Towards seamless prediction of Earth system feedbacks to air quality under climate change: Challenges and new modeling capabilities

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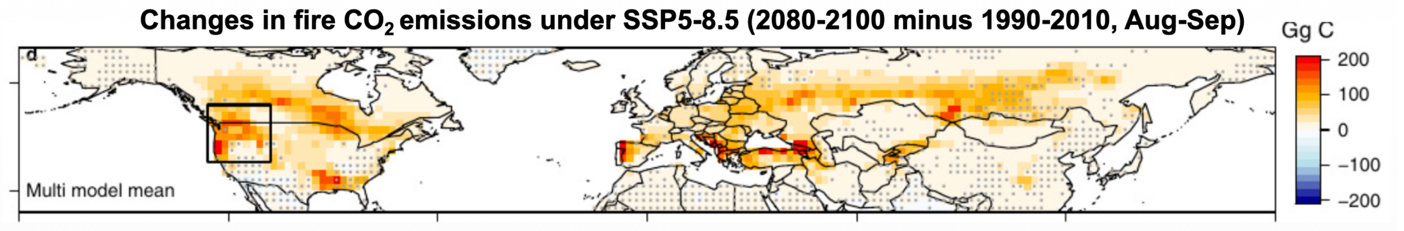
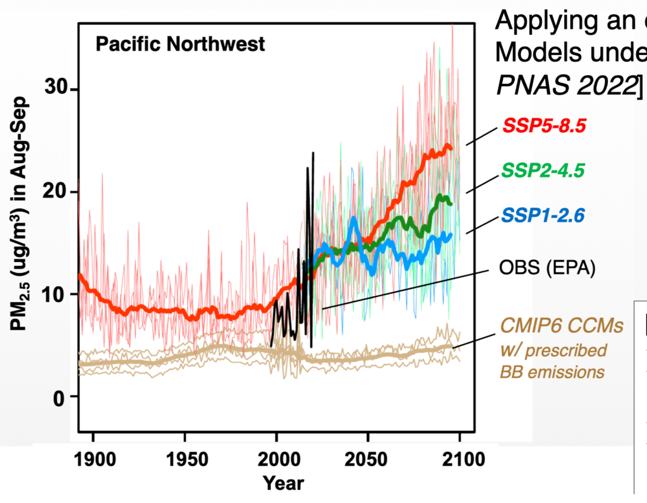
Increasing wildfire smoke in a warming climate





Applying an empirical statistical model to fires projected by Earth System Models under a suite of Shared Socioeconomic Pathways [*Xie & Lin et al., PNAS 2022*]

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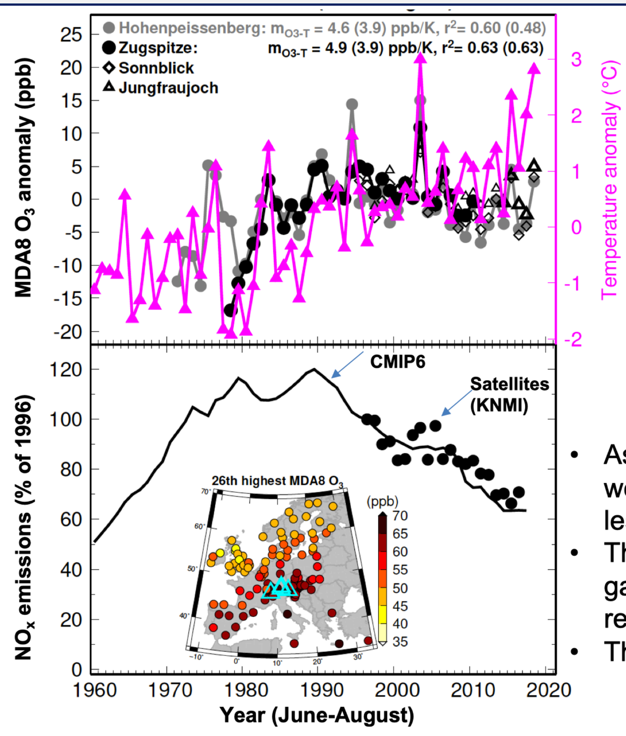
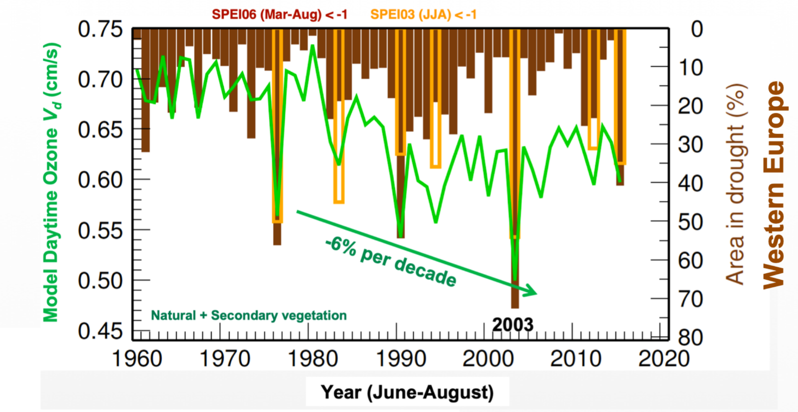
Moving forward, we need:

- high-res ESMs to improve representation of fire weather and interactions of wildfire smoke with urban pollution
- interactive fire emissions coupled to atmos chemistry to quantify co-occurrence of $PM_{2.5}$ and O_3 extremes

Declining ozone removal by drought-stressed vegetation

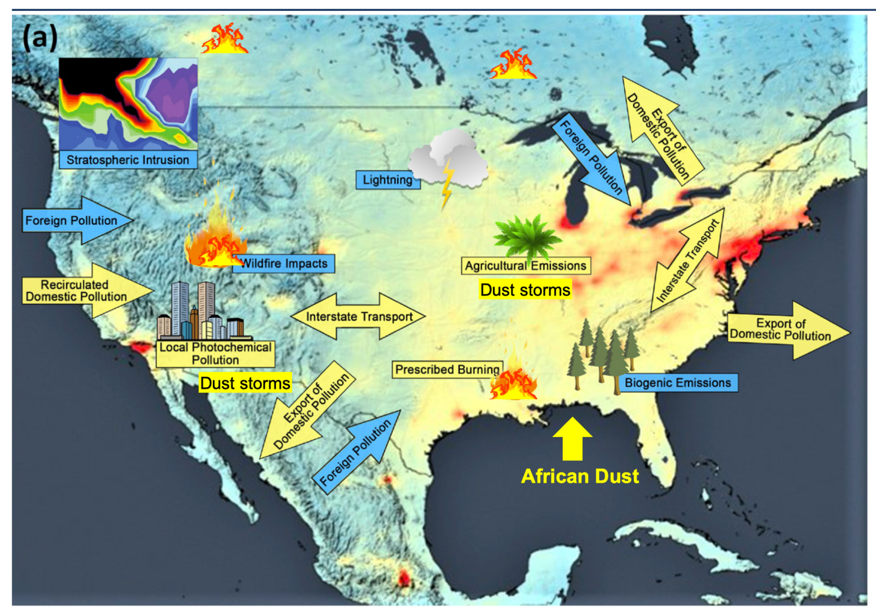




- As global climate change leads to more frequent hot and dry weather, the resulting droughts are stressing plants, making them less able to remove ozone pollution from the air.
- The climate penalty feedbacks can offset air quality improvements gained from regional emission controls, as occurred in Europe in recent decades.
- The feedback mechanisms are poorly represented in CMIP6 models

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

Sources of air quality variability in diverse US air basins



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

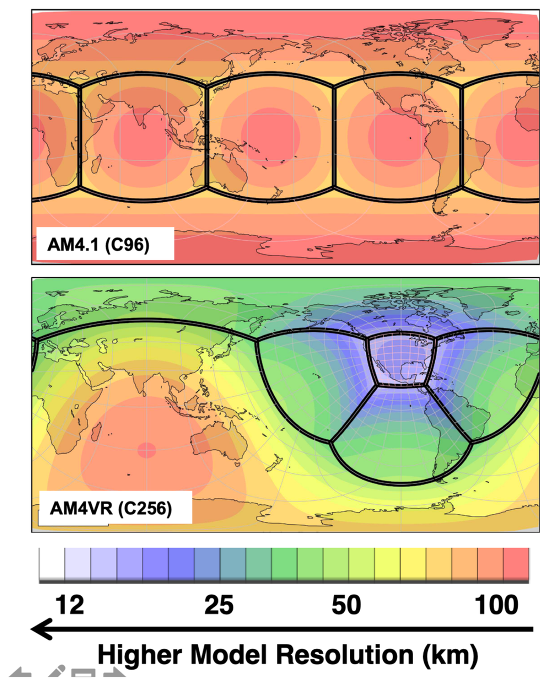
✗ The "stationarity" assumption in statistical downscaling is problematic

✗ Issues with imposing global model BCs on regional models

✓ Need a seamless modeling system that can provide detailed information over a targeted region, while still integrating global Earth system components

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



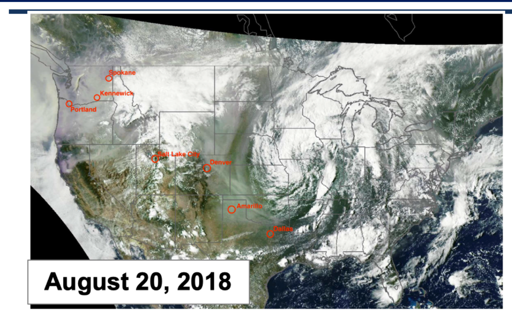
1990-2020 AMIP simulations driven by historical SSTs & forcings:

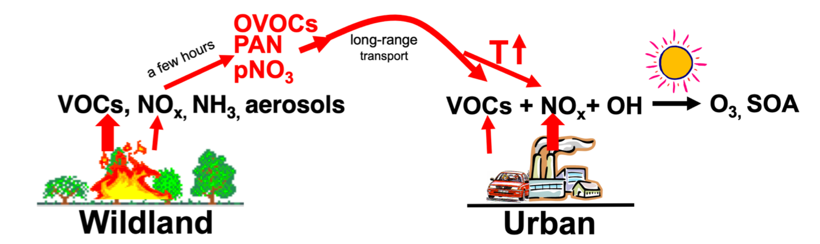
- GFDL FV3 Dynamical Core with regional grid refinement to 13 km over CONUS; sub-grid tiles for land sfc heterogeneity
- Retuned moist physics parameters from GFDL AM4.0 (CMIP6)
- Revised full atmospheric chemistry from GFDL AM4.1
- Interactive dust emissions from a dynamic vegetation land model (LM4.0), with retuned params
- Interactive dry deposition of gases, responding to drought and vegetation state (*Lin M. et al., Nature Clim Change 2020*)
- Revised interactive BVOC emissions (MEGAN2.1), with high-res emission potential maps and land cover data
- Revised BB VOC emissions, plume injection height, and NO_y parameterization for fresh smoke (*Lin M. et al., GRL2024*)
- Revised high-resolution anthropogenic emissions from CEDS-2021-04-21 (0.1°x0.1°)

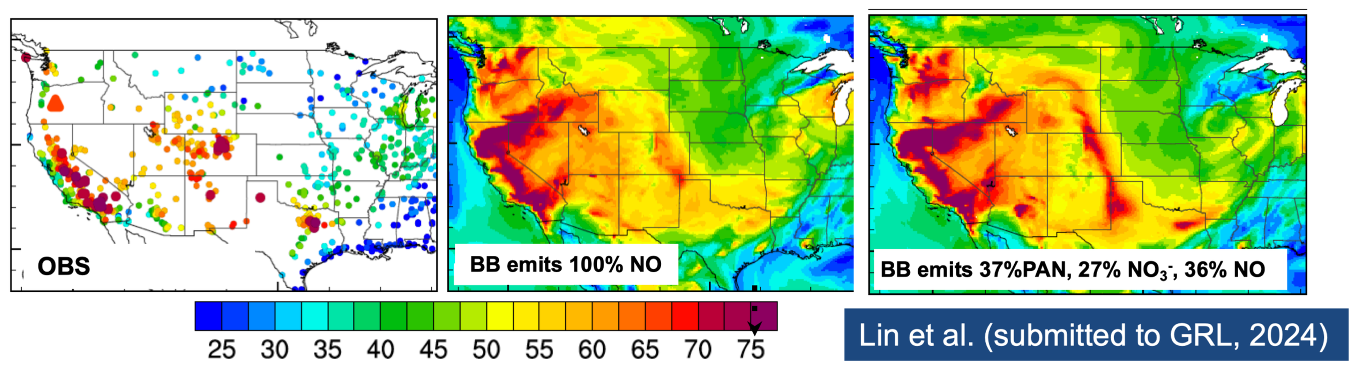
➢ **Much improved representation of US climate, aerosols, and air quality extremes**

Lin M et al. (JAMES, 2024)

Reactive nitrogen partitioning fuels contribution of O_3 from Canadian wildfire smoke to cities in US Deep South

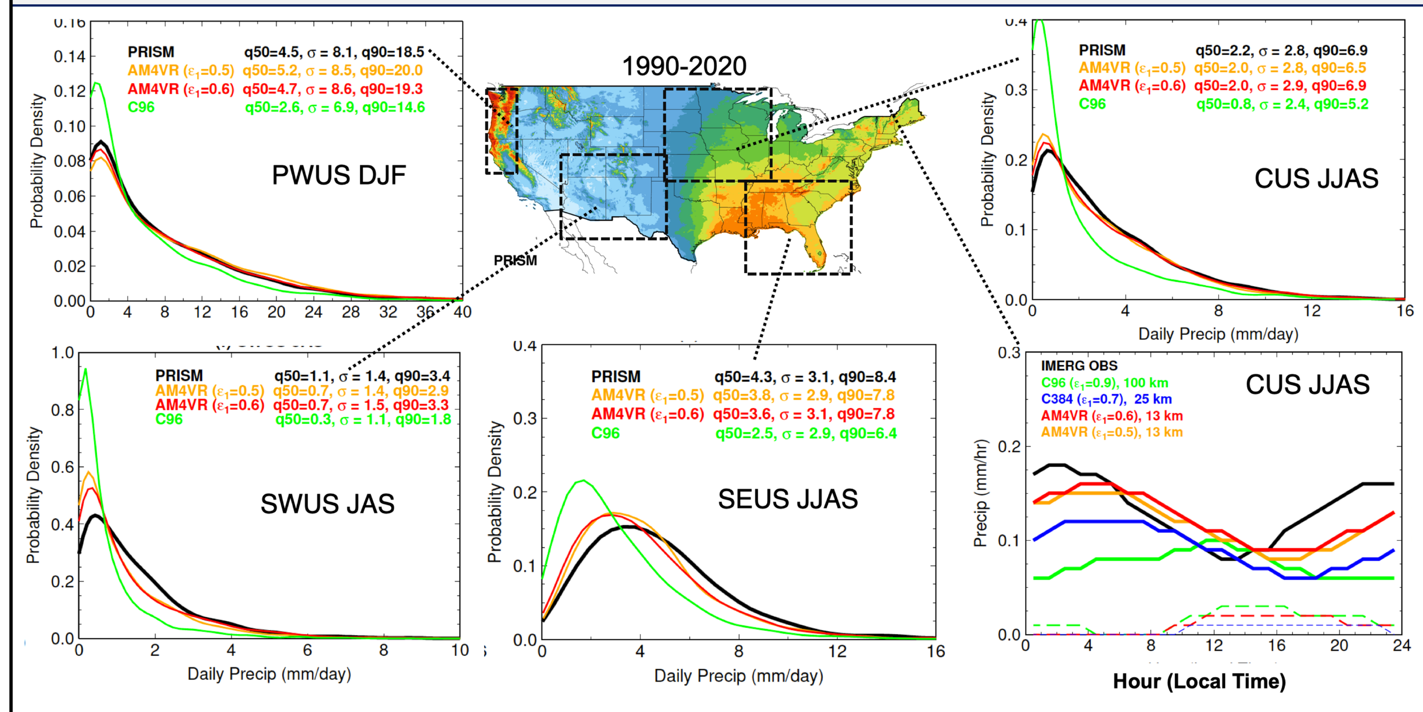




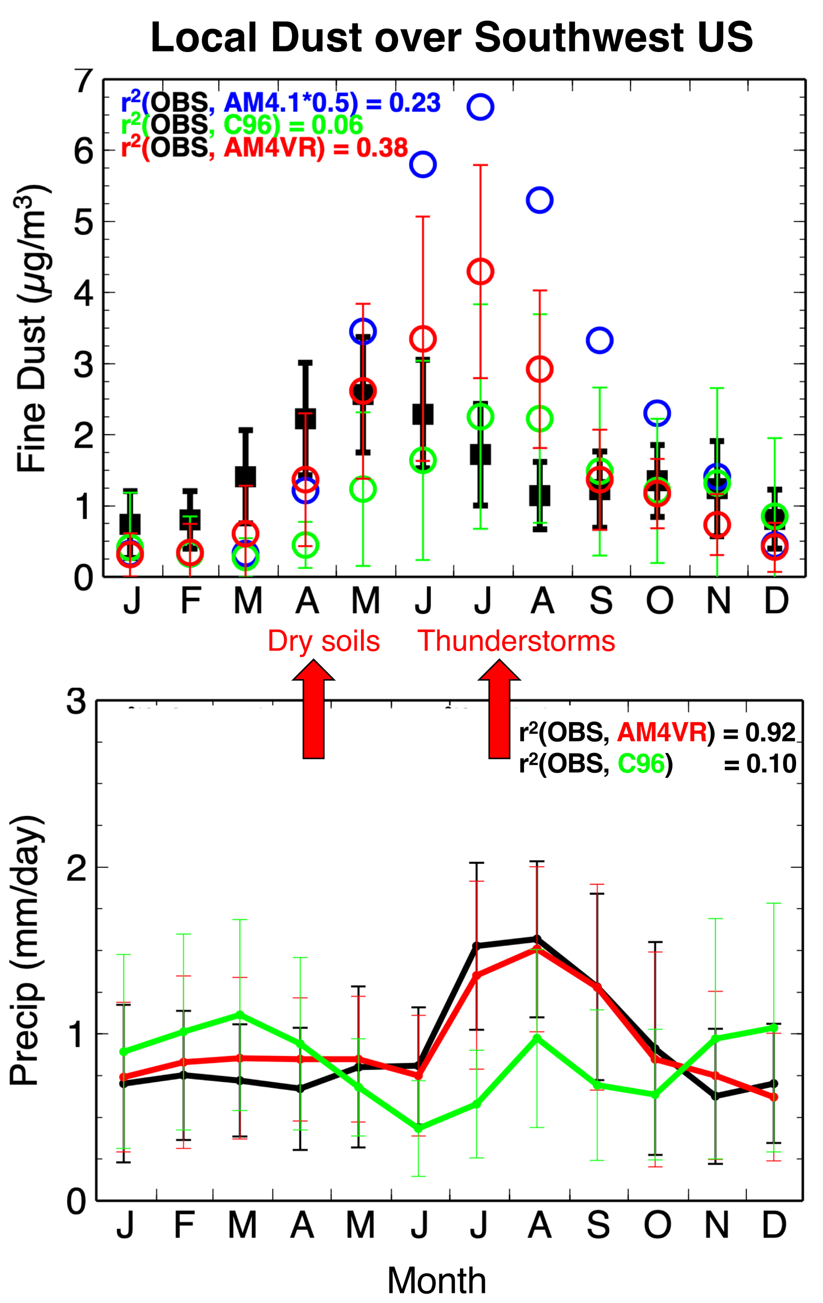


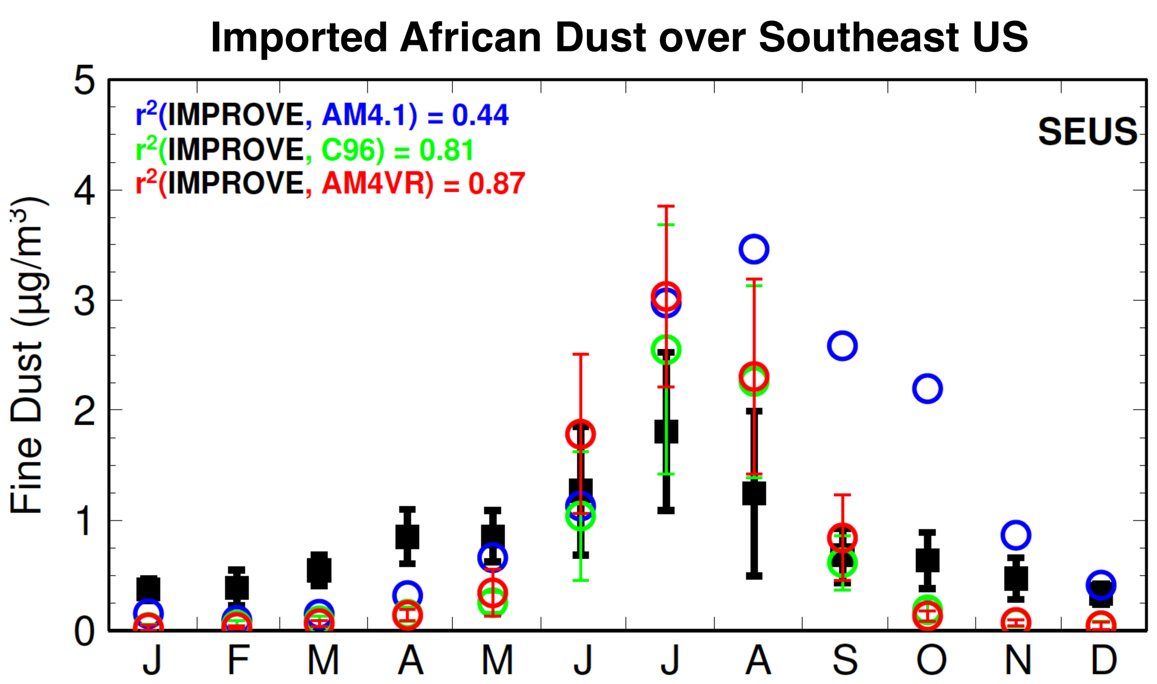
Lin et al. (submitted to GRL, 2024)

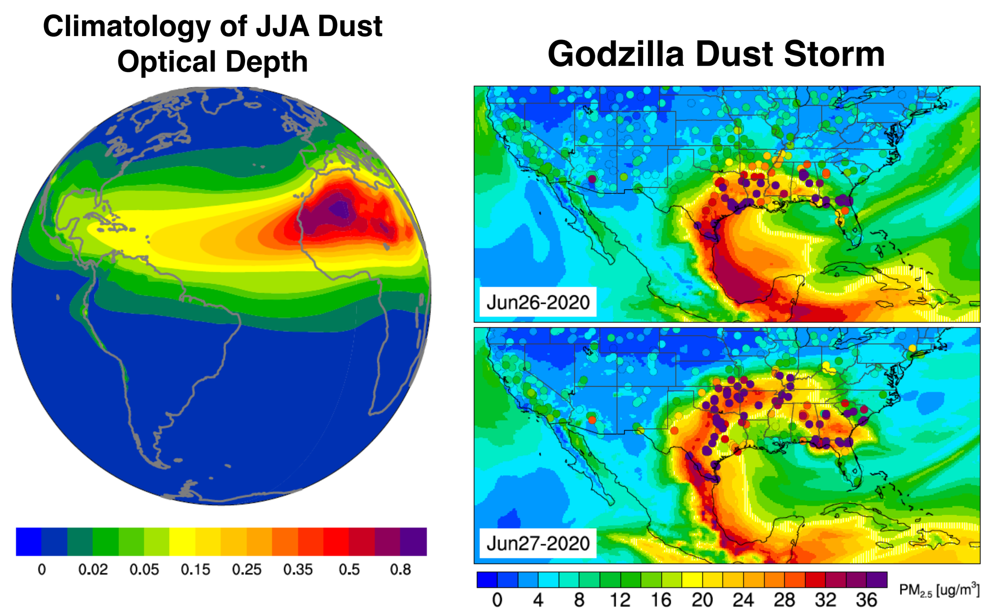
Improved representation of U.S. rainfall extremes and drought



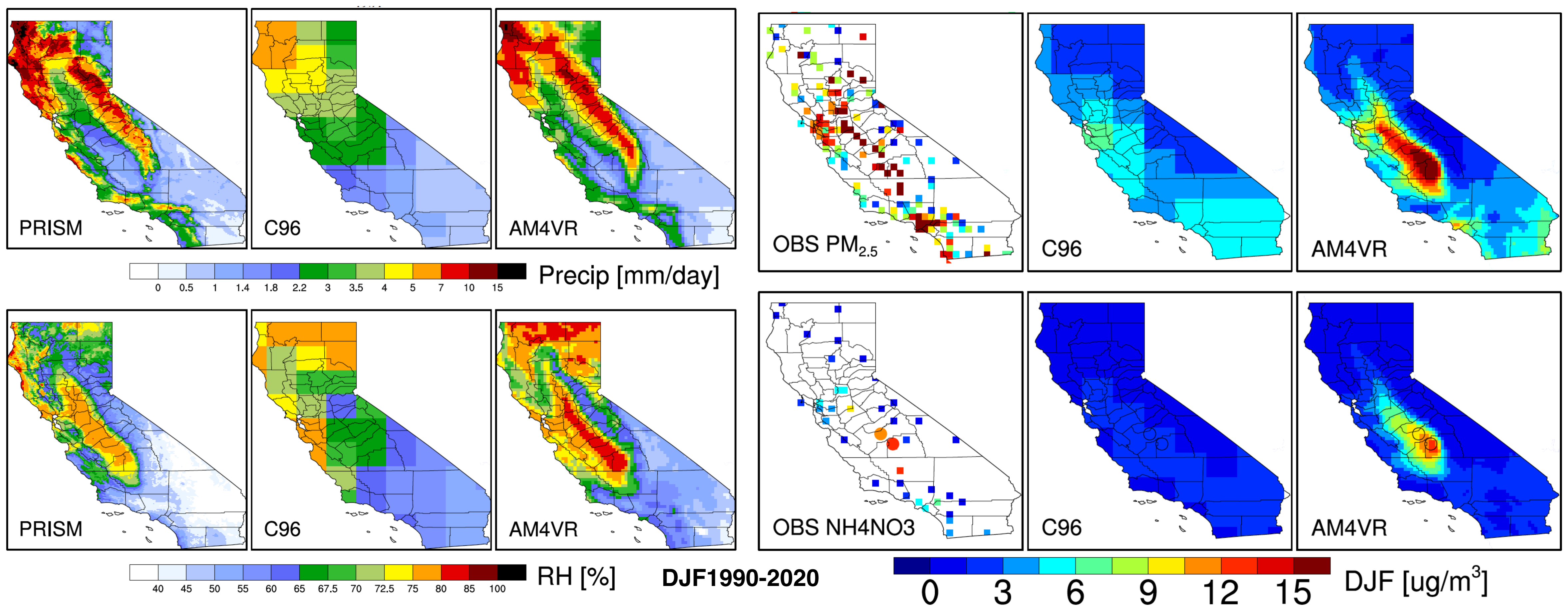
Seamless prediction of local and intercontinental sources of dust





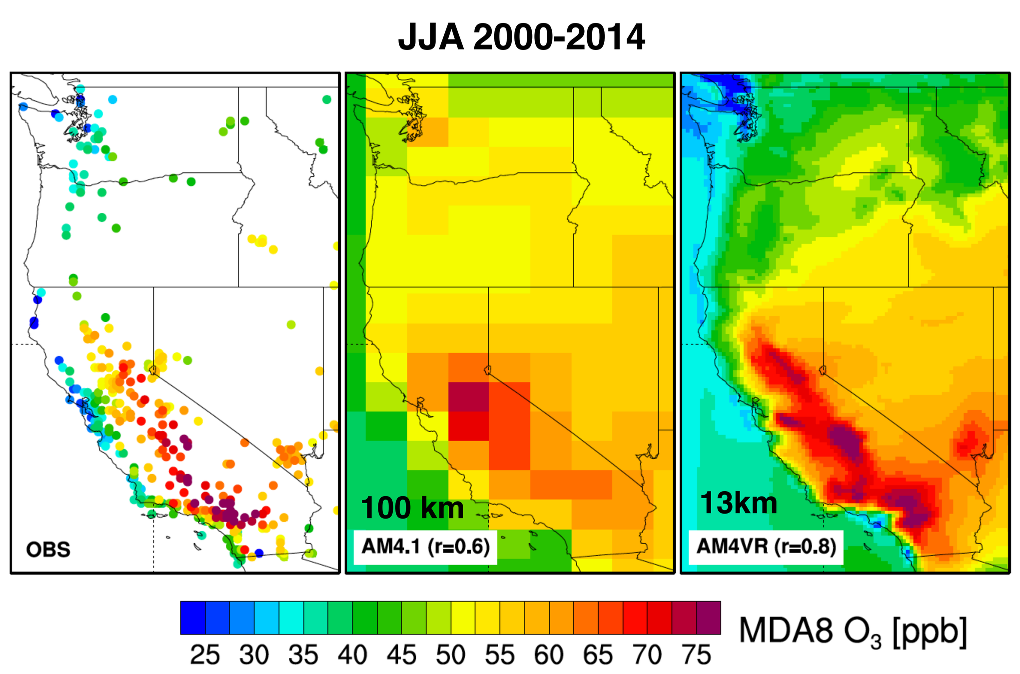


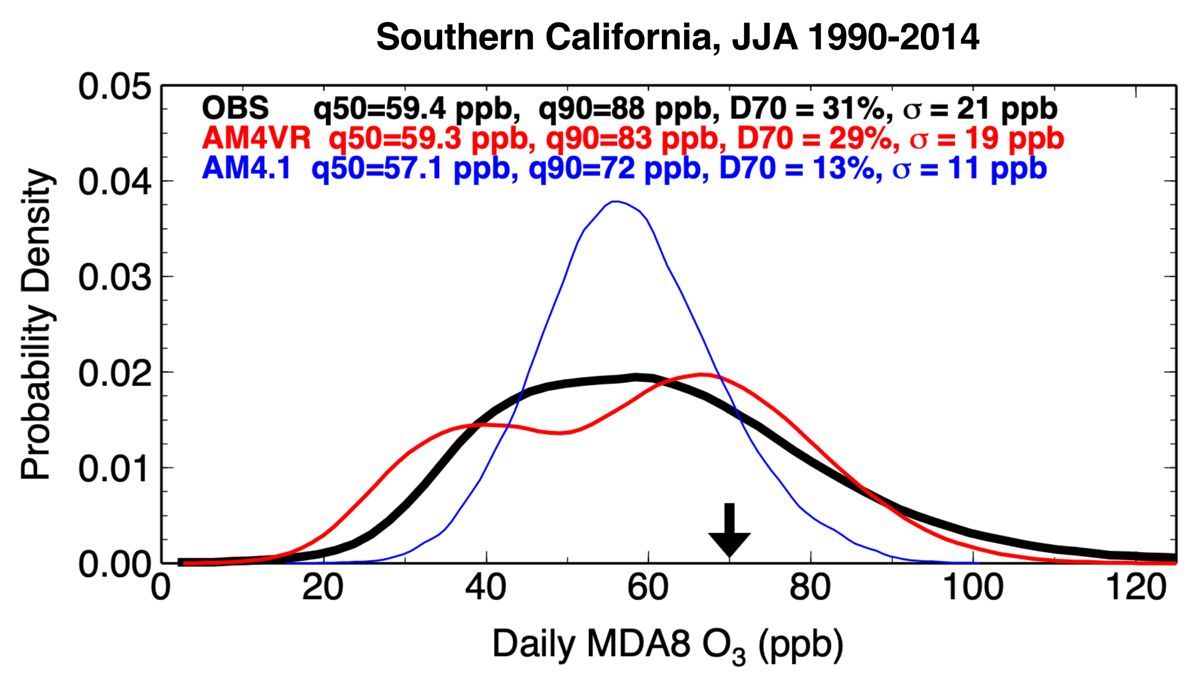
Winter haze and formation of Tule fog in the central valley



- Strong temperature inversion traps NH_3 and NO_x emissions to form ammonium nitrate aerosol (NH_4NO_3).
- Formation of fog requires moisture, cooling, and aerosols. But Tule fog occurs more frequently in the warmer and drier San Joaquin Valley, indicating that NH_4NO_3 aerosol acts as an efficient CCN for fog formation under low supersaturation.

Improved representation of ozone air pollution extremes over California





NOVEL APPLICATIONS & ONGOING DEVELOPMENTS

- Seasonal predictability of US air quality extremes
- Global dimensions to U.S. urban air quality in a changing climate
- Dynamic wildfire plume injection height (A. Pouyaei)
- Interactive wildfire emissions from land coupled to atm. chemistry

Read more: Lin M. et al. (JAMES, 2023MS003984, PDF Full Text)