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Wintertime hydro-dynamic response to anthropogenic aerosols along the Pacific Coast of North America

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Abstract

Previous studies show anthropogenic aerosols (AAs) can perturb regional precipitation changes, particular in the tropics. For example, the build-up of anthropogenic aerosols (AAs) over the 20^{th} century is found to lead to the southward shift of tropical rain belt and mid-1980s Sahel and Amazonia droughts. The 20^{th} century weakening of Asian monsoon is also suggested to be related to AAs. In the Northern Hemisphere mid-latitudes, however, the impact of AAs on regional climate and precipitation remains uncertain. This work investigates the influence of AAs on wintertime precipitation along the North America Pacific Coast using the Coupled Model Intercomparison Project phase 6 (CMIP6) archive. Responses to historical AA emissions, as well as to the projected AA emission reduction, are investigated.

Data & Method

- Model simulations come from CMIP6 archive. Historical AA-only simulations and historical all-forcing simulations are from the same 89 realizations of 13 CMIP6 models. Historical greenhouse gas (GHG) only simulations used are from 84 realizations of 12 CMIP6 models.
- Fixed sea surface temperature (SST) experiments, including piClim-histaer, histSST and histSST-piAer are used to quantify the aerosol transient effective radiative forcing (ERF). Four to six models for each experiment are available, dependent on data availability. histSST-aer is estimated as the difference between the histSST and histSST-piAaer simulations.
- Historical simulations are extended to 2100 following the CMIP6 Shared Socioeconomic Pathway 2-4.5 scenario. Limited by availability, the 21^{st} century analysis uses 13 realizations from 2 models.
- All data are spatially interpolated to 2.5° by 2.5° horizontal resolution.
- The long-term monthly means are removed from all data.
- Wintertime is defined as December-January-February (DJF).
- Model means are calculated by averaging over all realizations for a given model. The model agreement on the sign of the change is estimated at each grid box as the percentage of the models that yield a positive (increase) or negative (decrease) trend.

Precipitation responses to historical emissions

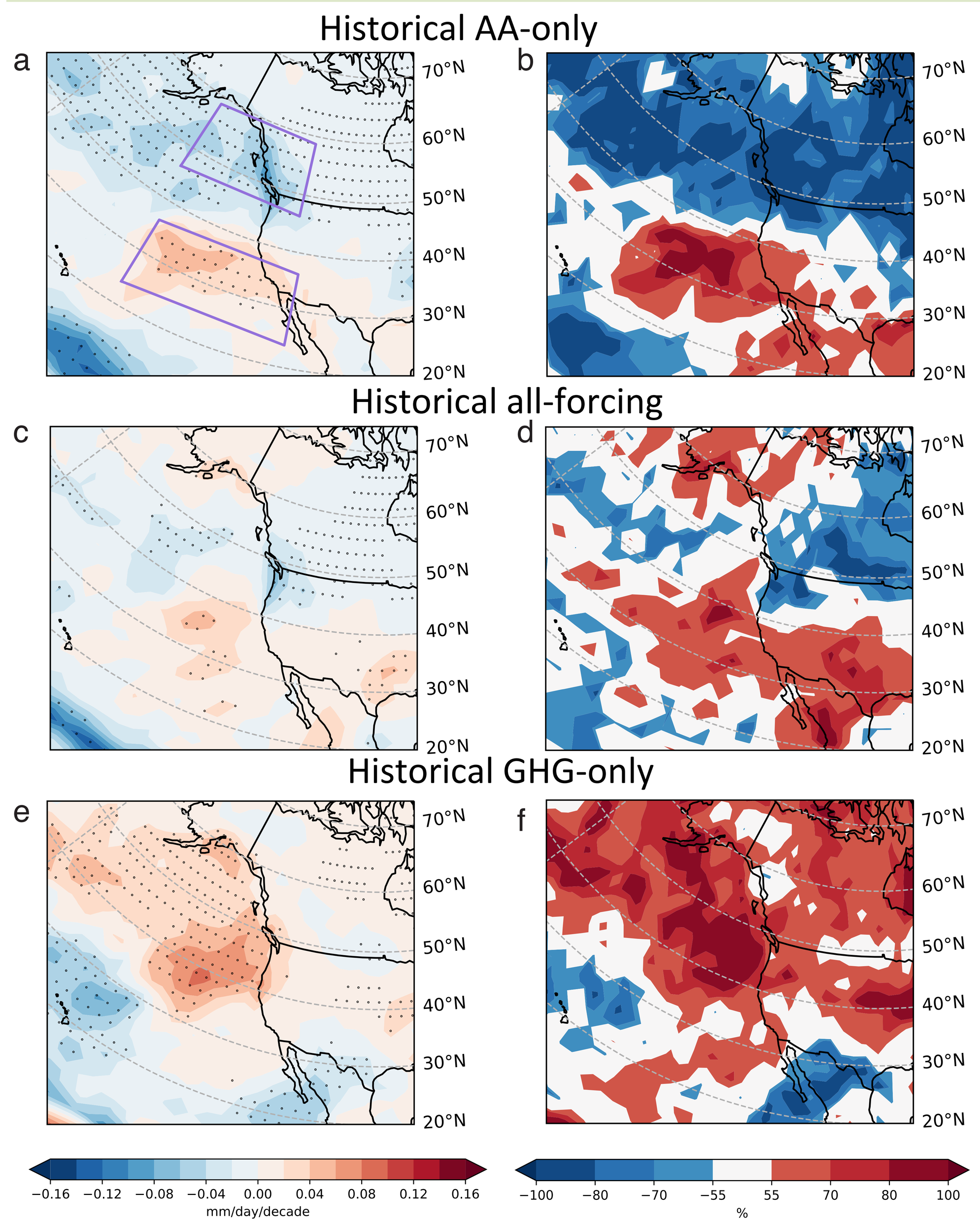

Fig 1. CMIP6 multi-model mean 1930-1975 wintertime precipitation response (a, c, e) and the corresponding model agreement (b, d, f; units of percent) on the sign of trend in (a, c, e). Red (blue) colors show the percentage of models that yield a positive (negative) trend of wintertime precipitation.

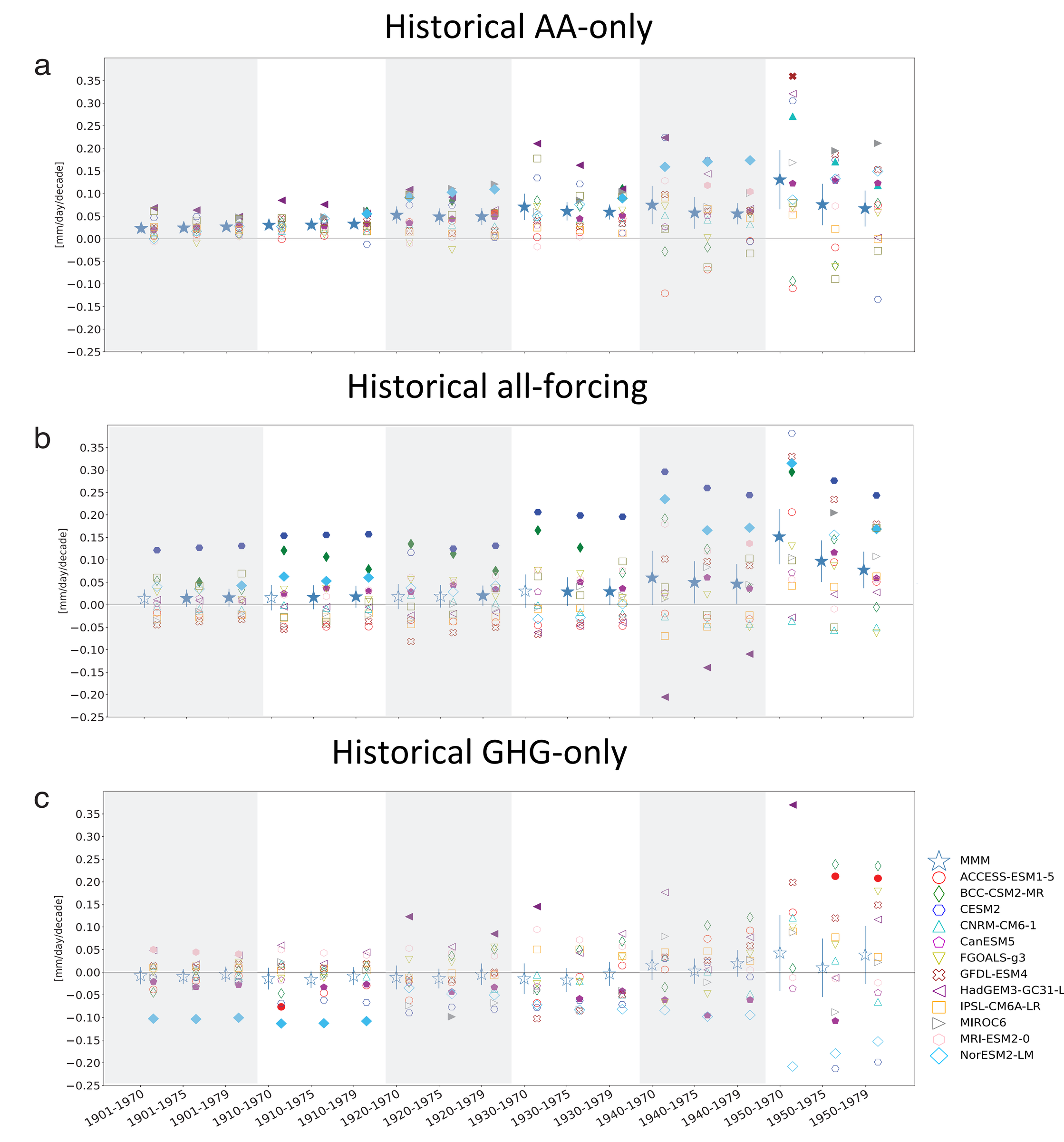

Fig 2.CMIP6 wintertime precipitation dipole trends along the Pacific Coast over different 20th century time periods. Precipitation dipole trends are calculated from southwest Pacific Coast precipitation anomalies minus northwest Pacific Coast precipitation anomalies. The regions used are denoted by purple boxes in Fig.1a.

Dynamic responses to historical AA emissions

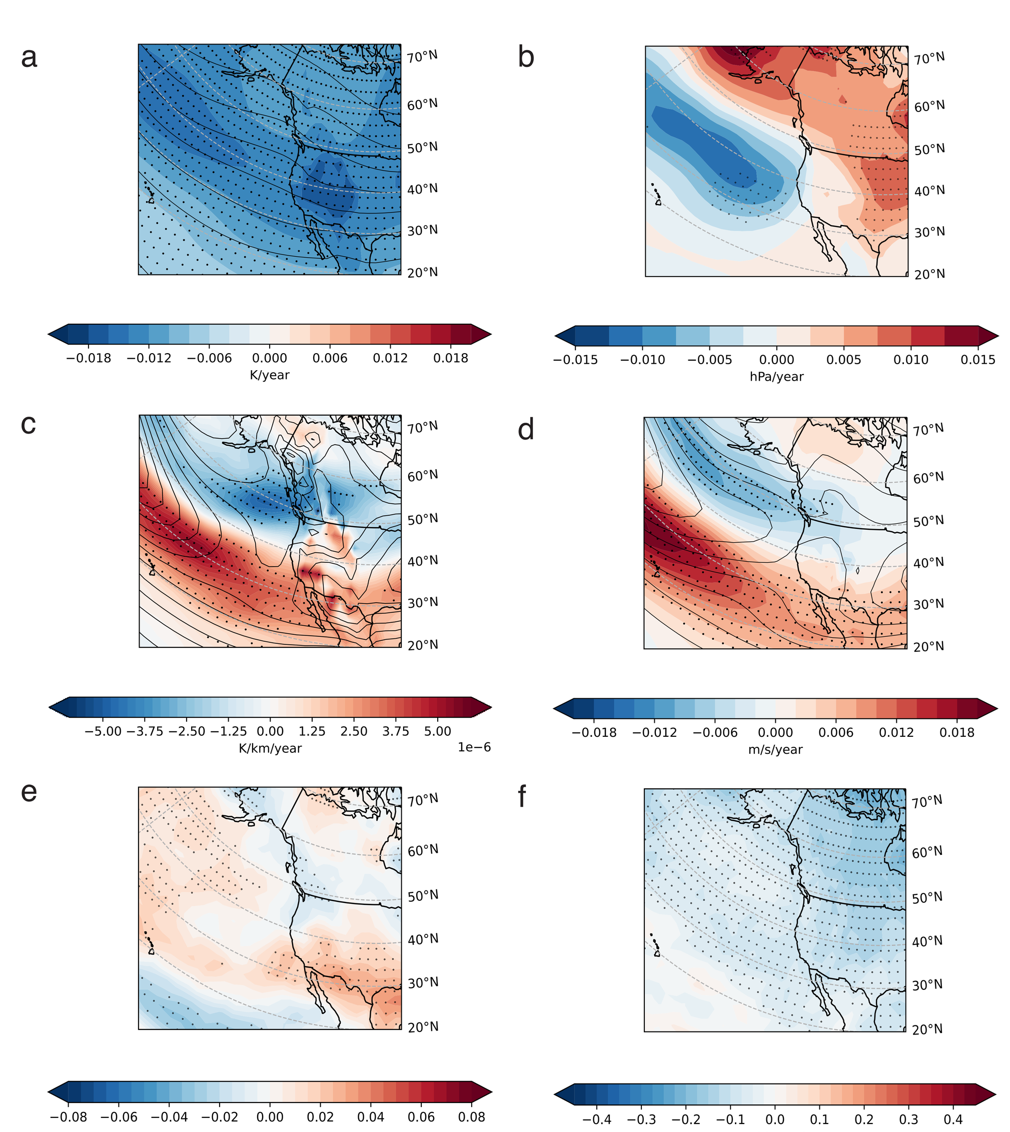

Fig 3. CMIP6 multi-model mean 1930-1975 wintertime dynamical responses to historical aerosol emissions. Trend of (a) 300-850 hPa tropospheric temperature, (b) sea-level pressure, (c) 300-850 hPa meridional tropospheric temperature gradient, (d) 300-850 hPa tropospheric zonal winds, (e) total cloud cover and (f) cloud-top effective radius.

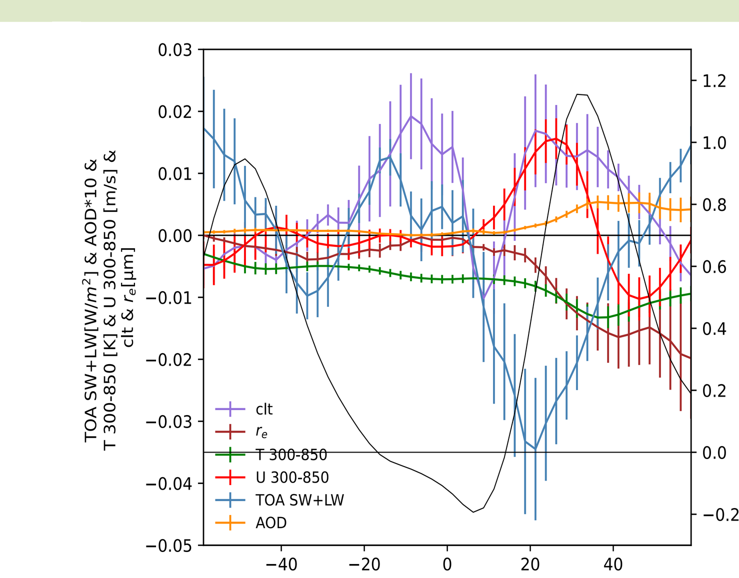

Fig 4. CMIP6 anthropogenic aerosol multi-model mean zonal mean wintertime 1930-1975 trends over the Pacific.

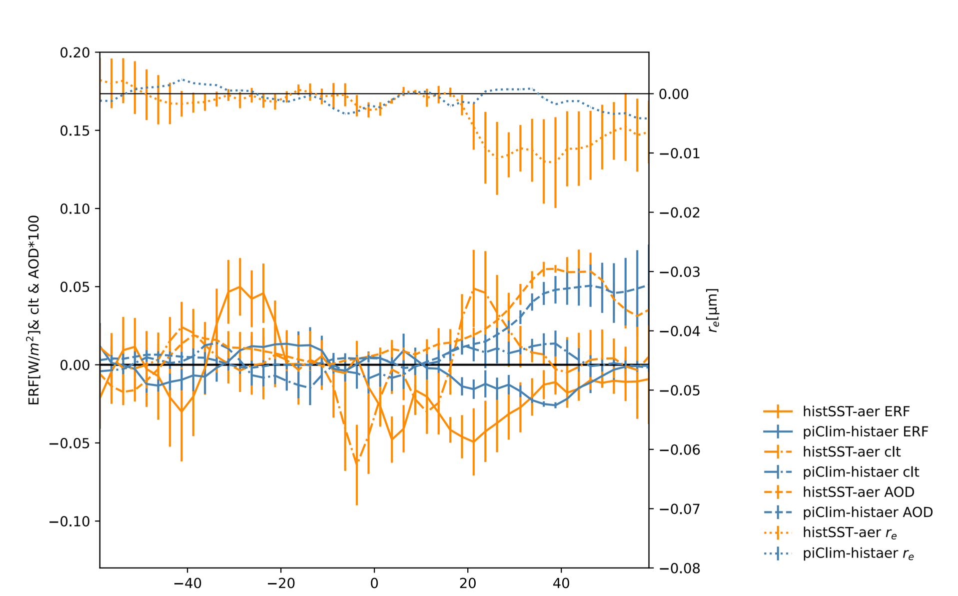

Fig 5. CMIP6 multi-model mean zonal-mean 1930-1975 wintertime responses to historical AAs in the fixed sea surface temperatures experiments over the Pacific.

Responses to projected emissions

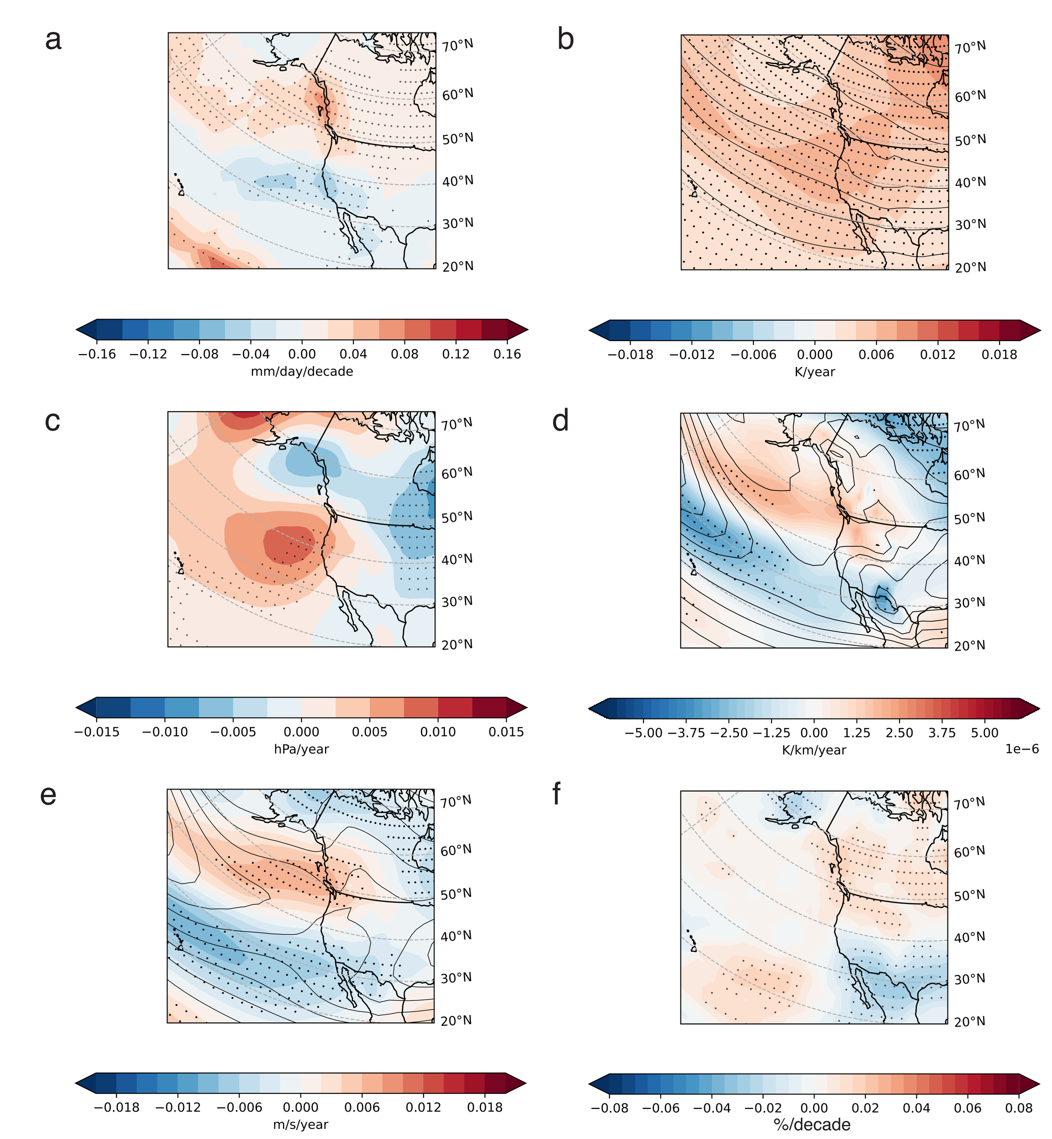

Fig 6. CMIP6 multi-model mean wintertime 2021-2099 response to the projected reduction in AA emissions. Trends of (a) precipitation, (b) 300-850 hPa tropospheric temperature, (c) sea-level pressure, (d) 300-850 hPa meridional tropospheric temperature gradient, (e) 300-850 hPa tropospheric zonal winds and (f) total cloud cover.

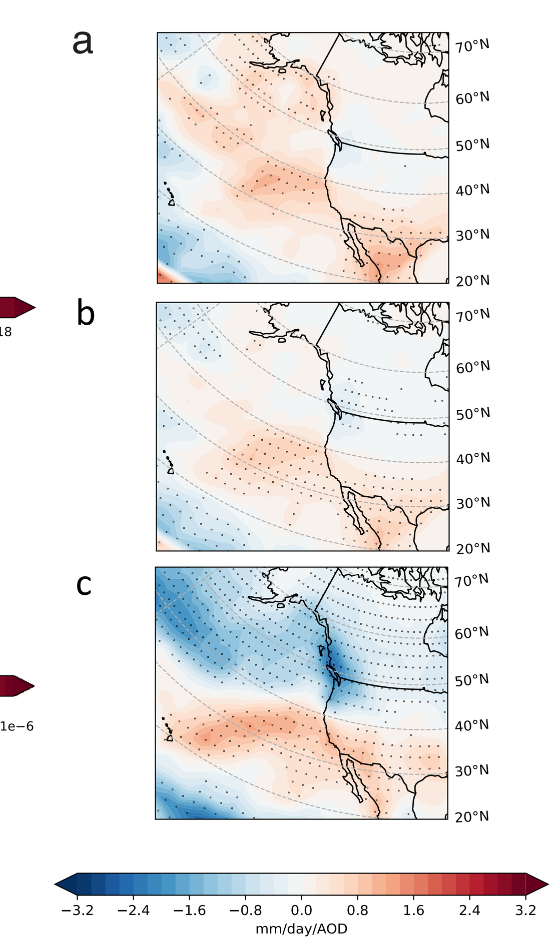

Fig 7. CMIP6 multi-model mean 1905-2095 wintertime precipitation sensitivity analysis to changes in regional AOD over U.S.(a), EU(b) and East Asian (c).

Conclusions

Although uncertainties remain, our results suggest aerosols can perturb precipitation along the Pacific Coast.

- Over much of the 20th century, particularly from 1930-1975 when U.S. and European AA and precursor gas emissions rapidly increased, a robust wintertime precipitation dipole pattern exists along the Pacific Coast, with wetting southward of 40°N and drying to the north.
- A corresponding dynamical dipole pattern is found, including increases in the East Pacific jet and baroclinicity southward of ~40°N and decreases to the north.
- These dynamical changes are related to AA-induced tropospheric cooling that maximizes near 40°N in the East Pacific, consistent with decreases in top-of-the-atmosphere radiation and changes in clouds.
- In response to future AA reductions, an opposite hydro-dynamic dipole pattern occurs, including drying southward of ~40°N and wetting to the north.
- The AA-induced dipole pattern is partially offset by greenhouse gases, resulting in a muted dipole response in both historical and future all-forcing simulations.
- A regression analysis suggests that the Pacific Coast precipitation dipole pattern is most sensitive to AAs from East Asia, relative to those from the U.S. and Europe.