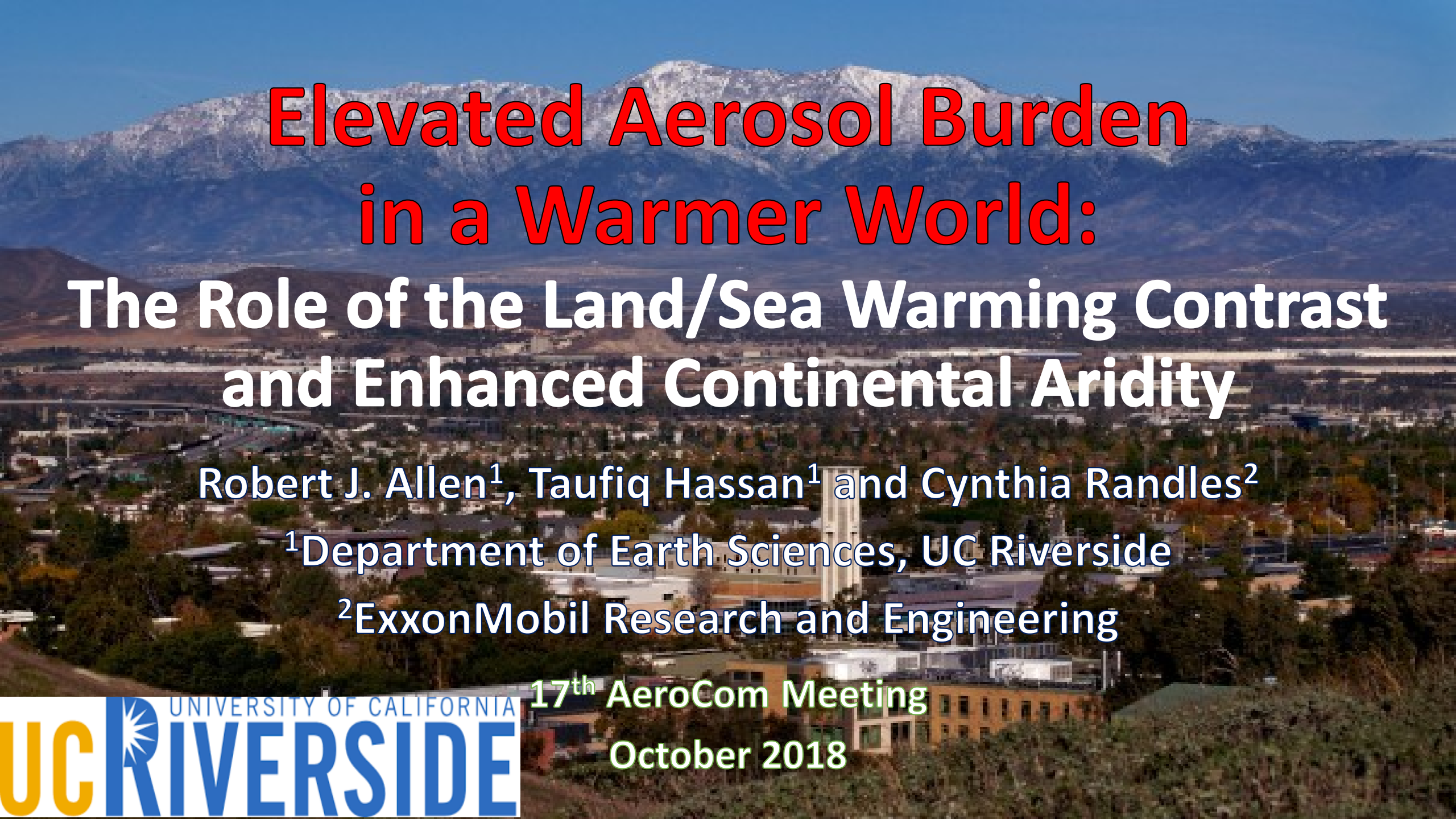

Elevated Aerosol Burden in a Warmer World:

The Role of the Land/Sea Warming Contrast and Enhanced Continental Aridity

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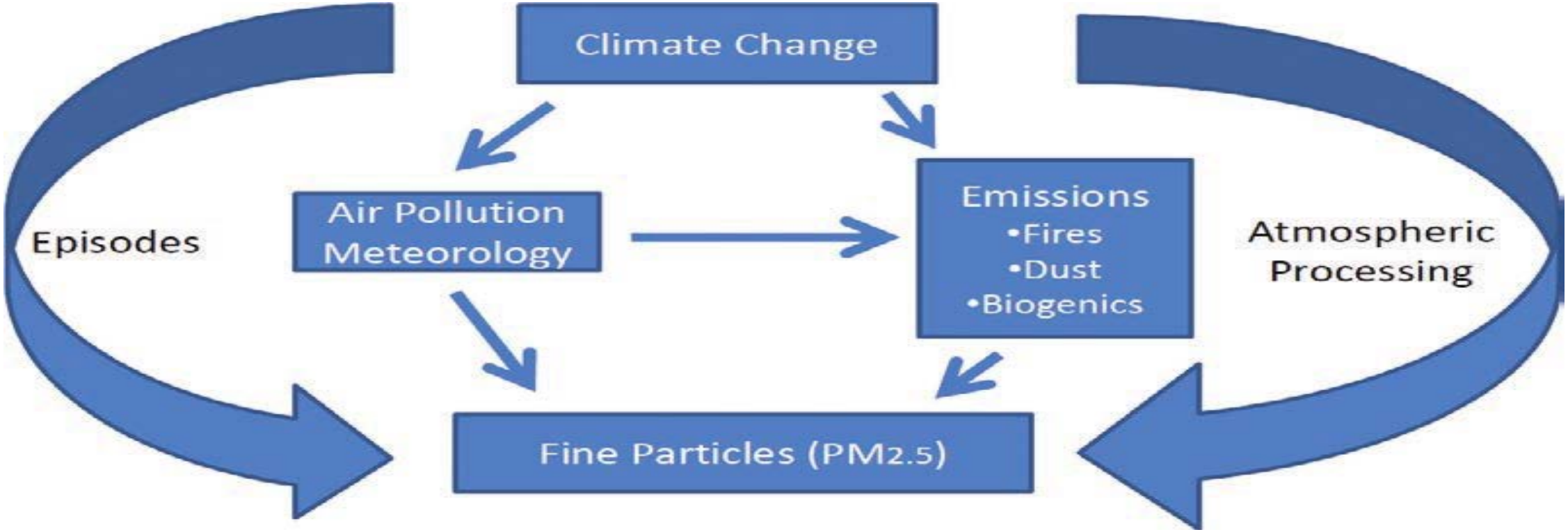
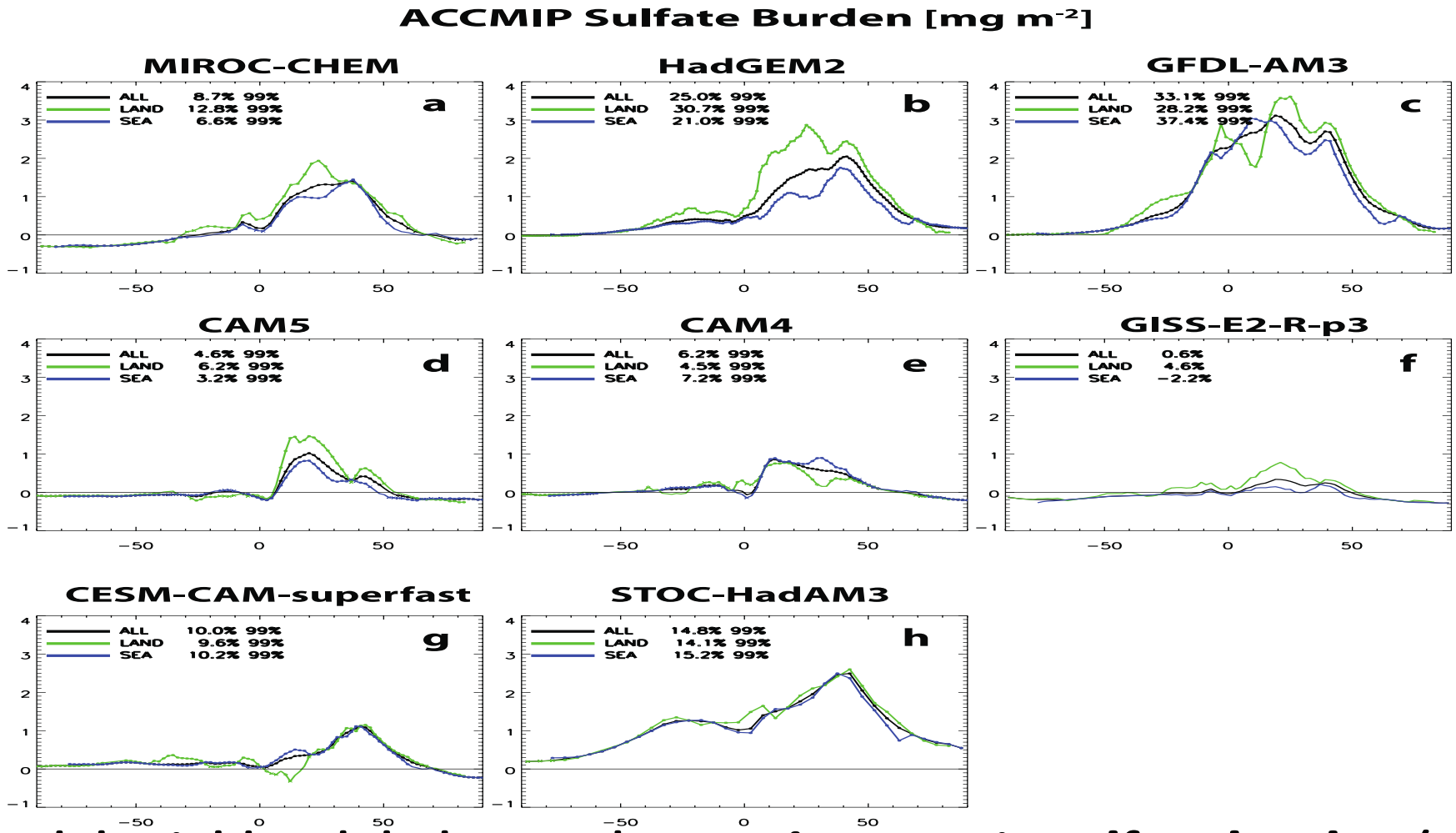
Impacts of Climate Change on Aerosols



- **Physical** → temperature, humidity, precipitation, soil moisture, wind speed, sea-ice extent
- **Chemical** → availability of oxidants; chemical production pathways
- **Biological** → vegetation cover/properties, plankton abundance

Dawson et al., BAMS 2014

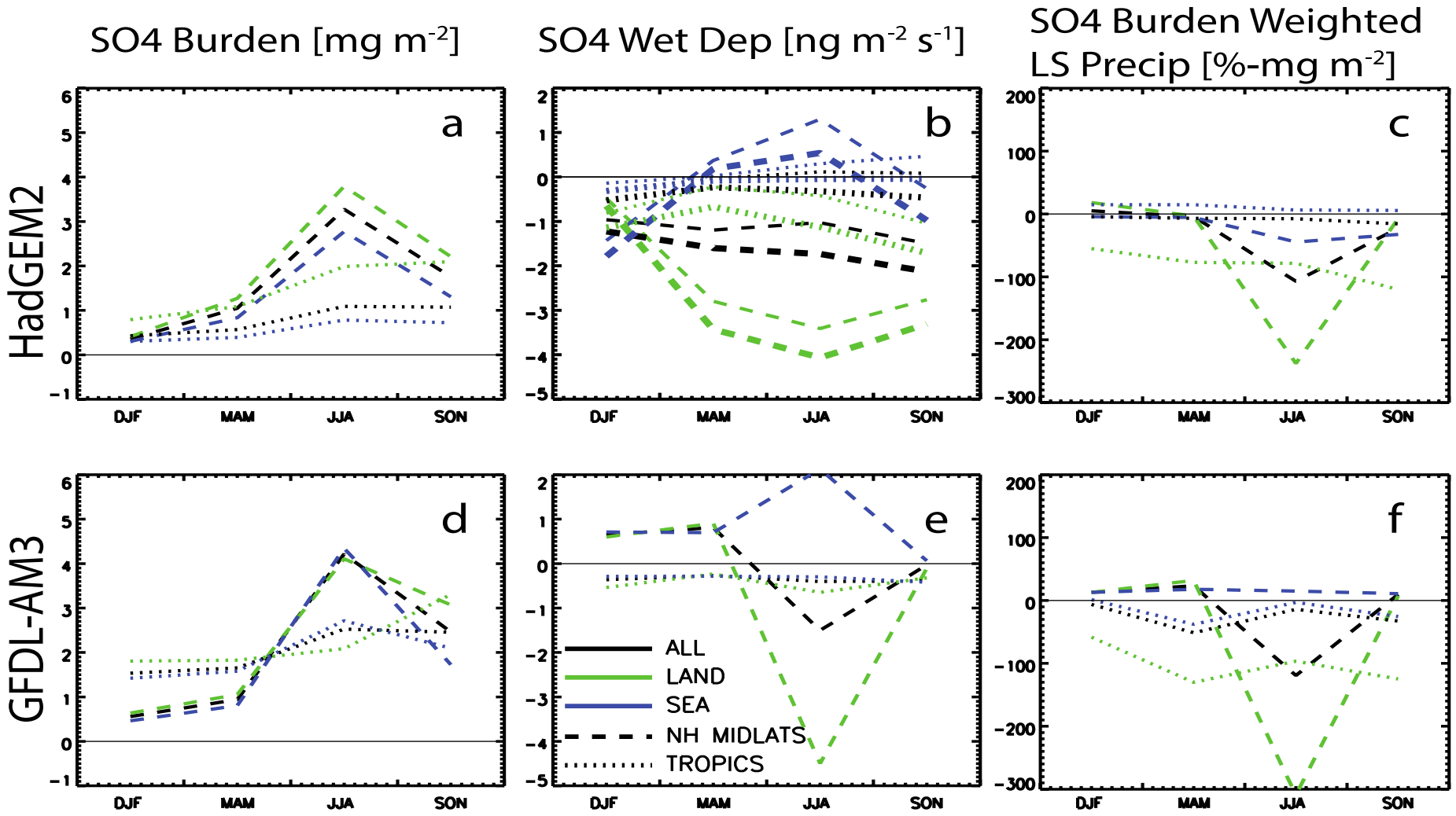
Prior ACCMIP Results: 2100 Warming Response for Sulfate Burden



- All **ACCMIP** models yield a global annual mean ***increase*** in **sulfate burden** (and surface concentration) in a ***warmer world*** → **12.9%** with a range from **0.6 to 33%.**
- **Increase** largest in the NH, especially the **NH mid-latitudes**.
- Generally similar responses for BC and POA.

Allen et al., Nat. Clim. Change 2015

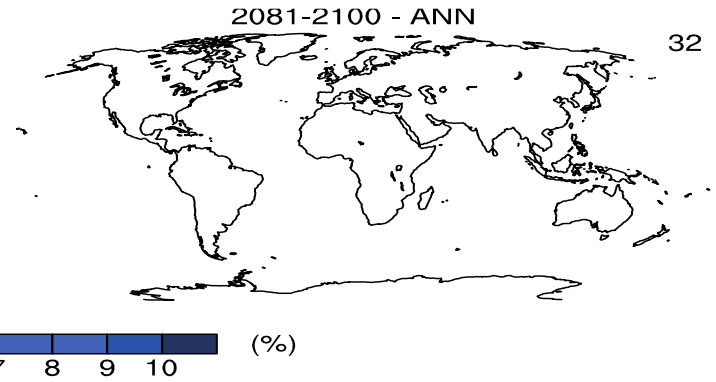
Prior ACCMIP Results: Sulfate Burden & Wet Removal



- Aerosol **Increase** largest during ***JJA*** over **NH mid-latitude continents.**
- Corresponding ***maximum*** **decrease** in **wet removal** (esp. due to **LS P**) **& burden-weighted LS P.**

Allen et al., Nat. Clim. Change 2015

Toward a Better Understanding of Mechanisms: Land/Sea Warming Contrast & Enhanced Continental Aridity



- Models project ***enhanced warming*** over land, and ***increased*** aridity.
  - *Reductions* in land **RH** and **soil moisture** (and other hydrological variables).
  - Saturated water vapor concentration exceeds growth in actual water vapor concentration.
- Does this contribute to the aerosol increase in response to warming?

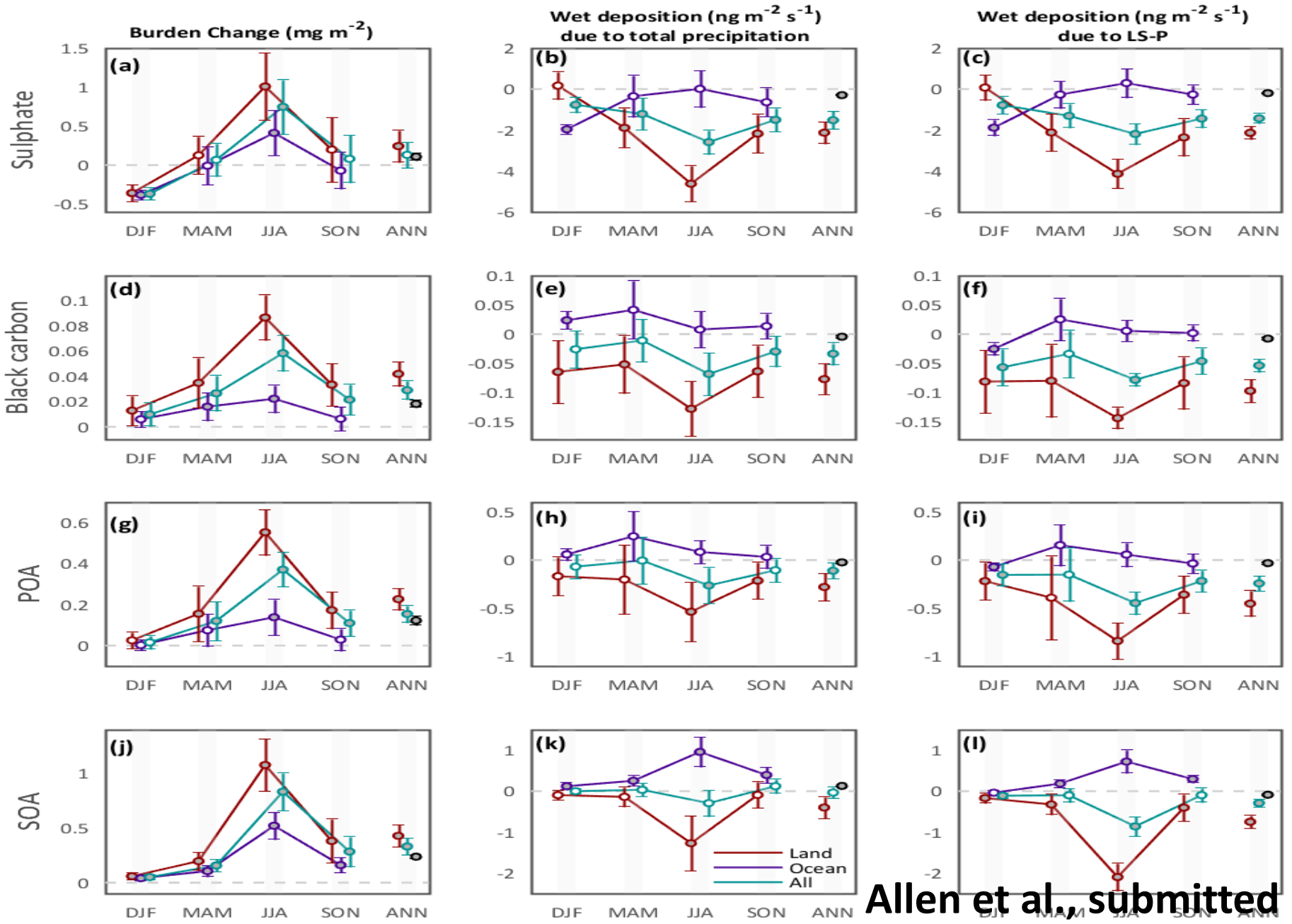
e.g., Joshi et al., 2008; Collins et al., 2013; Feng and Fu, 2013; Sherwood and Fu, 2014

CAM5 Experimental Design

- To evaluate how/why aerosol burden responds to warming:
  - Two 10-year CAM5 simulations with identical aerosol emissions.
  - One based on a present-day climate (SSTs, sea-ice, GHGs).
    - Similar to **ACCMIP Em2000Cl2000** simulations.
  - One based on a warmer climate (e.g., RCP8.5 2100).
    - Similar to **ACCMIP Em2000Cl2100** simulations.
- To evaluate the importance of enhanced land warming:
  - Muted land warming simulations:
    - Identical RCP8.5 2100 simulation, but near-surface land temperatures are nudged to the control (present-day) simulation.
  - Enhanced land warming simulations:
    - Identical control (present-day) simulation, but near surface land temperatures are nudged to those simulated under an RCP8.5 2150 scenario.
  - Three separate nudging simulations with nudging strengths of:
    - 1%, 2.5% and 5%.

CAM5 2100 Warming: ΔNH Mid-Latitude Aerosol & Wet Removal

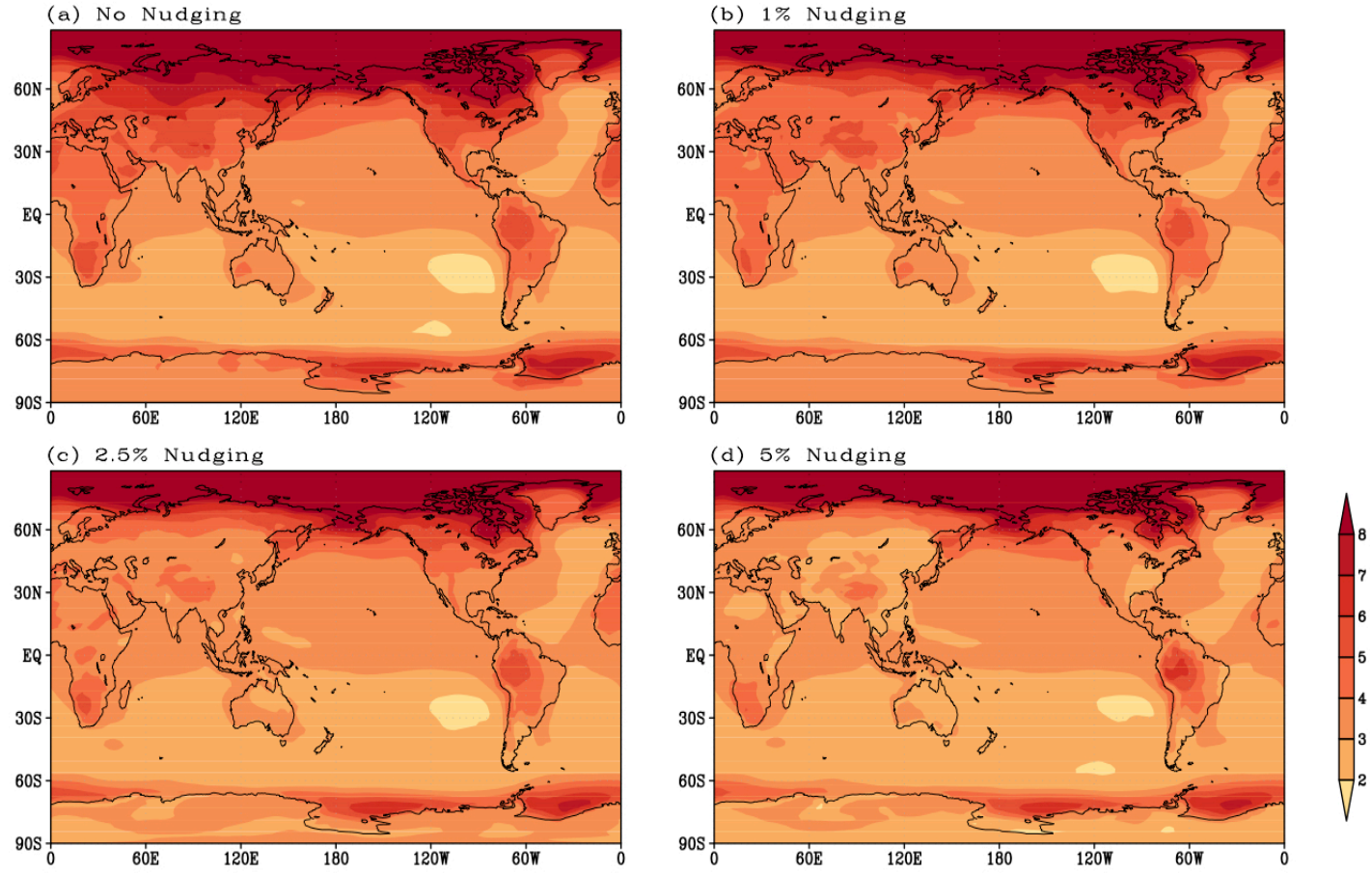
- Similar response in CAM5 for **all** anthropogenic aerosol species.
  - Global ANN aerosol *increase*.
- **Increase** largest during *JJA* over **NH mid-latitude continents**.
- Corresponding ***maximum*** **decrease** in **wet removal,** esp. due to LS P.



Allen et al., submitted

Muted Land Warming: ΔANN Lower-Tropospheric T

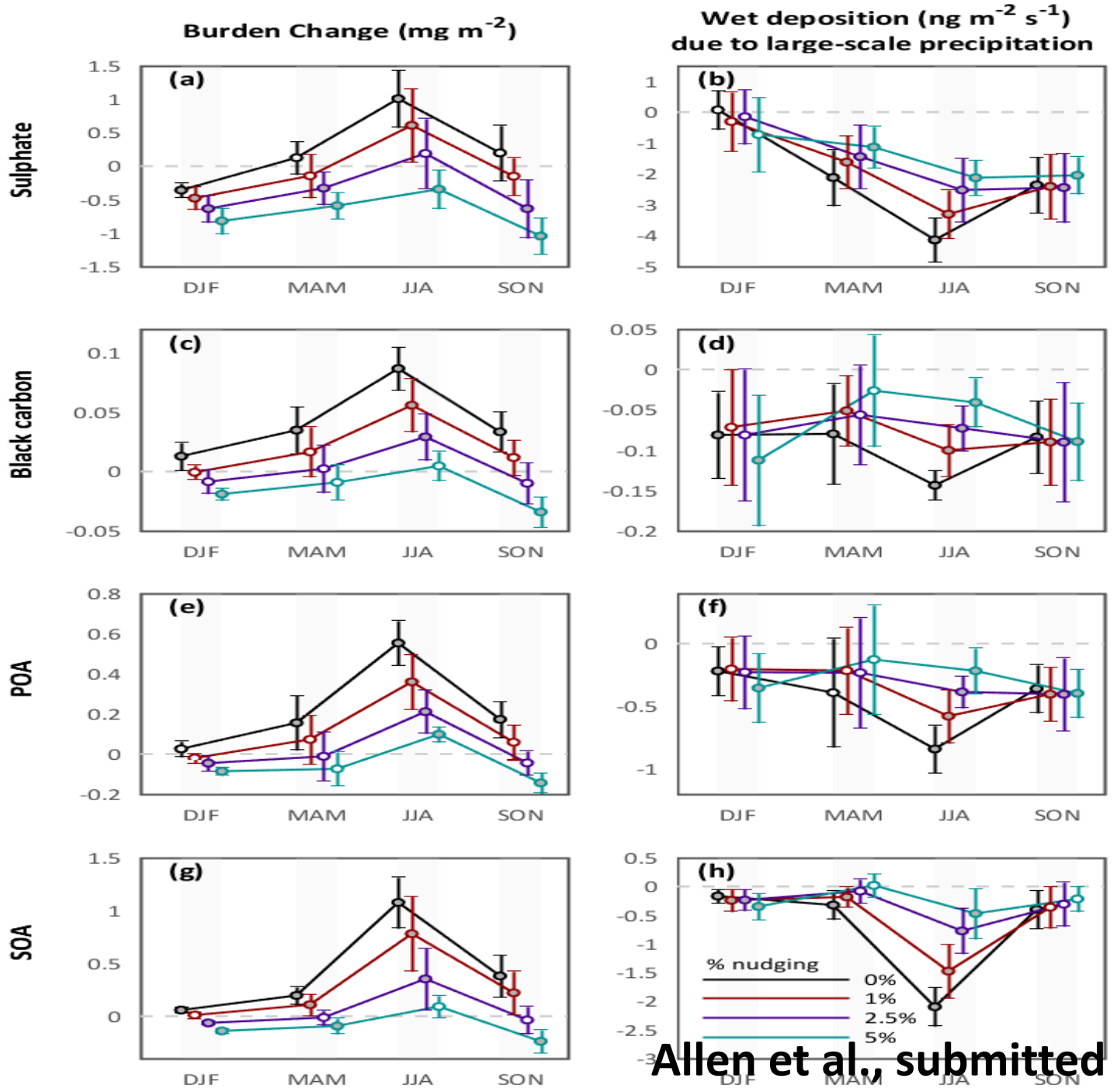
- In response to GHGs, land *warms more than* ocean.
- Nudging simulations *weaken* the land-sea warming contrast.



Land/Sea Warming Ratios	Global	NH-Mid Latitudes	Tropics
No Nudging	1.46	1.40	1.38
1% Nudging	1.34	1.25	1.32
2.5% Nudging	1.21	1.09	1.23
5% Nudging	1.08	0.93	1.14
ΔWR with 5% nudging (%)	25.8	33.2	17.8

Muted Land Warming: ΔAerosol & Wet Removal over NH Mid-Latitude Continents

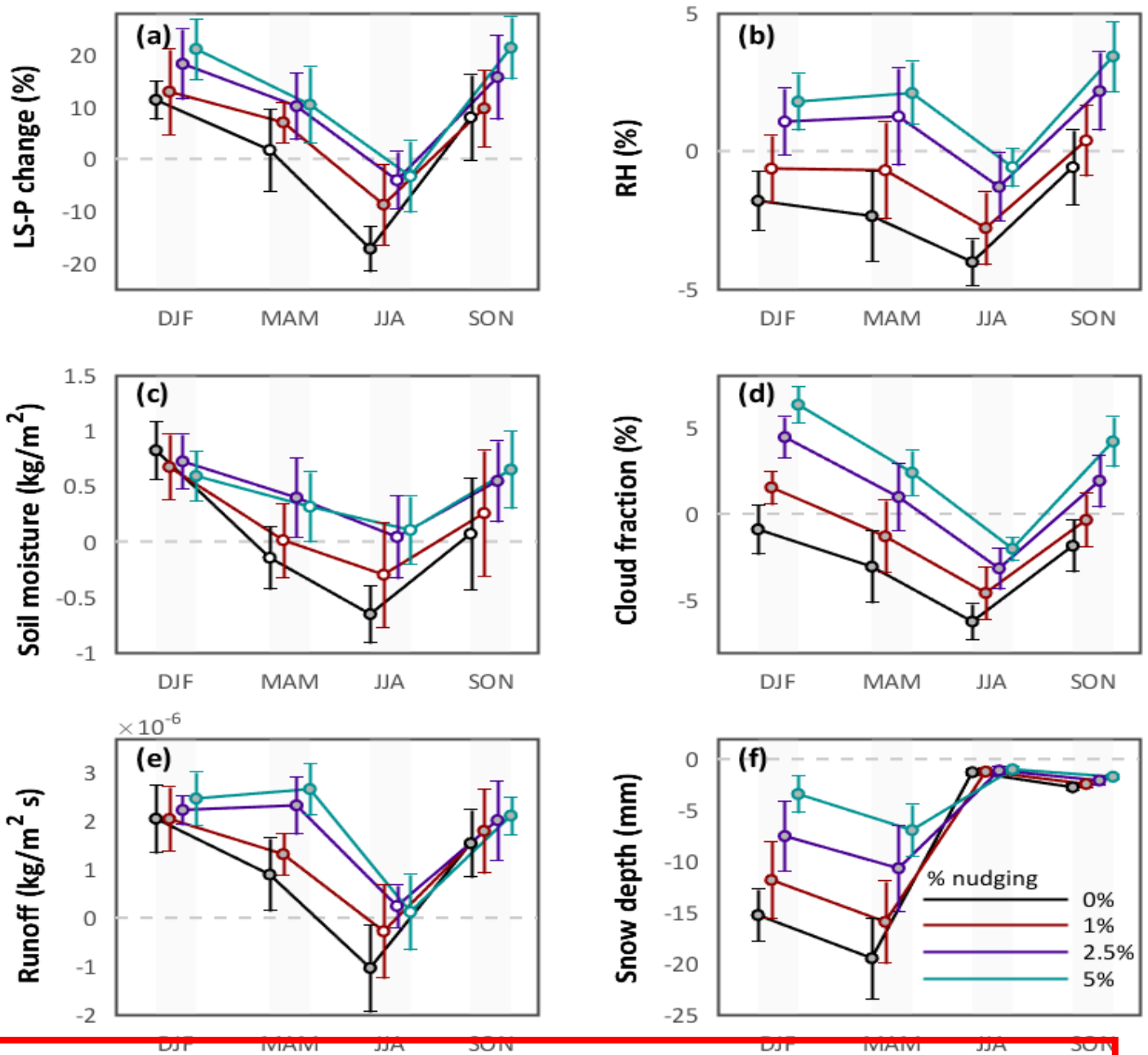
- When the land-sea warming contrast is *muted*:
  - The *increase* in anthropogenic aerosol species is *weakened*.
  - The *decrease* in LS P wet removal is *weakened*.



Allen et al., submitted

Muted Land Warming: ΔHydrology over NH Mid-Latitude Continents

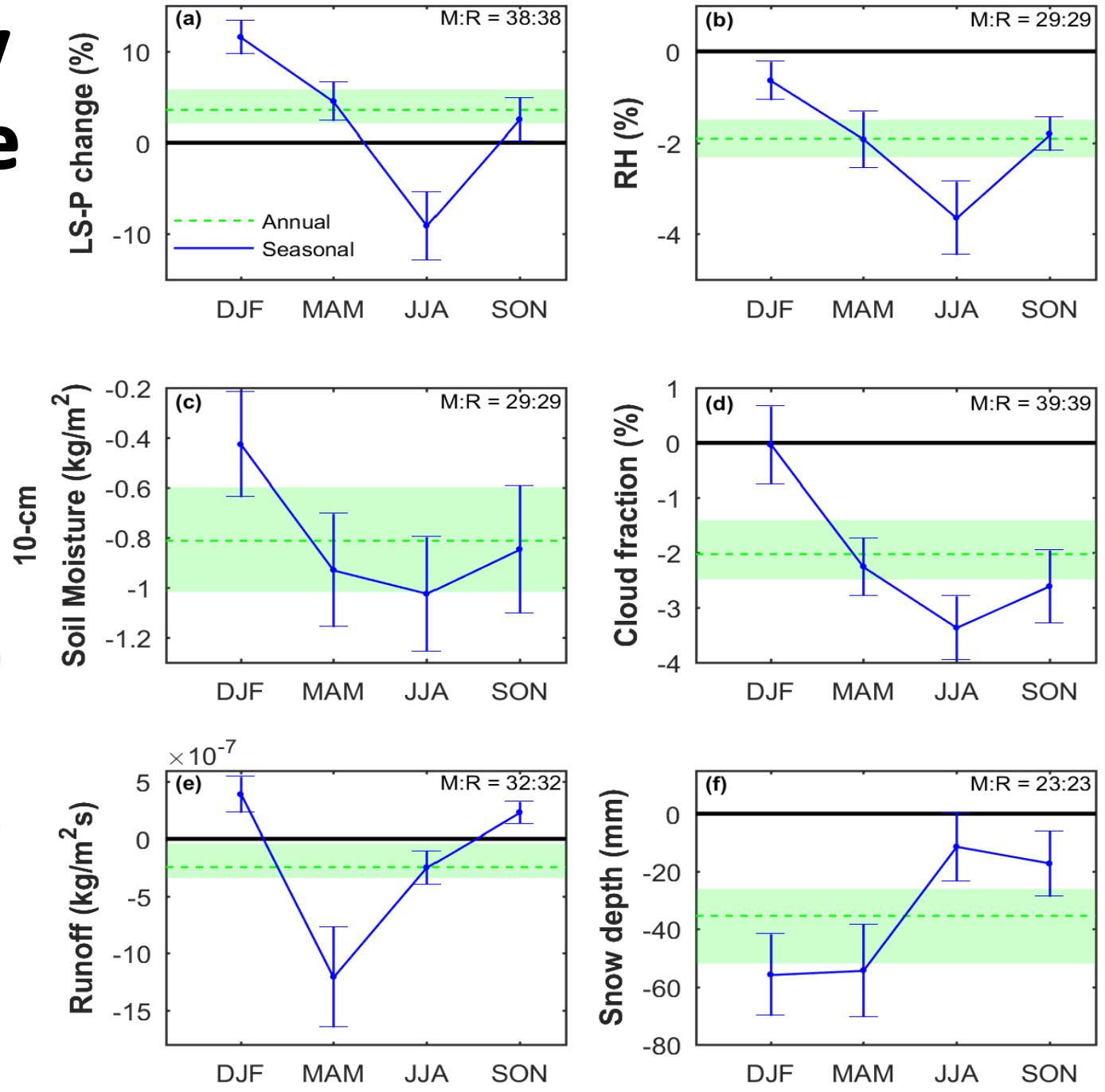
- The **JJA** ***decrease*** is ***weakened*** for:
  - LS precipitation
  - Lower tropospheric RH
  - Soil moisture
  - Low clouds
  - Runoff
- **MAM** snow depth ***decrease*** is ***weakened***



Less land warming → less drying → muted increase in aerosols.

CMIP5: ΔHydrology over NH Mid-Latitude Continents

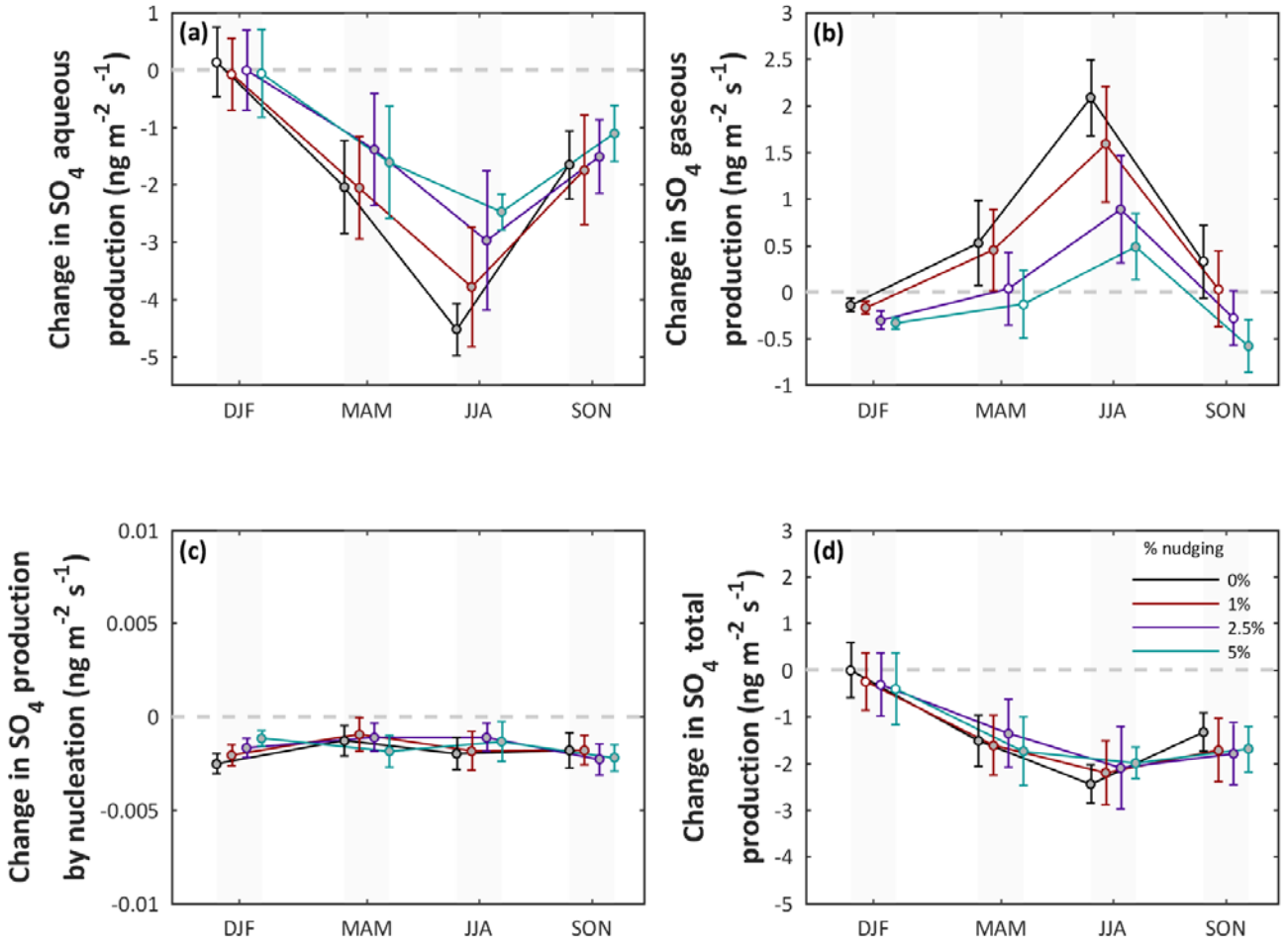
- CAM5 hydrological changes are generally consistent across **CMIP5 RCP8.5 models** (2090-2099 minus 2006-2015).



Muted Land Warming:

ΔSO_4 Chemistry over NH Mid-latitude Continents

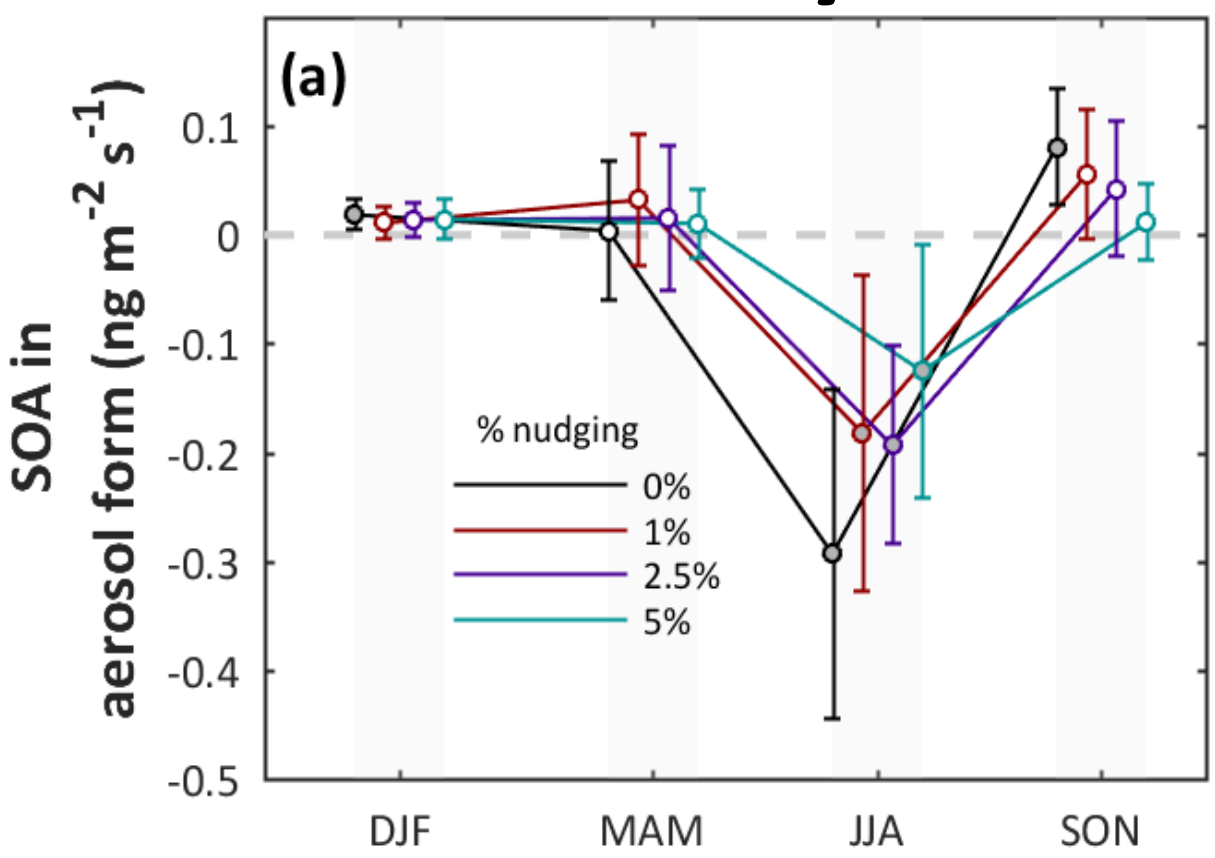
- ***Aqueous*** SO_4 production ***decreases***, esp. during **JJA**
  - Consistent w/ Δhydrology.
- Partially offset by ***increases*** in ***gasesous*** SO_4 production.
- Total SO_4 chemical production ***decreases***!

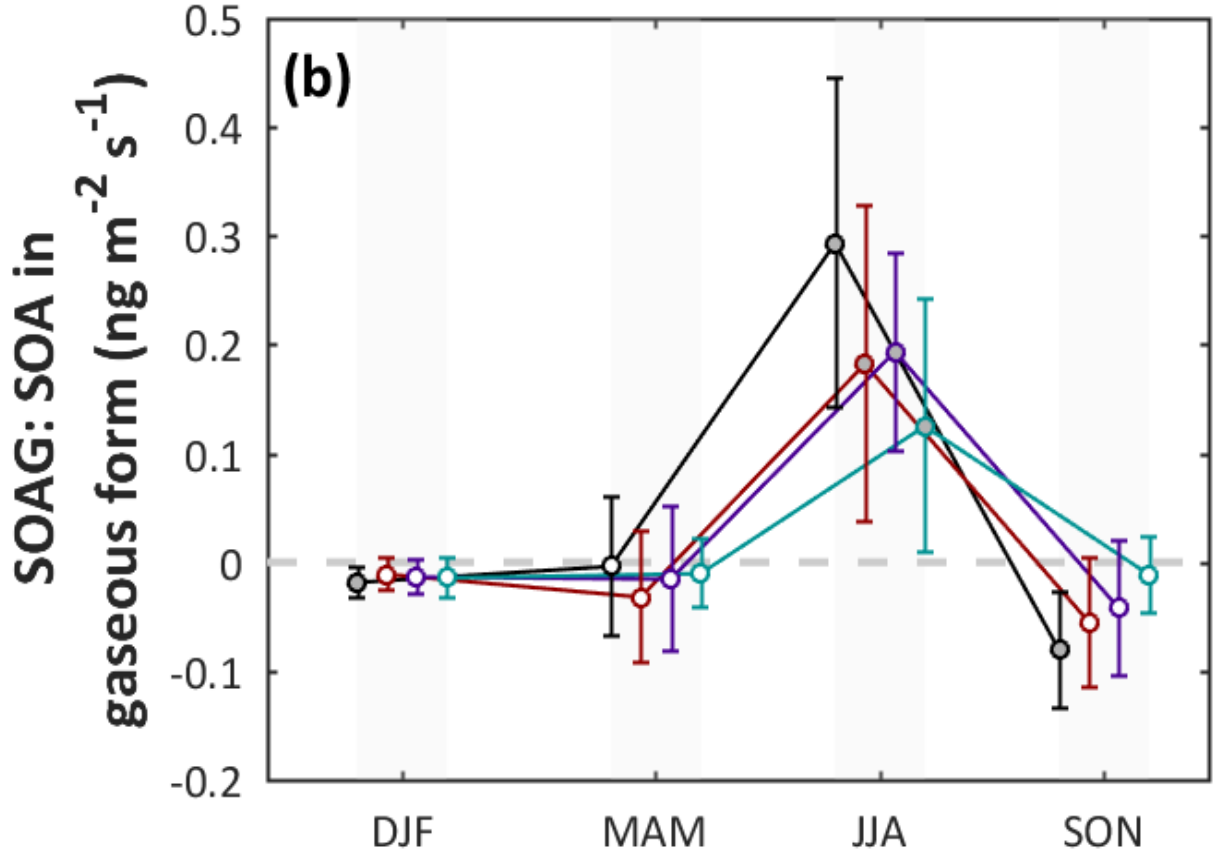


ΔChemical production not responsible for the ***increase*** in SO_4.

Muted Land Warming:

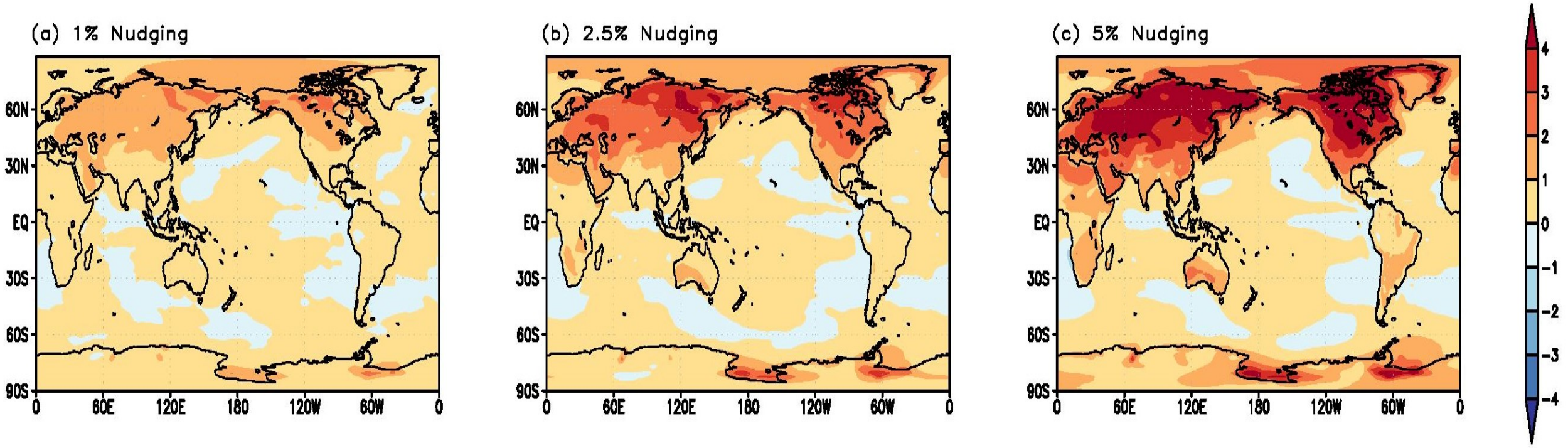
ΔSOA Chemistry over NH Mid-latitude Continents





- Total SOA production *decreases*, esp. during **JJA**.
- **ΔChemical production** not responsible for the *increase* in SOA.

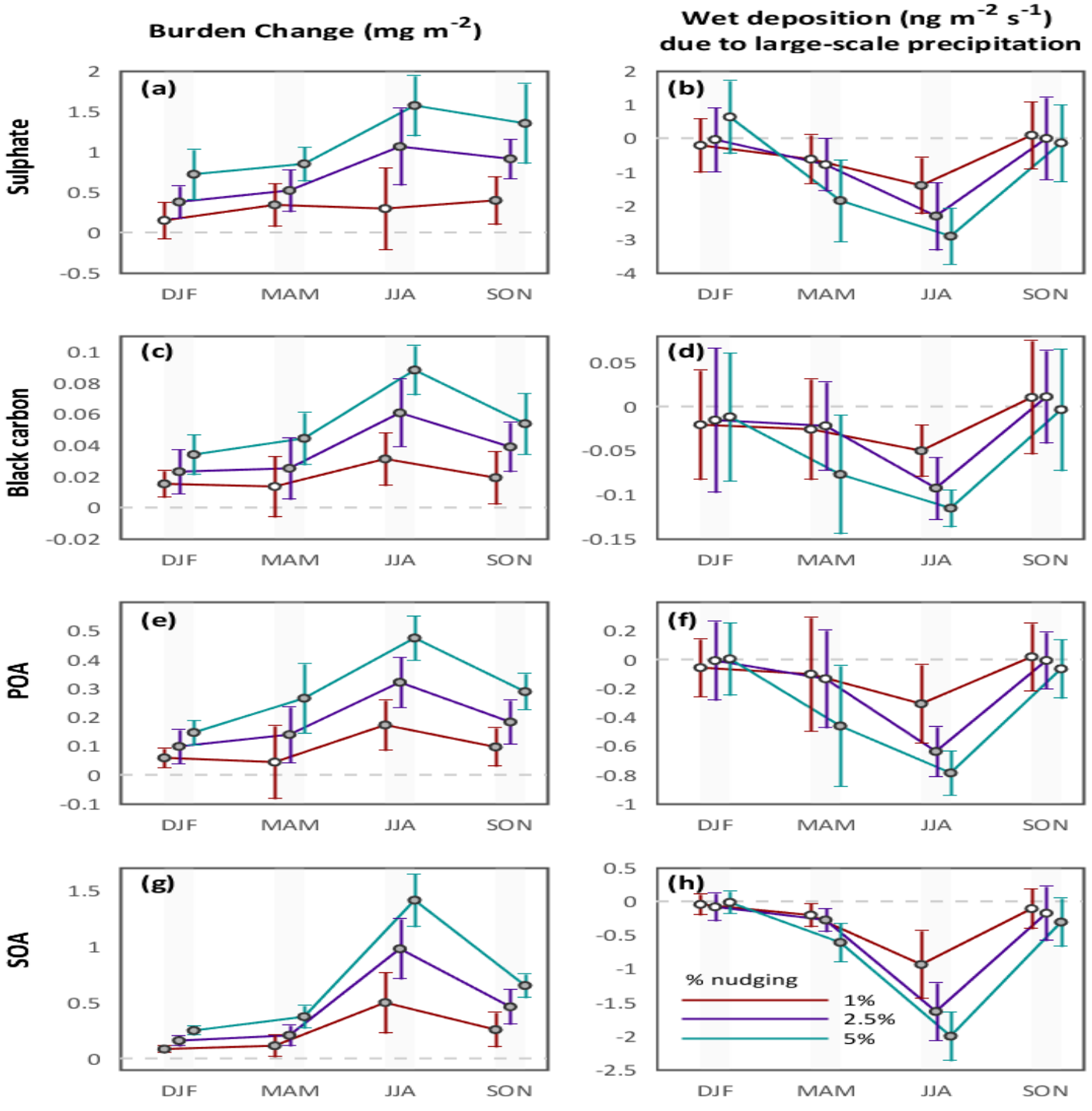
Enhanced Land Warming:
ΔANN Lower-Tropospheric T



- **Enhanced land warming** simulations ***increase*** the **land-sea warming contrast**.

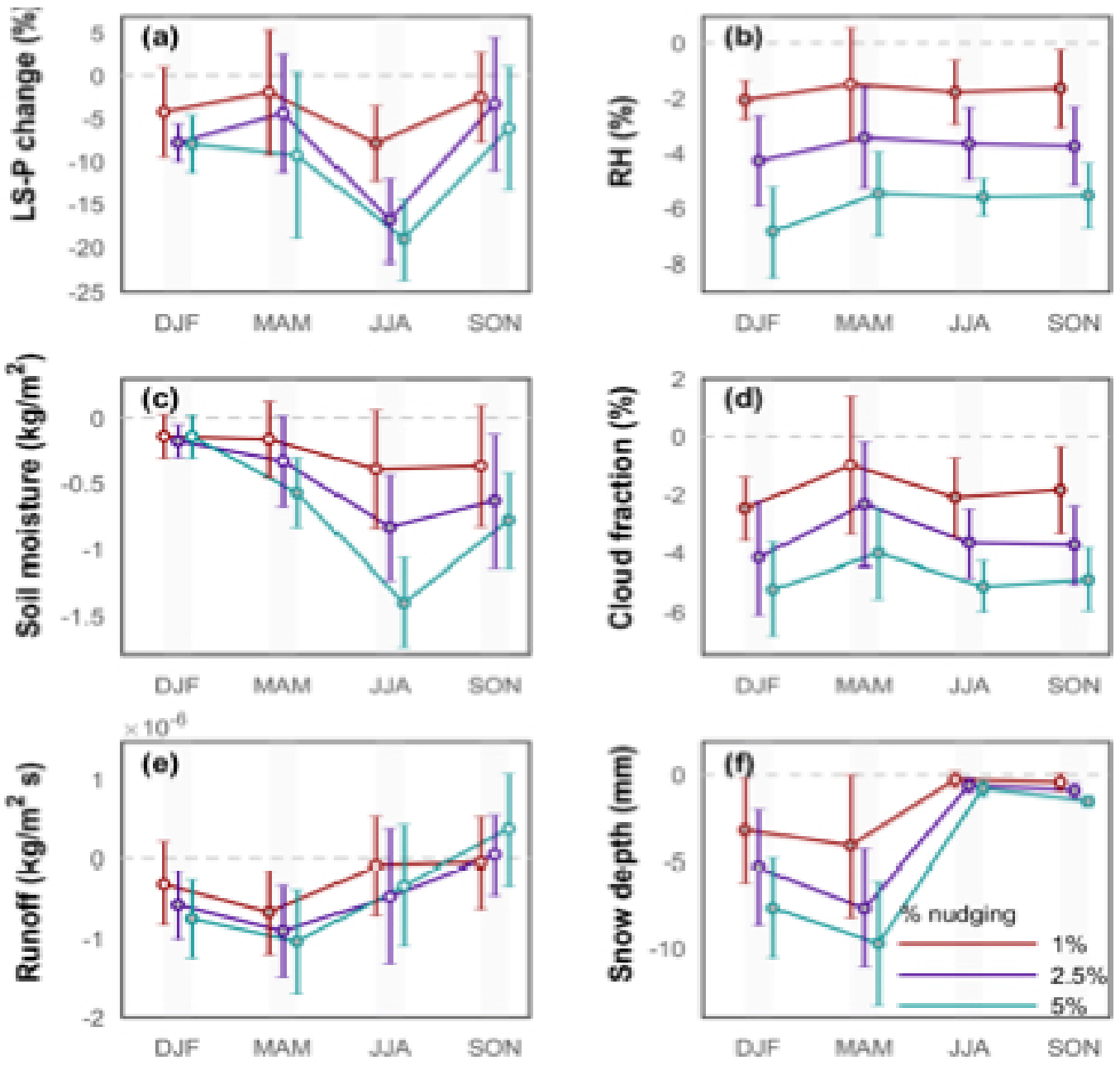
Enhanced Land Warming: ΔAerosol & Wet Removal over NH Mid-latitude Continents

- When the land-sea warming contrast is *enhanced*:
  - Anthropogenic aerosol burden is *enhanced*, esp. during **JJA.**
  - LS P wet removal is *weakened*.



Enhanced Land Warming: ΔHydrology

- *Decreases* in:
  - LS precipitation
  - Lower tropospheric RH
  - Soil moisture
  - Low clouds
- **MAM** *decrease* in snow depth



***More* land *warming* → *more* drying → *larger increase* in aerosols.**

Conclusions

- State-of-the-art chemistry-climate models simulate a global ANN mean ***increase*** in ***most*** aerosol species under warming.
  - ***Largest increase*** over the **NH mid-latitude continents** during **JJA**.
- Targeted CAM5 simulations show this response is due to the land-sea warming contrast and associated summertime drying.
- **Muting** the **warming contrast** ***weakens*** the aerosol burden ***increase.***
  - ***Smaller decreases*** in soil moisture, runoff, low clouds, lower-tropospheric RH, LS P (and associated wet removal).
- **Land warming** alone yields ***increased*** aerosol burden.
  - ***Decreased*** soil moisture, low clouds, lower-tropospheric RH, and LS P (and wet removal).
- Future work:
  - Analyze new simulations (CMIP6; AerChemMIP)
  - Perform similar nudging experiments with additional models (GFDL, ECHAM, UKESM, others?).

We have linked model projections of ***enhanced*** **aerosol burden** to a **robust climate change signal** → **enhanced land warming.**