Predictions and Projections of Extremes, Weather/Climate, and Air Quality

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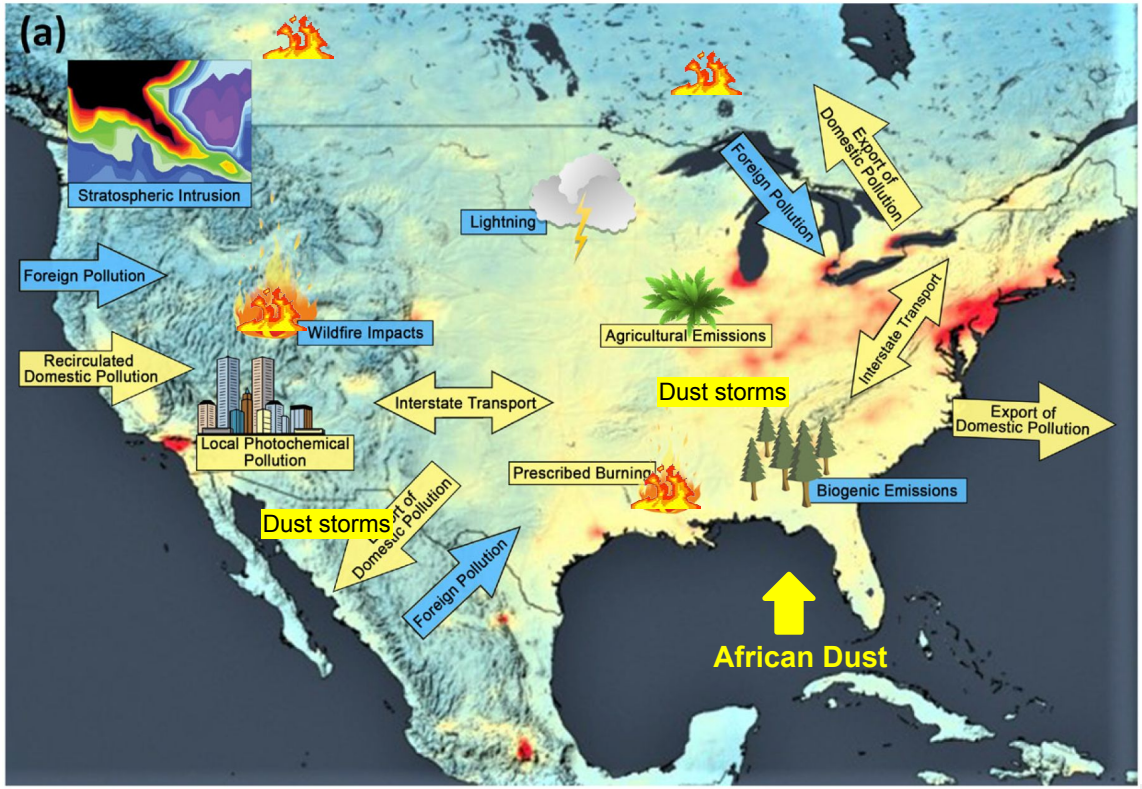
Q2: Concerning NOAA's key mission element of understanding, predicting, and projecting changes in the Earth System, how can GFDL drive further advances in these areas, including extremes and environmental hazards, through scientific innovation based on observations, theory, and modeling? Where are the strengths, gaps, and new frontiers?

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



Challenges:

- Compound drought & heat events
- Large land-biosphere feedbacks
- Transported plus local pollution
- Diverse air basins & complex terrain

Limitations in current tools:

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

Future:

- ✔ Need increased coupling of atmos. composition with dynamic vegetation
- ✔ Need a seamless modeling system that can provide detailed info over a targeted region, while still integrating global Earth system components

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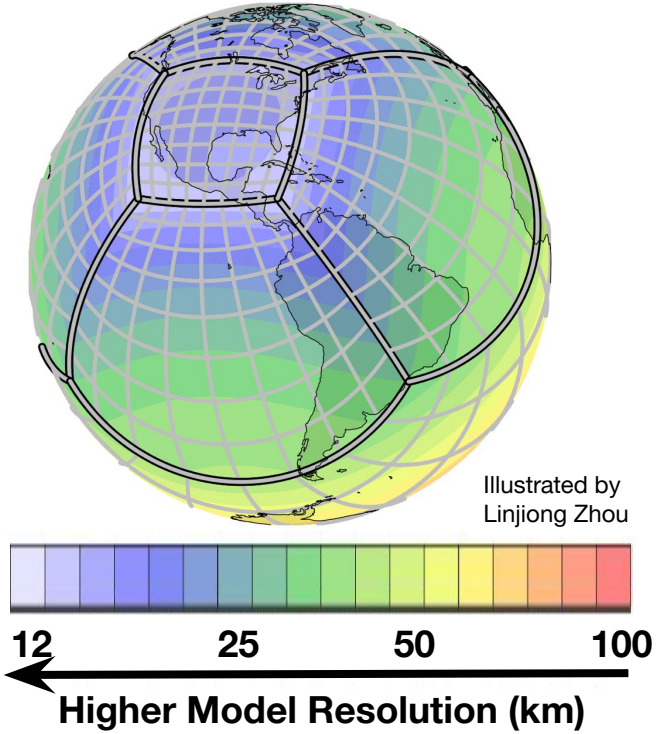
Lin et al. (2012ab, 2015ab, 2017, 2019, 2020); Jaffe et al. (2018, 2020); Ginoux et al. (2012)

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



Meteorology-chemistry coupling, feedbacks & interactions:

- 13 km spatial resolution over North America
- 50% of the computational cost for a 25 km uniform-resolution grid
- Comprehensive gas-phase & aerosol chemistry
- Increased coupling of atmos. composition with land-biosphere:
  -Dynamic O_3 removal by vegetation, responding to drought stress (Lin M. et al, Nature Climate Change 2020)
  -Interactive dust emissions from a dynamic vegetation land model
  -Revised interactive biogenic VOC emissions
- Improved representation of wildfire emissions, plume chemistry, and interaction with urban pollution (Lin et al., GRL 2024)
- Improved representation of US climate mean patterns and variability, incl. mesoscale convective systems, hydroclimate extremes, and drought
- Improved representation of aerosols & US air quality extremes

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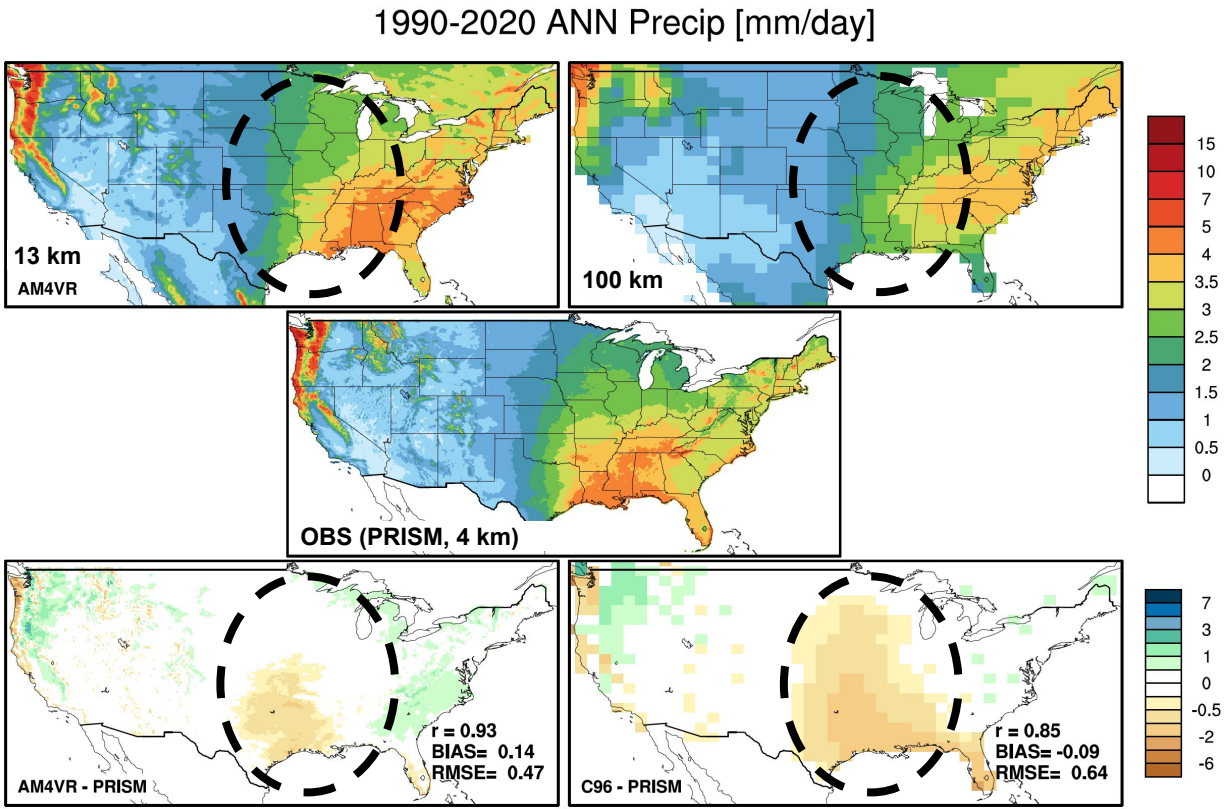
5-YEAR REVIEW
JANUARY 28-30, 2025

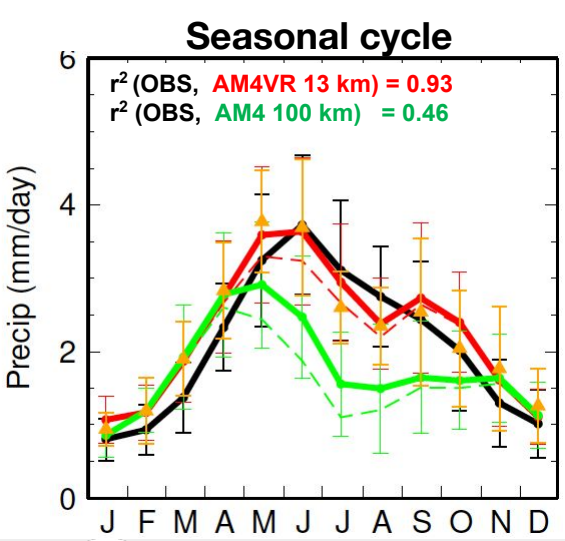
Marked improvements in U.S. regional precipitation patterns

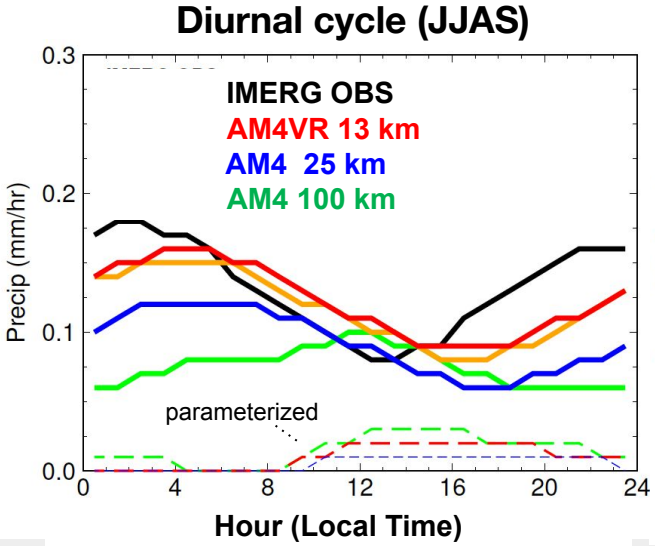


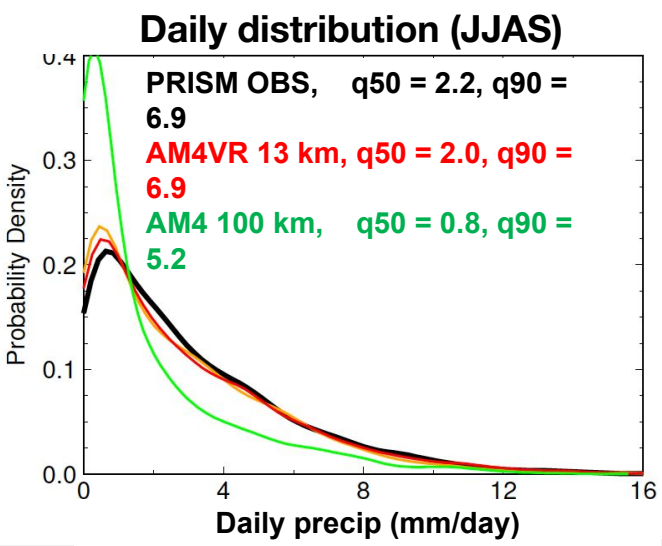
Notably reducing the central US dry bias that has persisted in many generations of weather forecast and climate models

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)
- In contrast, AM4VR at 13 km resolution exhibits:
  →superior fidelity in representing the nocturnal peak of precip from mesoscale convective systems
  →reduced drizzling bias and increased rainfall extremes

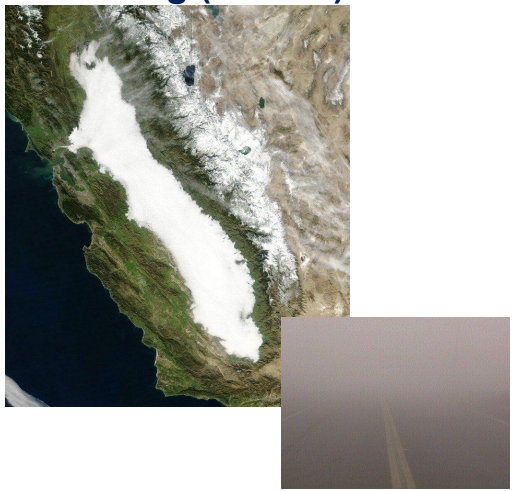




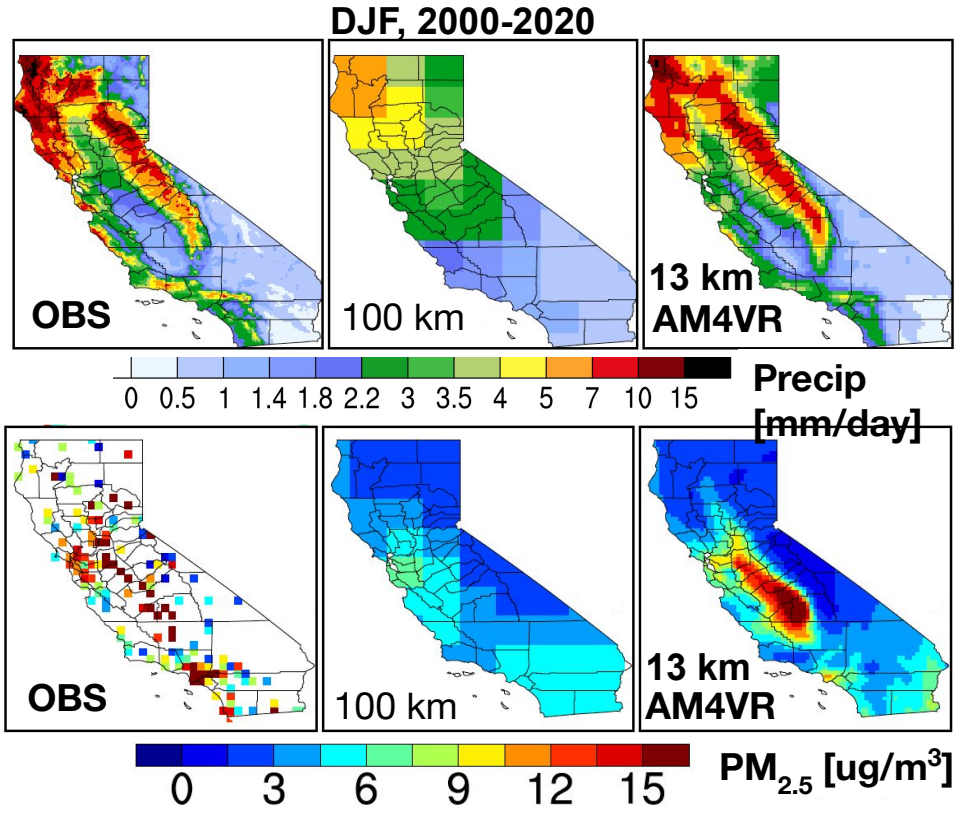


Application to Winter Haze and Tule Fog in the Central Valley

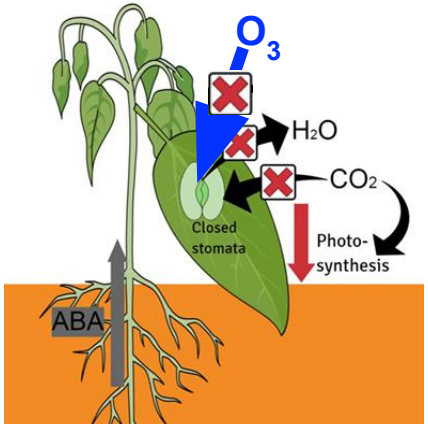
Tule Fog (MODIS)

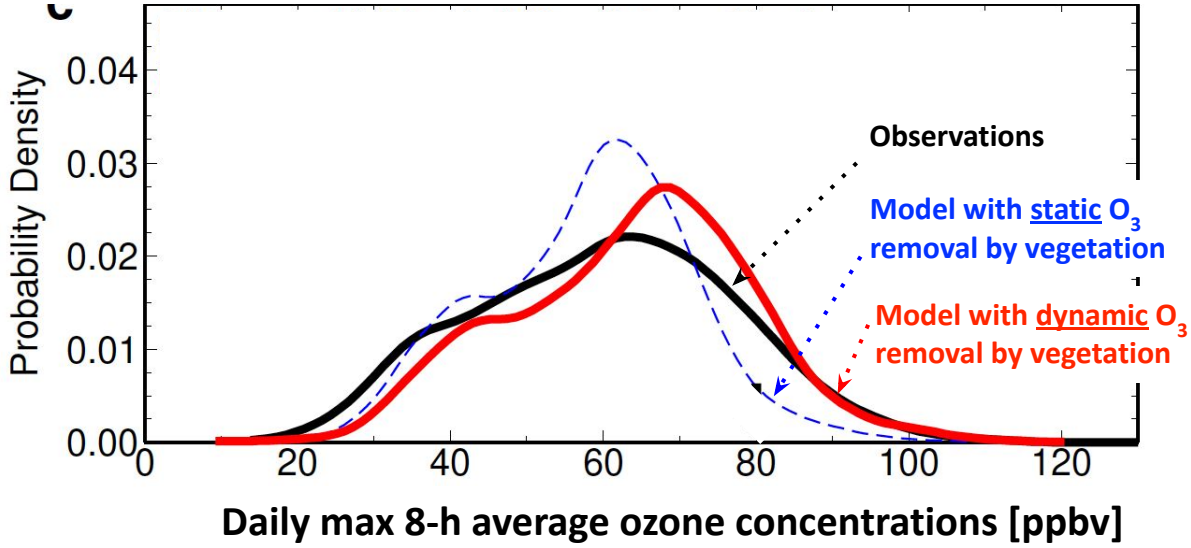


- Tule fog significantly affects transportation, human health, and agriculture
- NH_4NO_3 aerosol as an efficient CCN for fog formation under strong temperature inversion
- AM4VR offers novel opportunities to study the role of large-scale climate variability & change

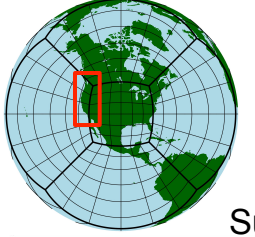


Reductions in ozone removal by vegetation exacerbates ozone air pollution extremes during compound drought and heat events



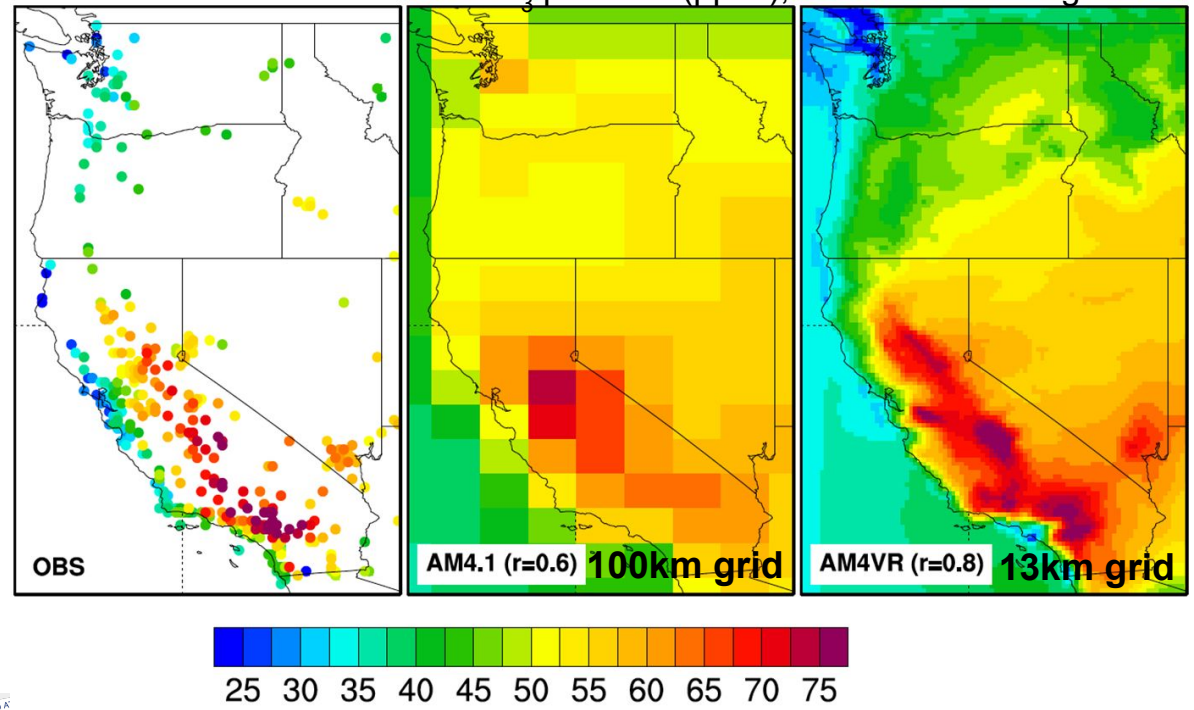


- Extreme heat & drought stress plants, reducing removal of air pollutants
- Implications for future air quality with more prevalent hot droughts in a warming climate
- Soil moisture initialization towards seasonal air quality forecast; pushing beyond the current operational weather scale



Towards Seamless Assessment of Global Dimensions to U.S. Urban Air Quality

Summer surface O_3 pollution (ppbv), 2000-2020 average



Applications relevant to regional and local Stakeholders & policy makers:

- Seamless assessment of global dimensions to U.S. urban air quality
- Drought and land-biosphere feedbacks in a changing climate
- Fire and smoke at the wildland-urban interface
- Towards Seasonal Air Quality Forecasting

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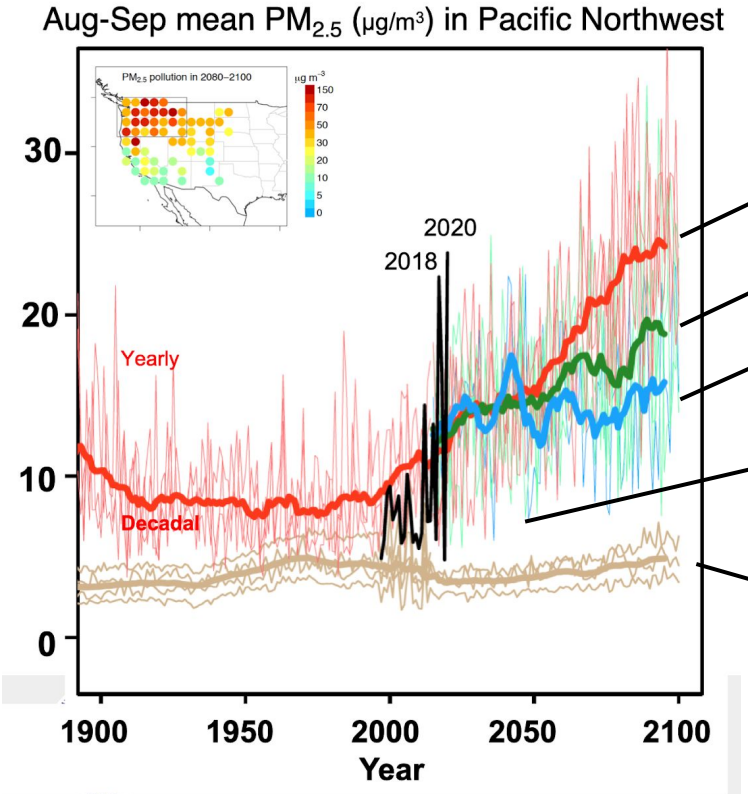
Increasing Smoke Pollution from Western Wildfires under 21stC Climate Change



Applying an empirical statistical model to fire CO_2 projected by three Earth System Models (GFDL ESM4.1 | NCAR CESM2 | CNRM ESM2)

SSP5-8.5: Events like 2020 could recur every 3 yrs

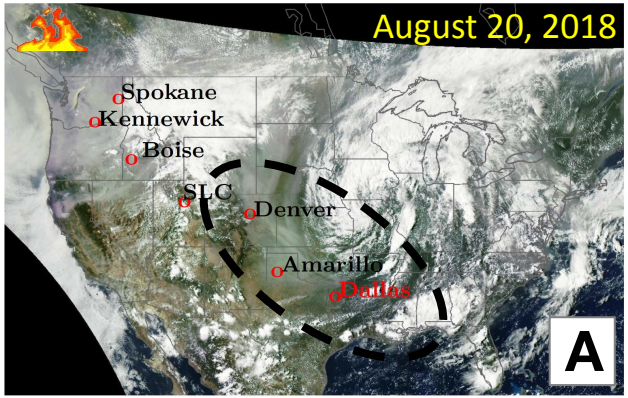
SSP2-4.5: Events like 2020 could recur every 5 yrs

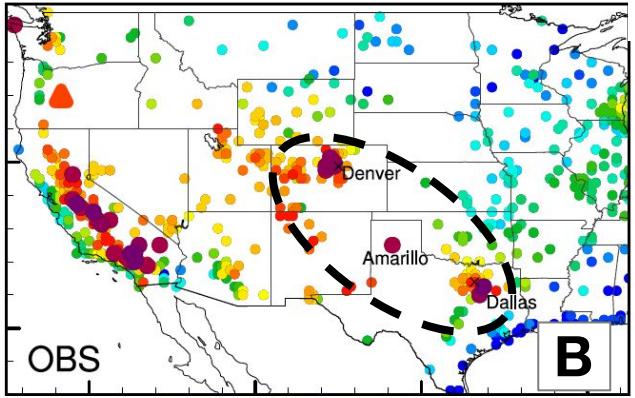
SSP1-2.6: Increase by mid-century and then level-off

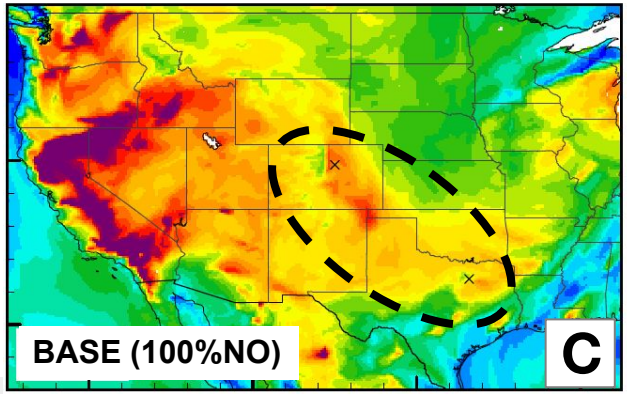
Observations from EPA's Air Quality System

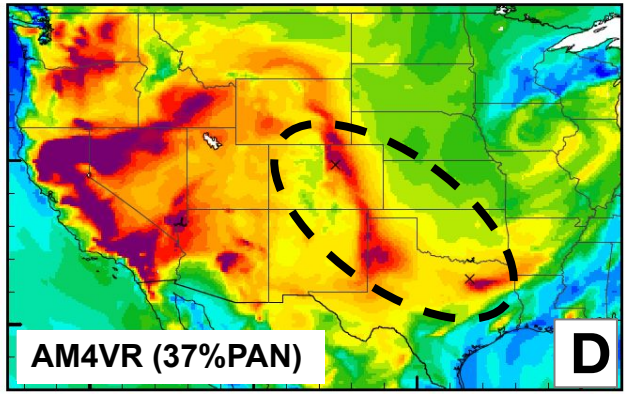
CMIP6 CCMs w/ prescribed BB emissions not accounting for the impacts from climate change

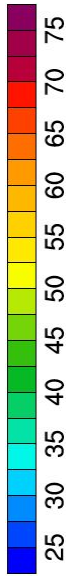
Reactive nitrogen partitioning enhances the contribution of Canadian Wildfire Plumes to US Ozone Air Quality











EPA Limit

- Aged smoke from Canadian wildfires caused ozone pollution in Denver and Dallas to exceed the EPA limit.
- Near-fire reactive nitrogen (NOy) partitioning enhanced O_3 production in aged smoke
- AM4VR allows us to investigate interactions between urban pollution and smoke plumes from wildfires thousands of kilometers away

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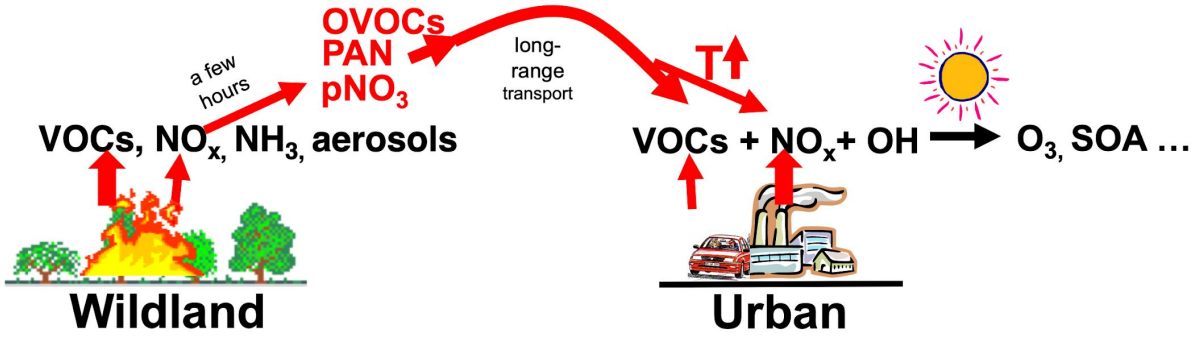
Lin M. et al. (GRL 2024)

Using novel observations and models to understand the complex chemical cocktails of wildfire plumes mixed with urban emissions

GFDL AM4VR



- Near-fire NO_y parameterization based on aircraft observations
- Improve representation of VOCs in wildfire plumes
- Improve plume injection height (A. Pouyaei)
- Feedbacks to NOAA/NWS National Air Quality Forecast Capability

Collaborators: S. Brown and A.O. Langford (NOAA CSL), F. Moshary and Y. Wu (NOAA CESSRST/CCNY); M. J. Newchurch (U. of Huntsville), J. Sullivan (NASA); Lu Hu and W. Permar (U. Montana)

Lin M. et al. (GRL 2024)
Lin M. et al. (AGU Fall Meeting 2024)