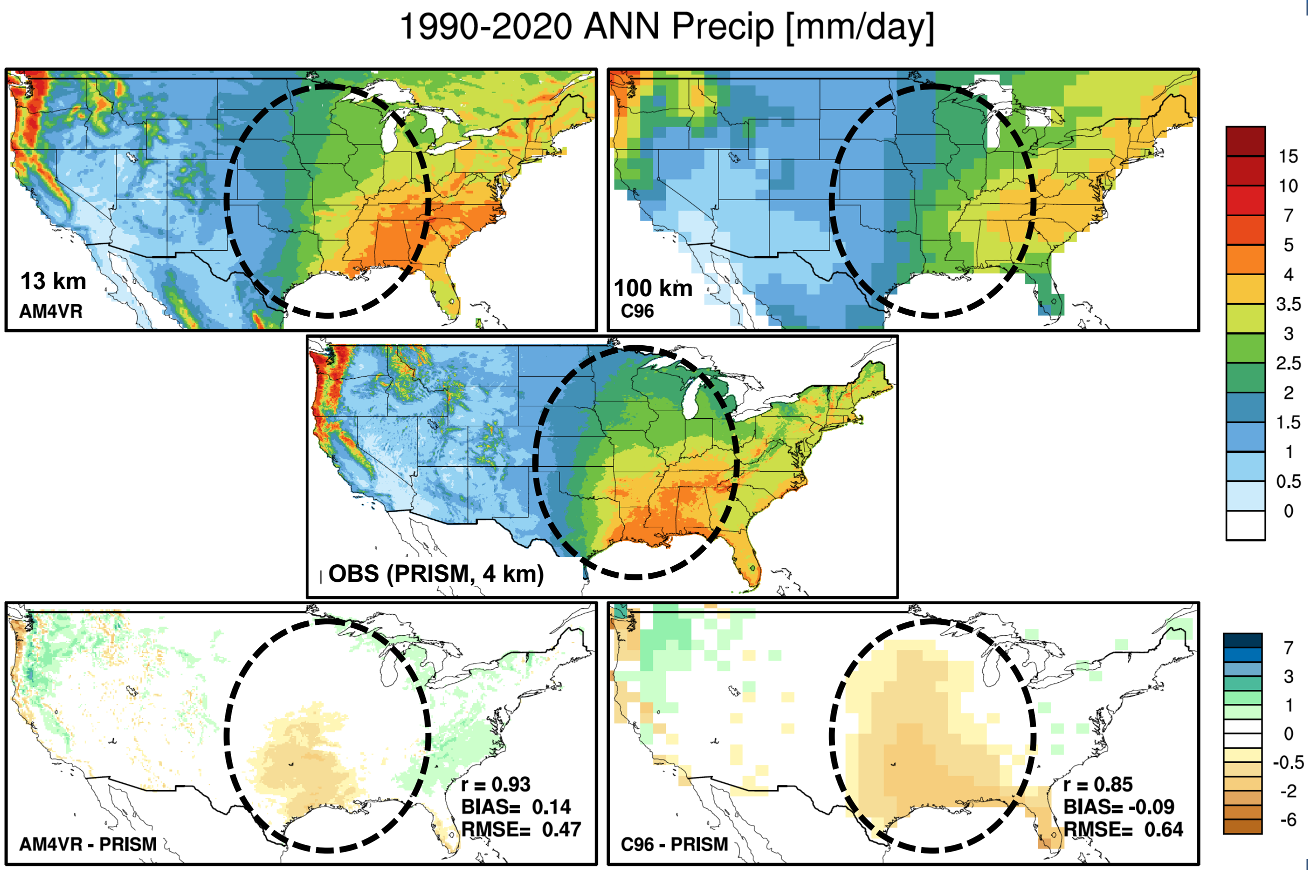
1990-2020 AMIP simulations with prescribed ocean
50% of the computational cost for a 25 km uniform-res grid

Lin M. et al. [JAMES, 2023MS003984]

AM4VR maintains a good simulation of global-scale circulation and climate comparable to AM4.1 (CMIP6) at uniform 100 km resolution



Marked improvements in U.S. regional precipitation patterns

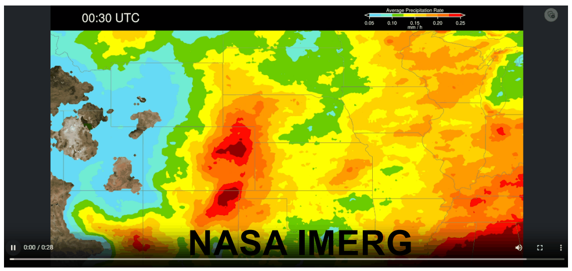


Notably reducing the central US dry bias that has persisted in many generations of weather forecast and climate models

Lin M. et al. [JAMES, 2023MS003984]

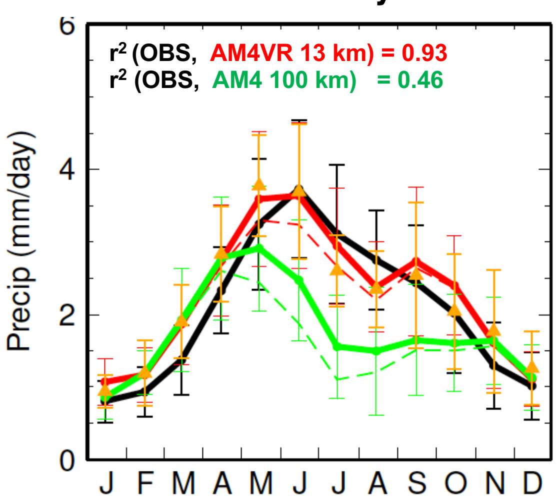
Improved skill in simulating the central US warm-season precipitation from mesoscale convective systems

- Limited skill from recent models at 25 km resolution, e.g. DOE E3SM (Tang et al., 2019; 2023); CMIP6 (Dong et al., 2023)

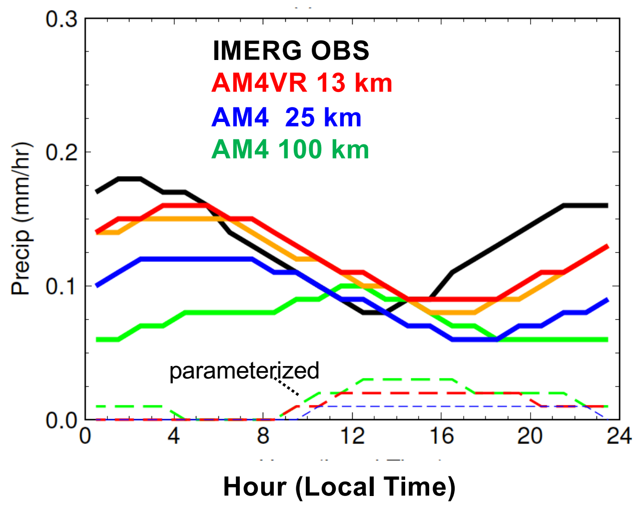


AM4VR at 13 km resolution exhibits:
→ **superior fidelity in representing the nocturnal peak of precipitation driven by mesoscale convective systems**
→ **reduced drizzling bias and increased rainfall extremes**

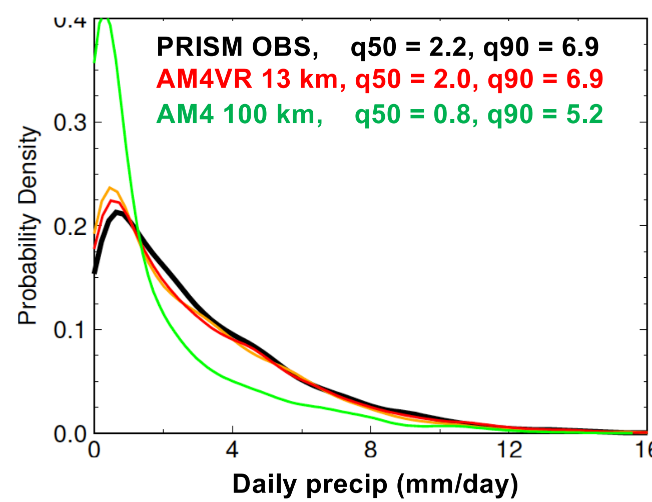
Seasonal cycle



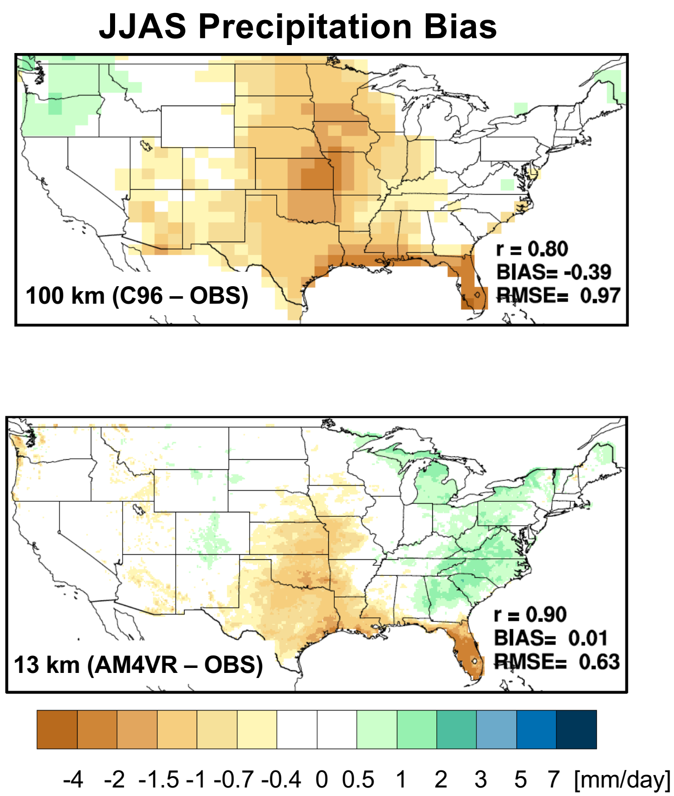
Diurnal cycle (JJAS)

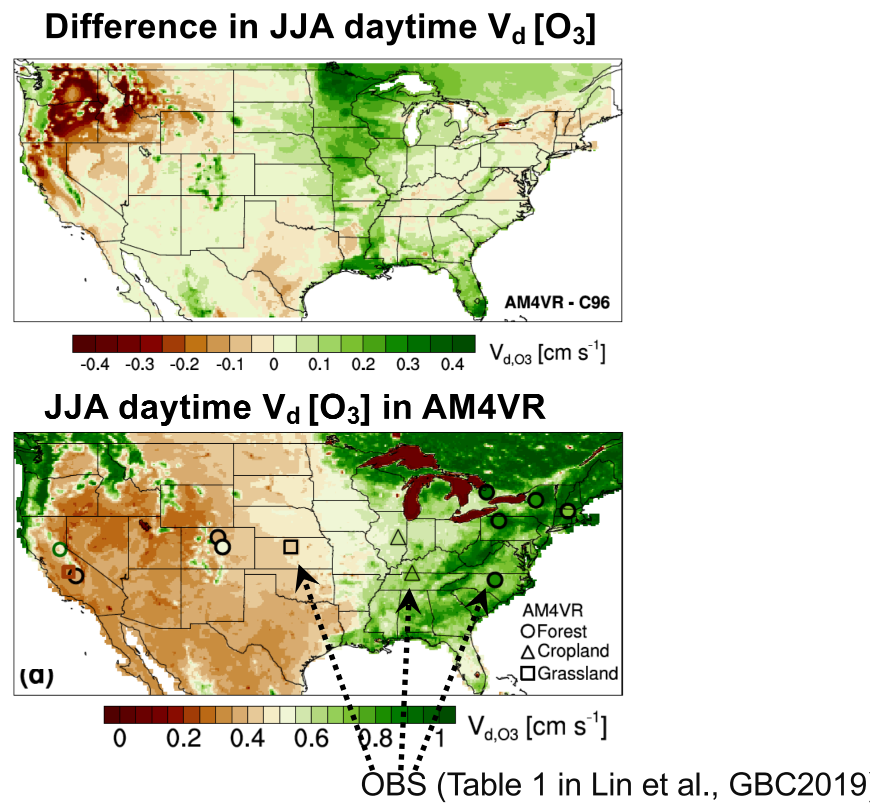


Daily distribution (JJAS)

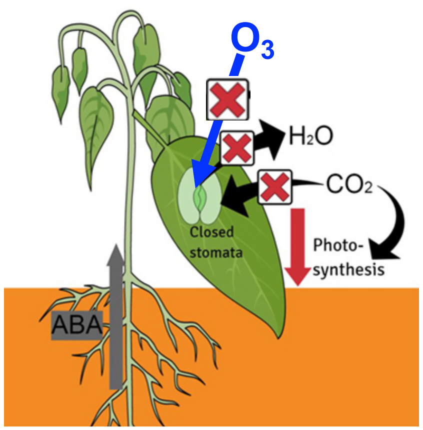


Improved precipitation affects ozone removal by vegetation

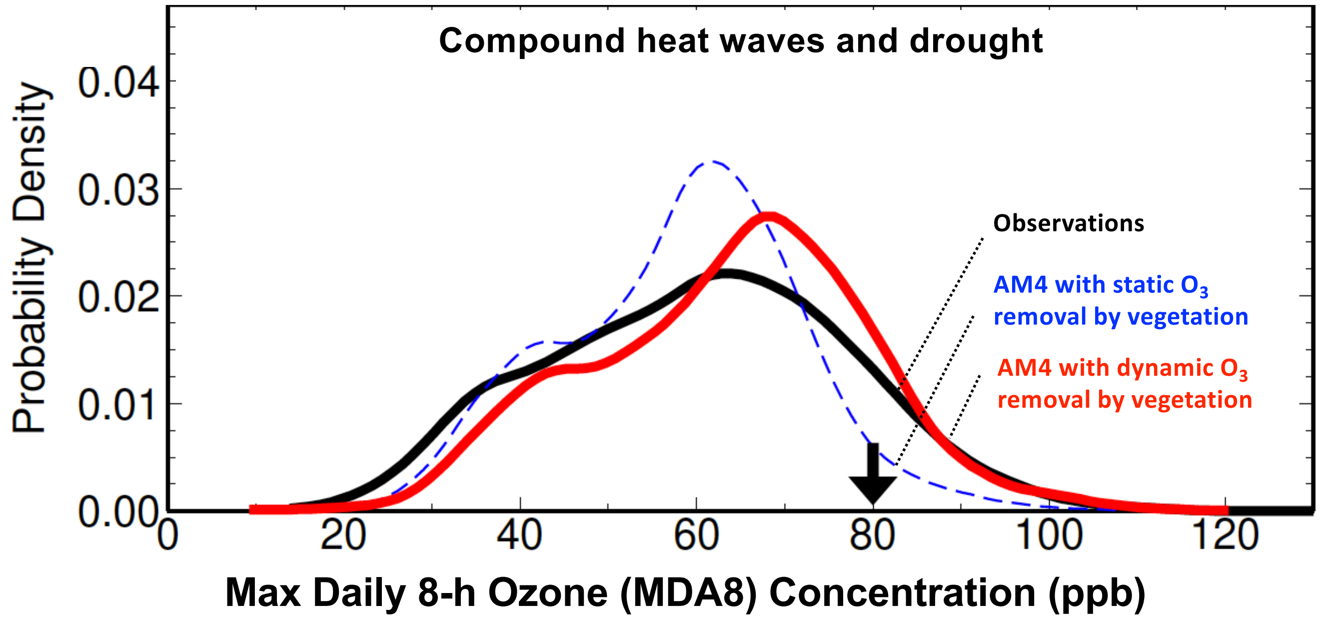




Reduced ozone removal by drought-stressed vegetation worsens ozone air pollution extremes during heatwaves



Drought-stressed vegetation



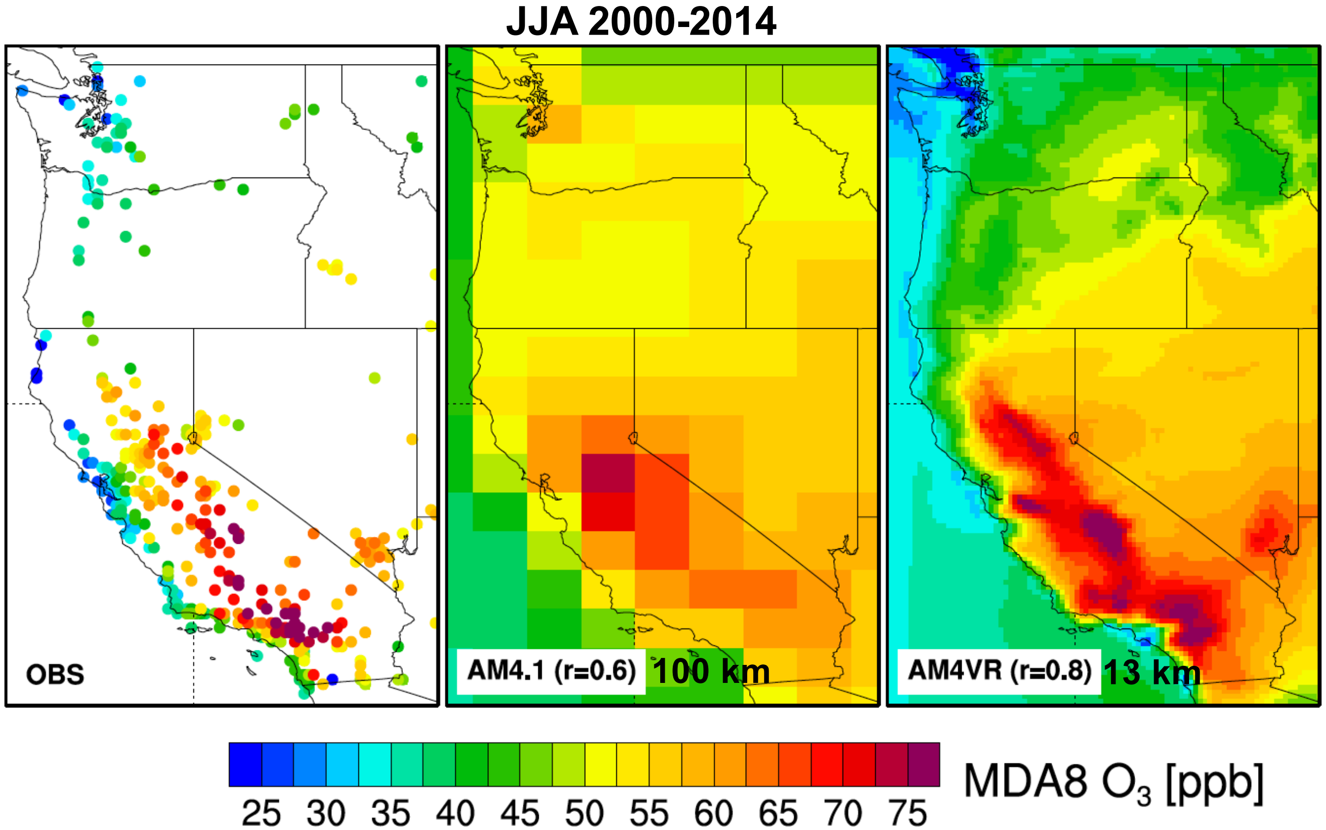
- The Wesely scheme (used in CMAQ/WRF-Chem/GEOS-Chem) does not account for stomatal closure induced by soil drying or rising atmospheric CO_2 concentrations

→ A new, mechanistic scheme in GFDL models yields process insights

→ Offer novel opportunities to study vegetation feedbacks in future climate

Lin M. et al. (Nature Climate Change, 2020; GBC2019)

Summer ozone pollution in the western US



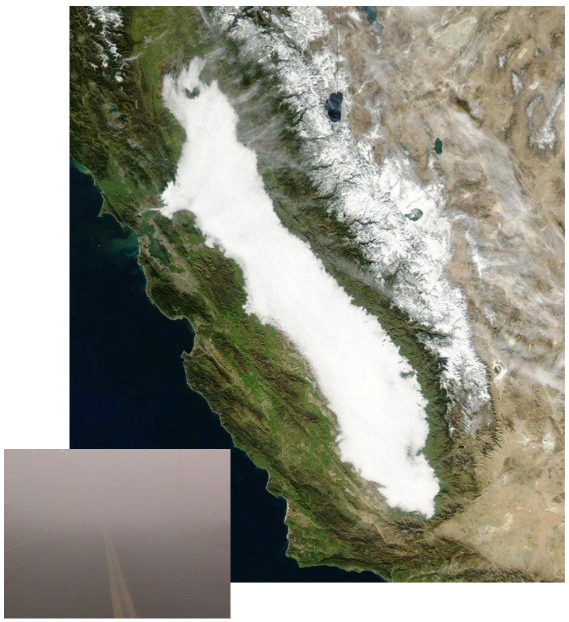
Improved representation of:

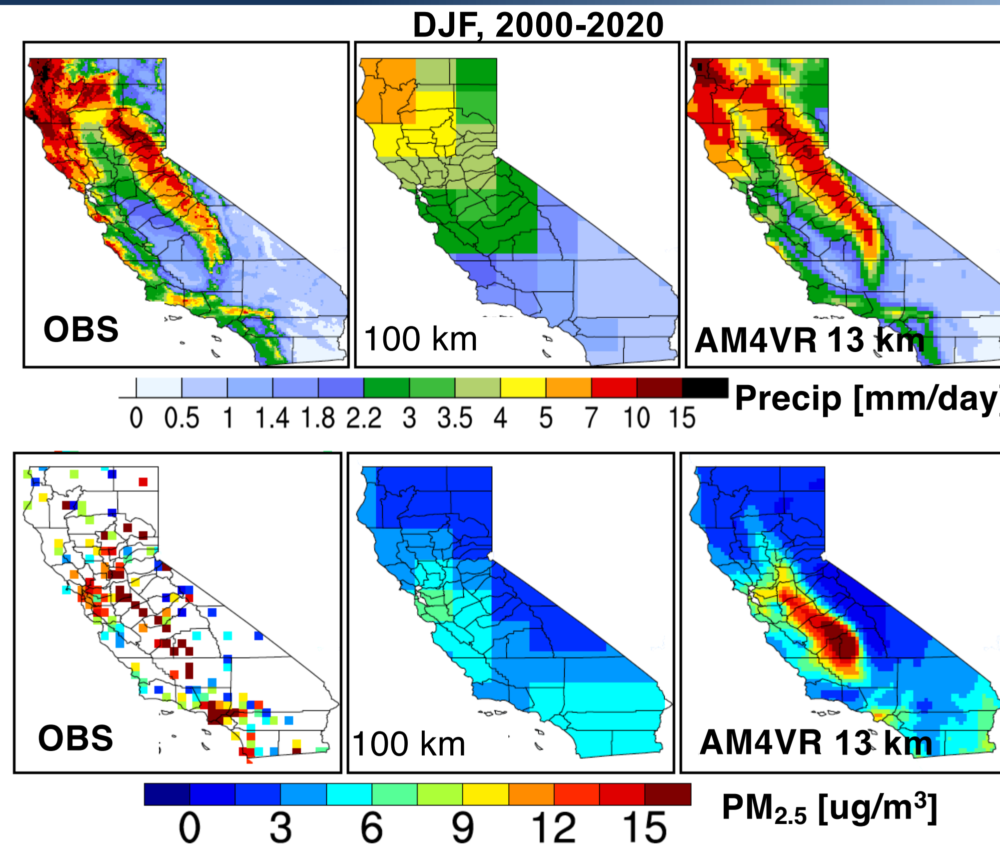
1) air pollution meteorology
2) urban-rural chemical regimes
3) BVOC emissions
4) drought
5) ozone removal by vegetation

Lin M. et al. [JAMES, 2023MS003984]

Winter Haze and Formation of Tule Fog in the Central Valley

Tule Fog (MODIS)



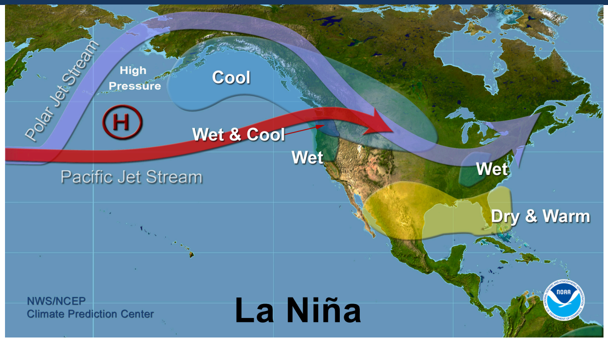


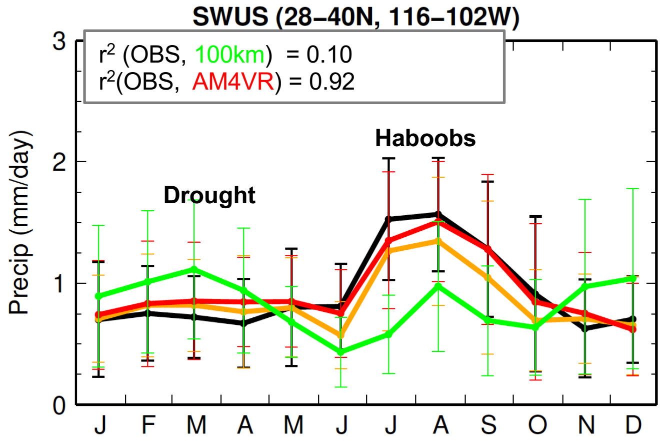
- Strong temperature inversion
- NH_4NO_3 aerosol as an efficient CCN

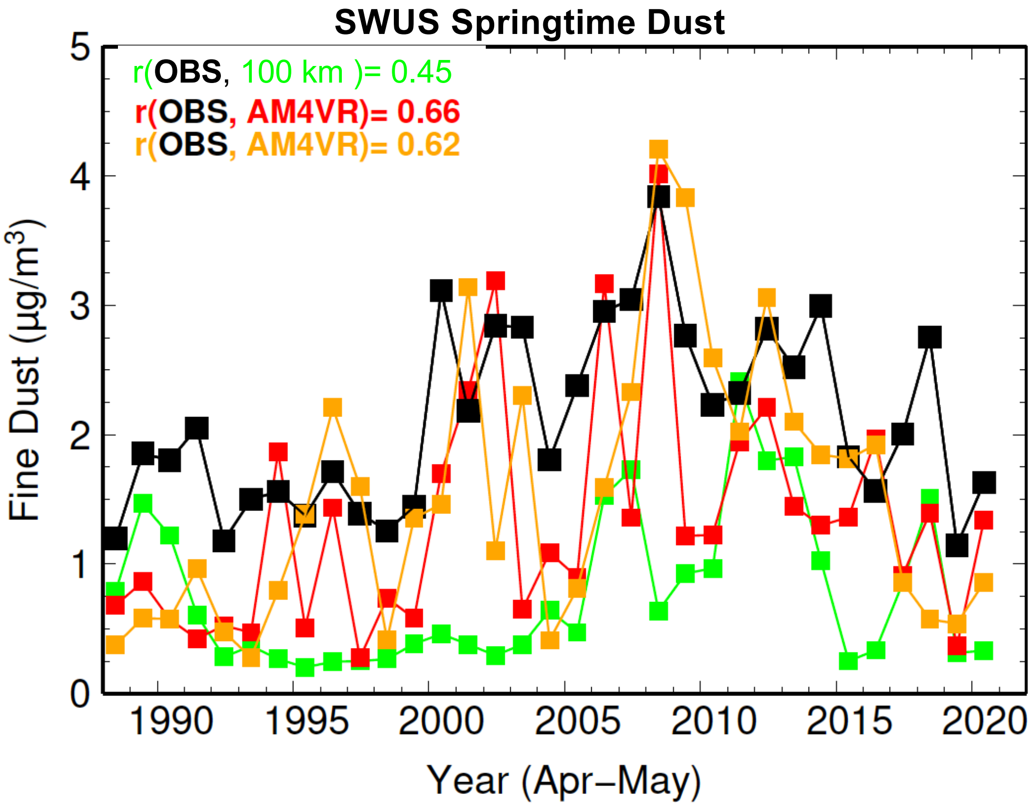
→ Impacts from large-scale circulation and climate change?

Lin M. et al. [JAMES, 2023MS003984]

ENSO → Southwest US Hydroclimate and Dustiness

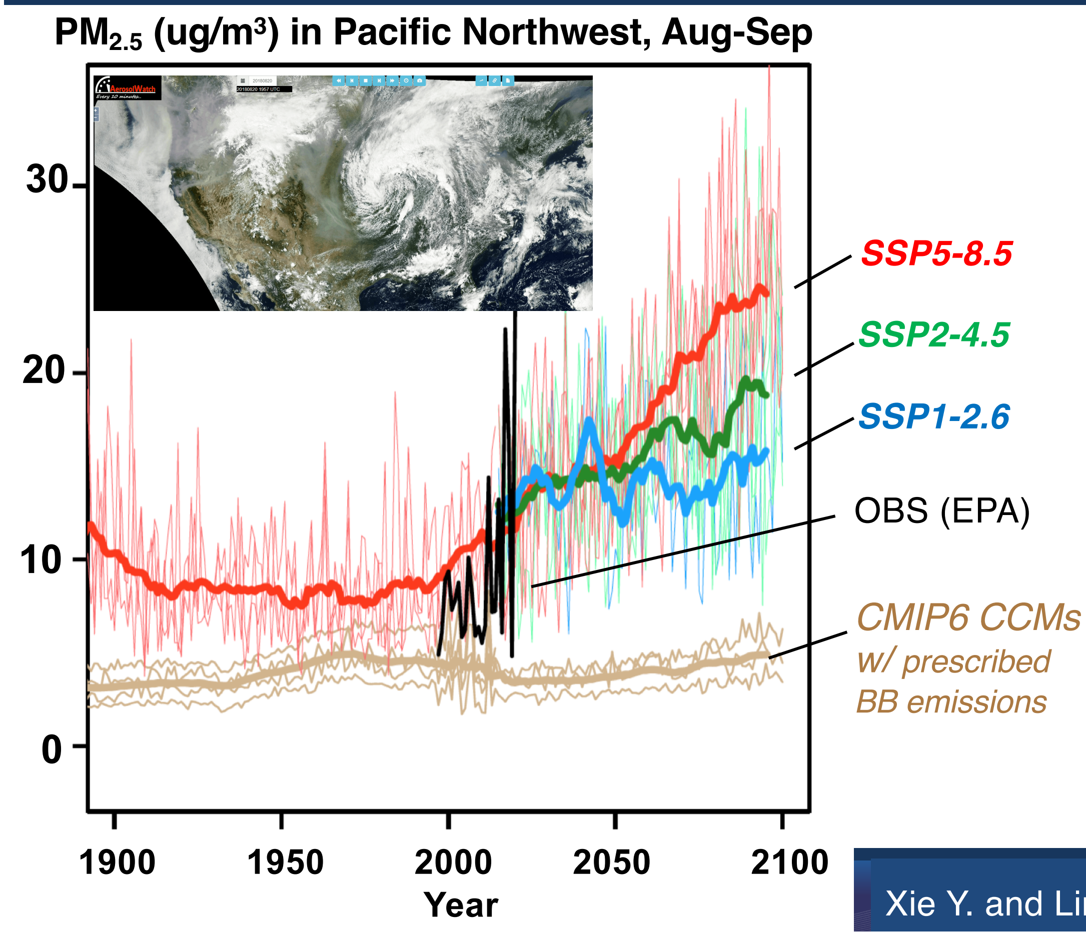


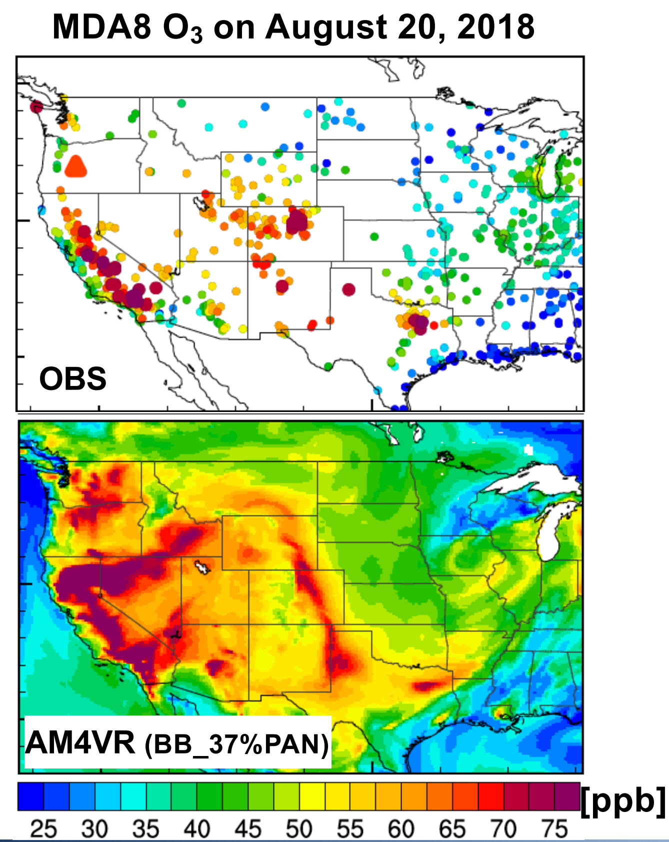




→ **AM4VR driven by observed SSTs captures SWUS dust variability, implying seasonal forecast potential**

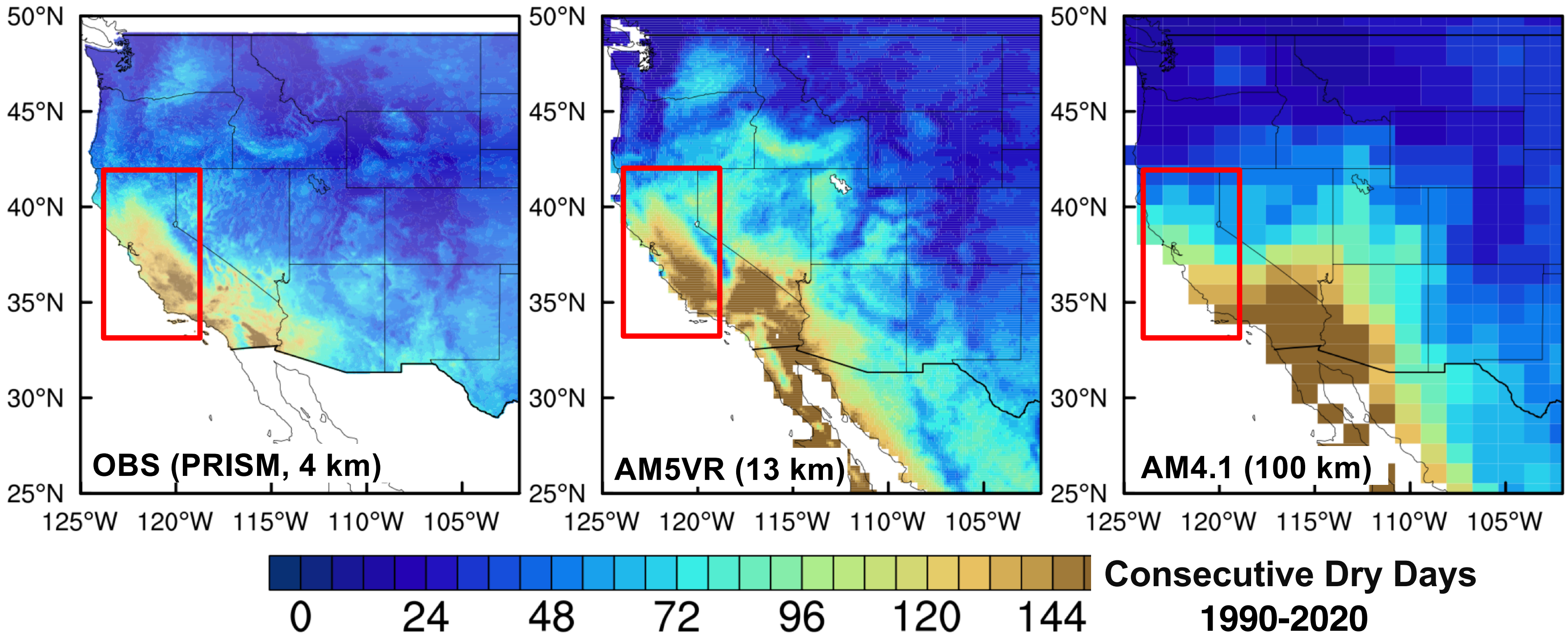
Impacts of local & transported wildfire plumes on US urban air quality





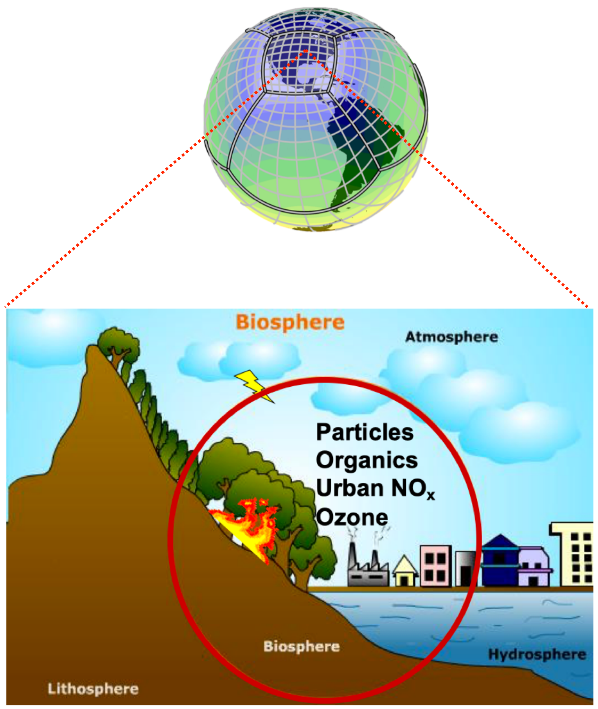
Xie Y. and Lin M. et al. (PNAS 2022); Lin M. et al. (in prep)

Improved representation of fire weather



Lin M. et al. [JAMES, 2023MS003984]

TAKE-HOME MESSAGE:
Towards seamless prediction of climate – air quality interactions



- **Integrating the global Earth System components within a seamless variable-resolution framework**
- **Increased coupling and interactivity of atmospheric composition with land-biosphere**
- **Improved representation of US regional precipitation, drought, and air quality extremes**

→ Develop seasonal air quality forecasting

→ Multidecadal projections from global to urban scales

→ Impact-oriented research

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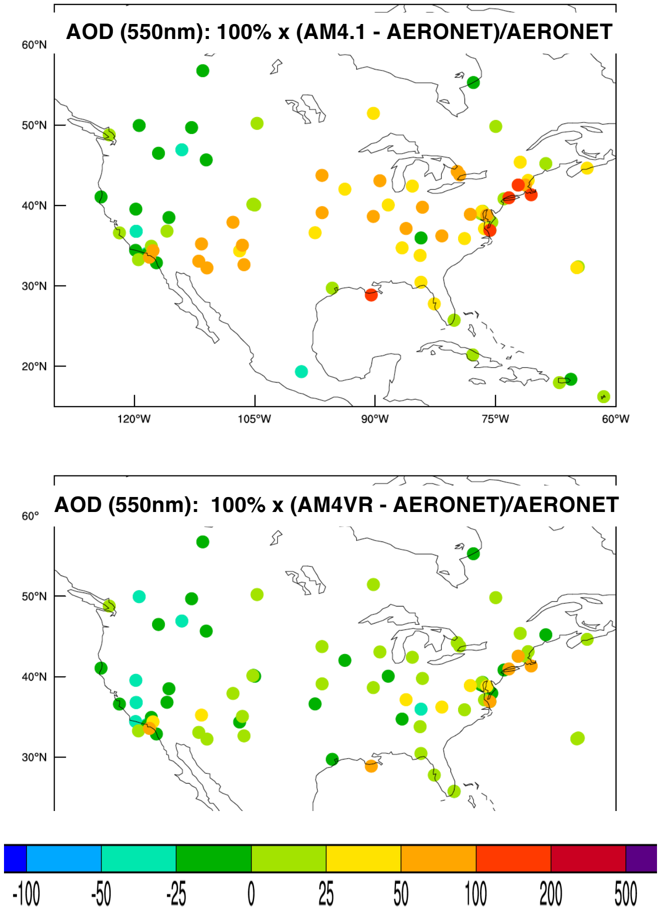
AM4VR features vastly improved representation of aerosols from AM4.1 CMIP6 simulation



- Improved representation of biogenic VOC emissions and secondary organic aerosols
- Improved representation of dust
- Improved representation of nitrate aerosols due to interactive dry deposition of nitric acid + NH_3 to land