Arctic precipitation in circulation-constrained CESM1/2 simulations and the role of meridional moisture transport

June 13, 2023

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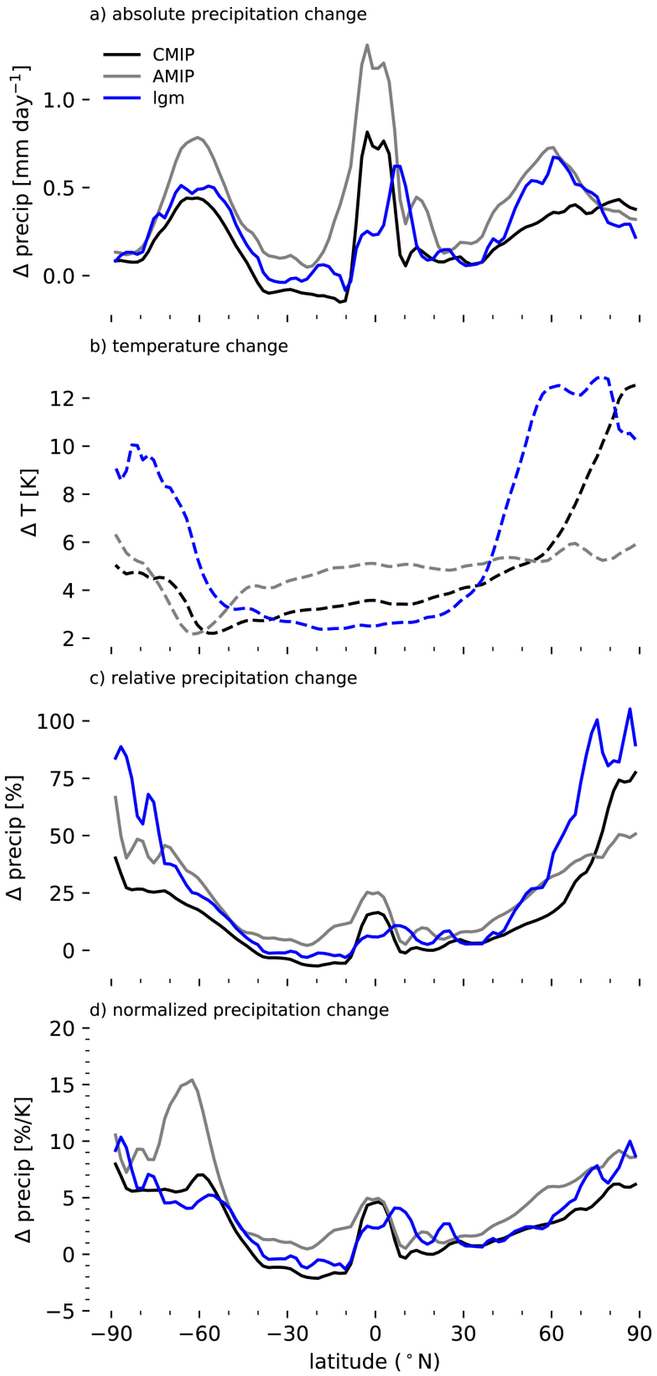
CESM Polar Climate Working Group

Increasing precipitation rates in the Arctic

- Polar Hydrological changes greater because of small initial precipitation rates with larger warming

- Polar Hydrological Change
  - Moisture availability hypothesis (Singh et al. 2017, Harrington et al. 2021)
  - Radiative hypothesis (Pithan & Jung 2021, Bonan et al. 2023)
    - ✓ Held & Soden (2006)

- Previous water tagging studies have looked only at decadal means with the CESM's inherent circulation



Pithan & Jung (2021)

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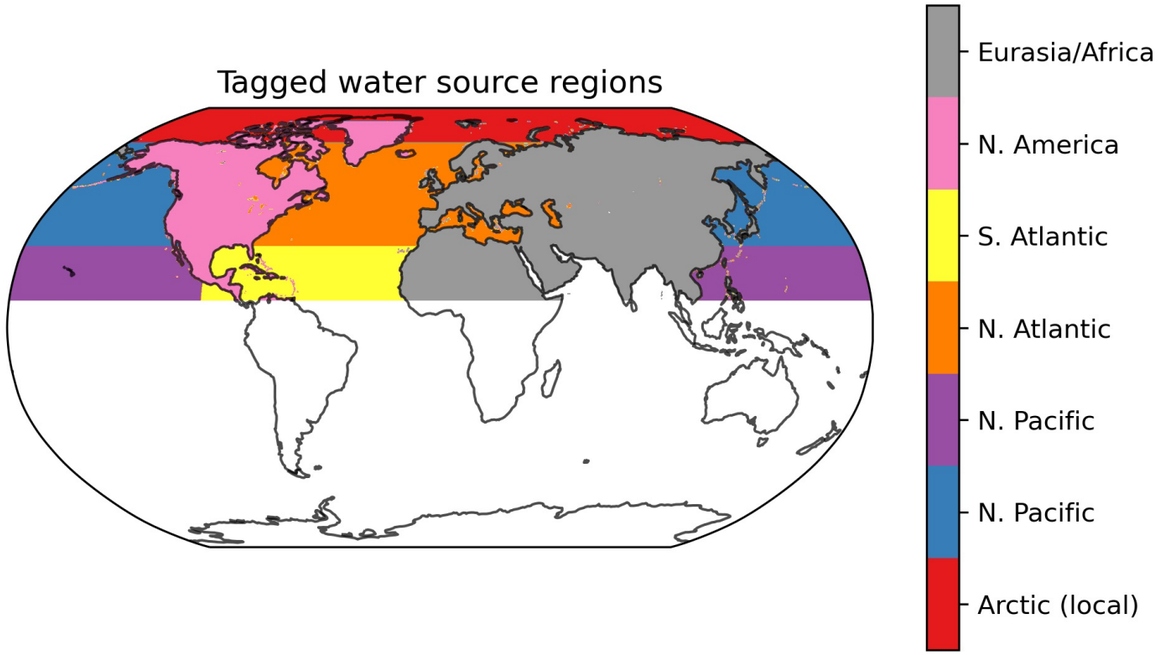
Experiment Design

Tagged water source regions



CESM1/2 Nudging Simulations

- Fully-coupled
- Same fixed CO2 concentrations
- Winds nudged to same ERA5 horizontal winds (60-90N, 1979-2020)

CESM1 water tagging + nudging

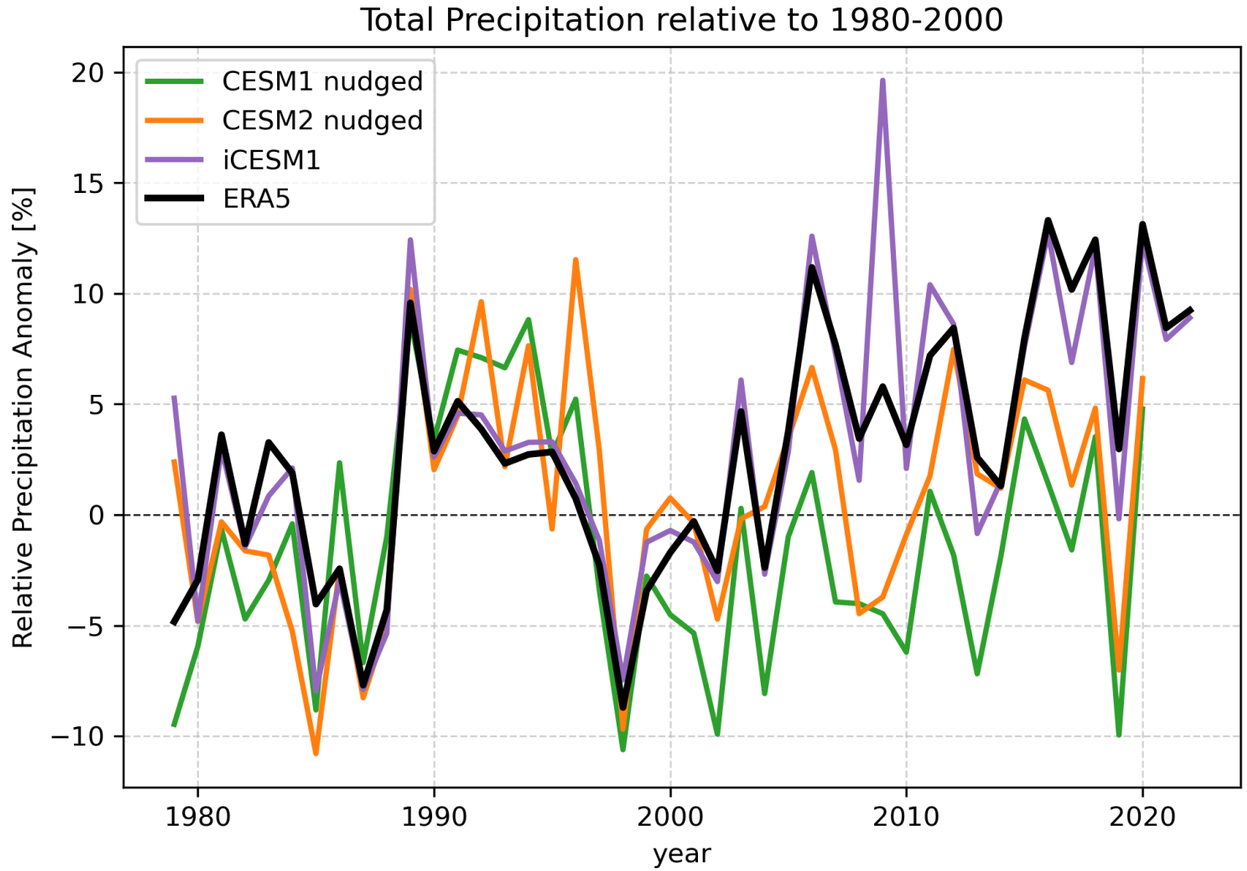
- Nudged U,V,T (1979-2022)
- Nudged Q in the lowest model level near surface
- AMIP-style
  - ERA5 SST/SEAICE

Goals:

- Replicate hydrological changes from ERA5 using nudging & prescribed surface
- Characterize trends in source region moisture contributions to precipitation changes

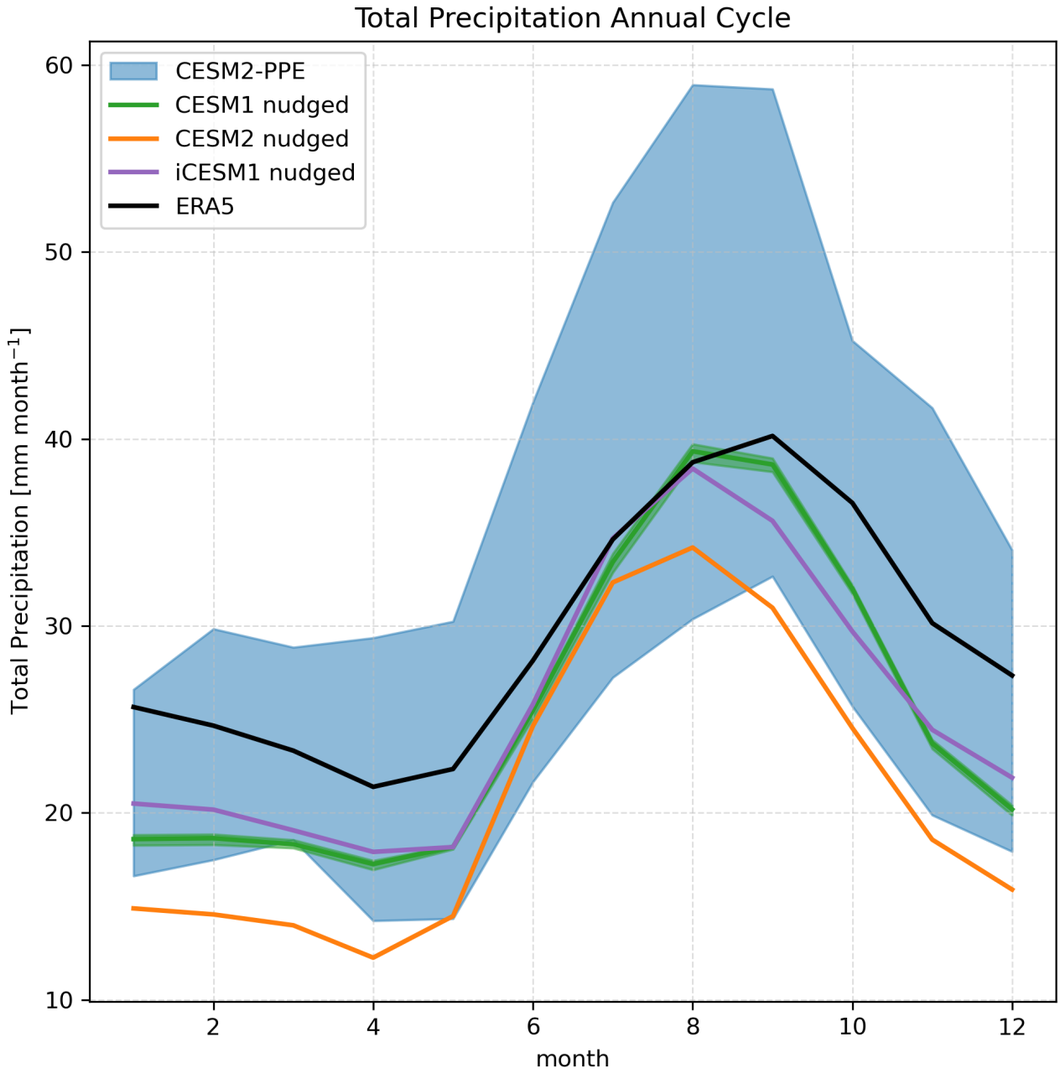
Annual Mean precipitation in CESM w/ ERA5 winds

- Annual mean total precipitation rate from ERA5 well replicated by iCESM1 with nudging
- Temperature plays a larger role than winds



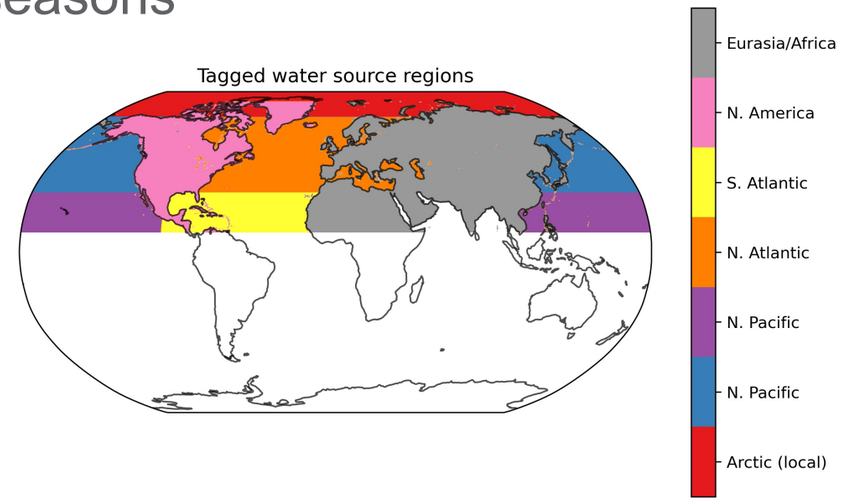
Precipitation in CESM w/ ERA5 winds

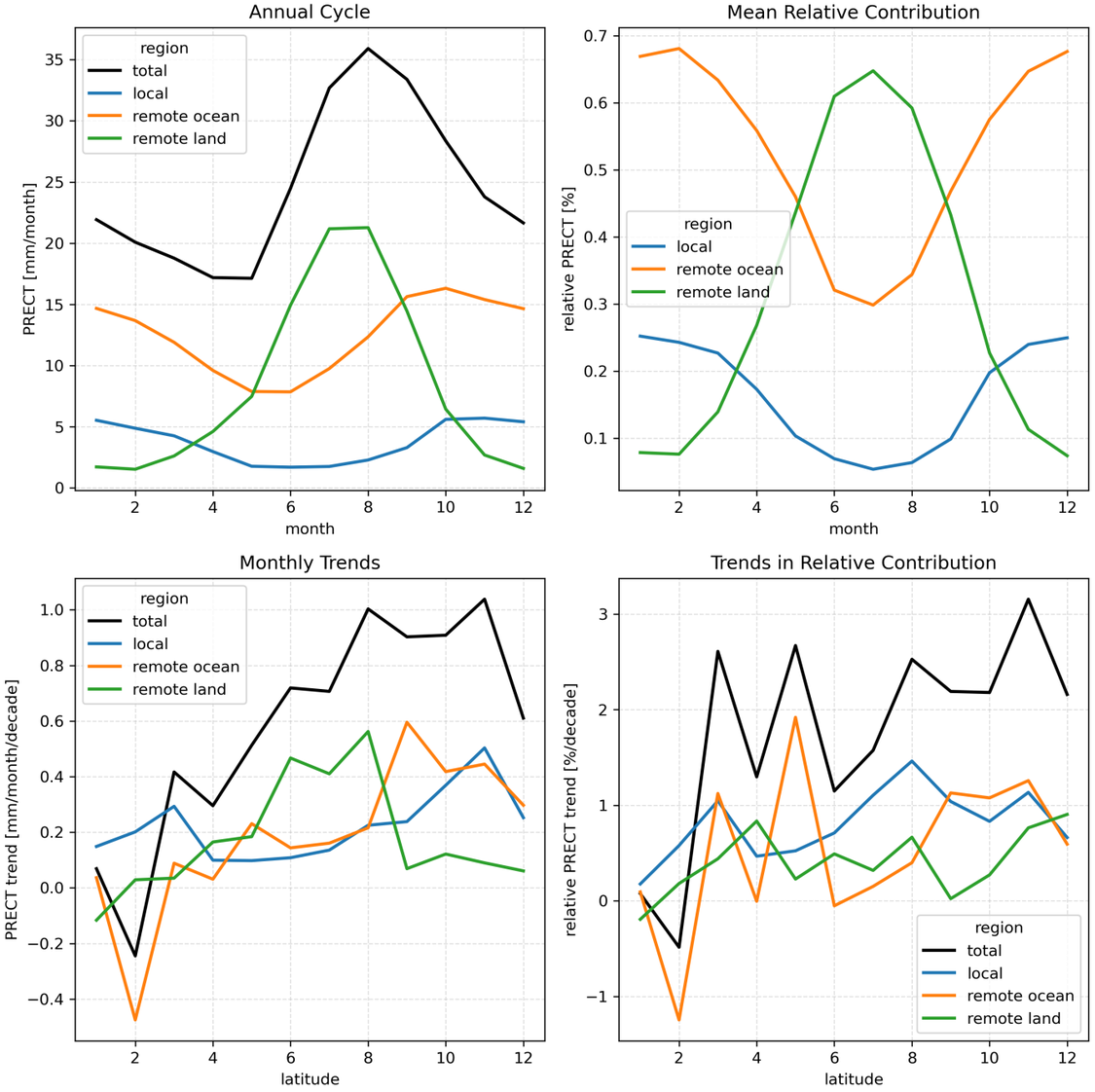
- Early Summer
  - Nudging winds captures good agreement between CESM1/2 simulations
- Fall
  - Temperature nudging & prescribed surface produces less precipitation
- Winter/Spring
  - Nudging winds captures good agreement between CESM1/2 simulations



Annual Cycle vs. Trends

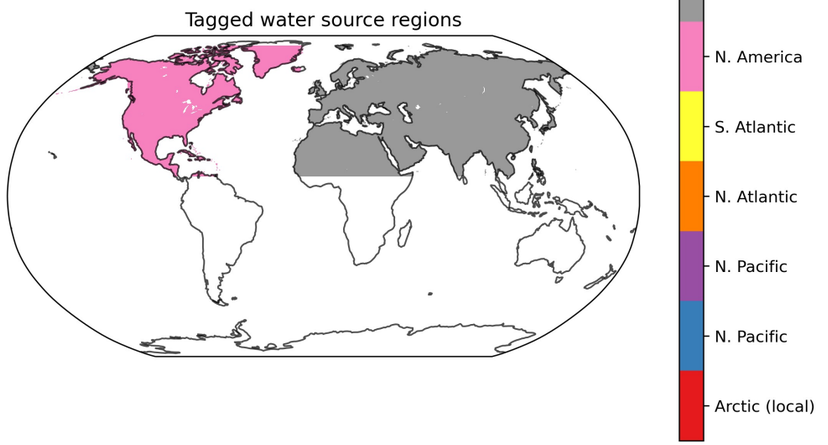
- Land sources dominate in summer (~65%)
- Remote ocean sources (North Atlantic) dominate in other seasons (~68%)
- Relative changes favor local sources in summer and remote ocean in other seasons

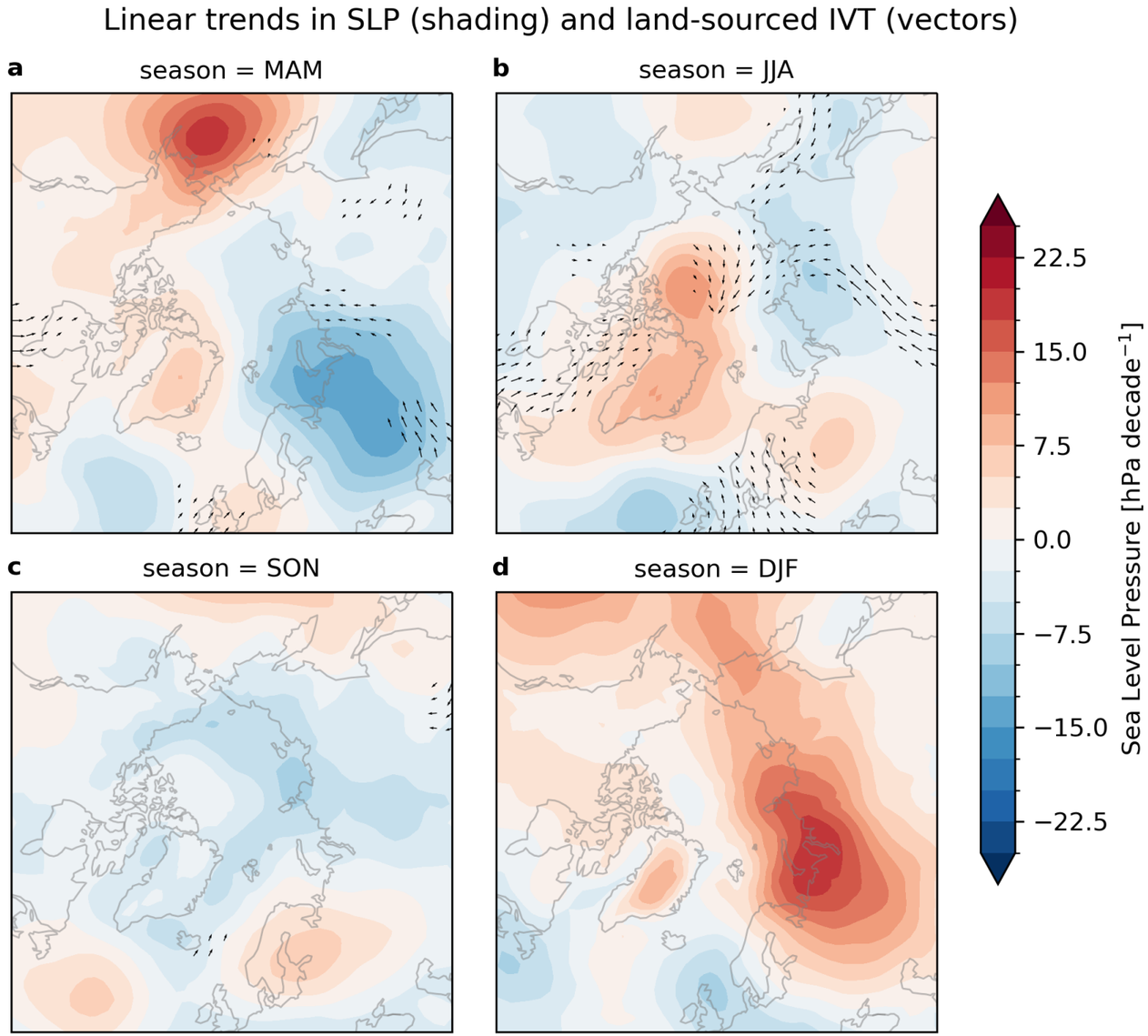




Linear Trends in Land-based pathways

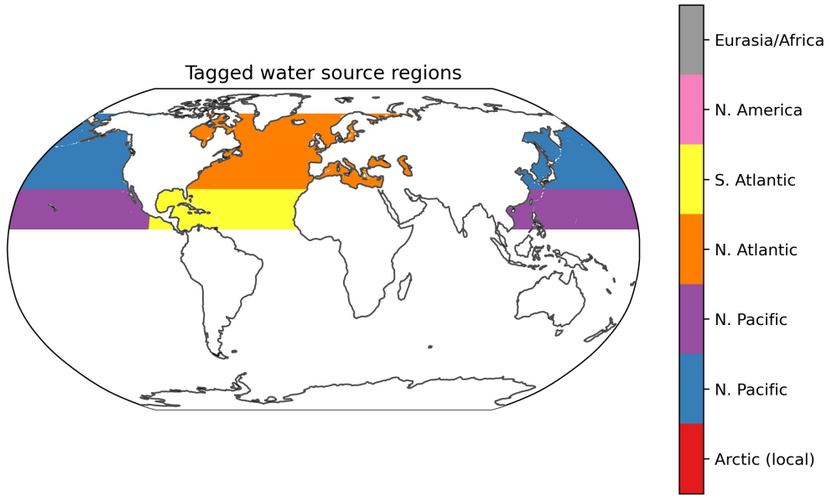
- Trends in circulation patterns control the changes in contributions:
  - Spring/Summer
    - ✓ Increase in Eurasian/North American sourced moisture
  - Fall/Winter:
    - ✓ Weak transport (lack of winds or moisture sources)

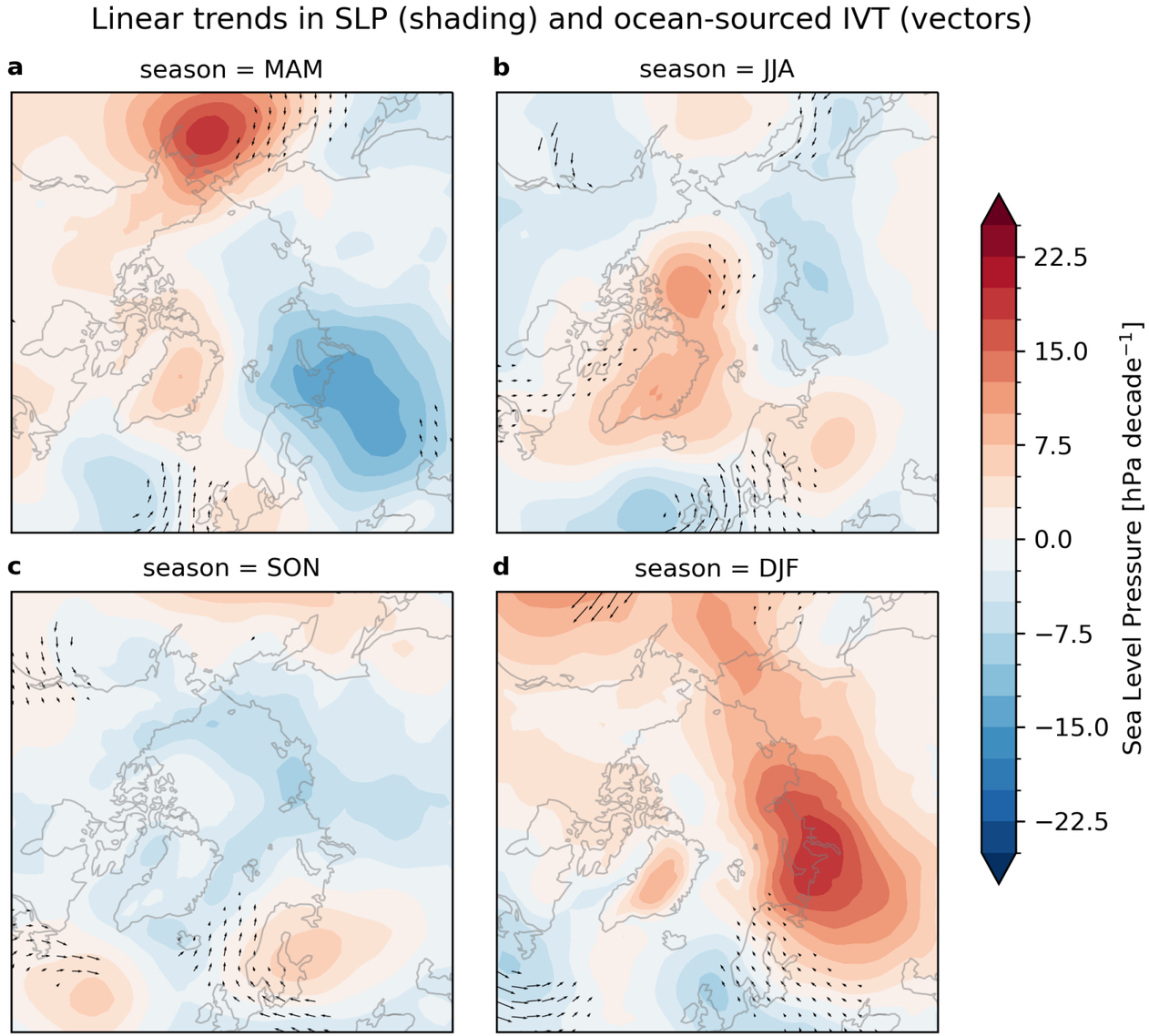




Linear Trends in Remote Ocean-based pathways

- Trends in circulation patterns control the changes in contributions:
  - Summer
    - ✓ Same pathways with weaker magnitudes
  - Fall/Winter:
    - ✓ Stronger N. Atlantic signal





Summary

- Nudging winds leads to good agreement between CESM1 and CESM2 in early summer but not in colder months
  - Temperature nudging better replicates annual mean ERA5 precipitation
- The contributions to the annual cycle are similar to the trends
- Relative changes favor increased local and N. American role in summer and role of remote oceans (N. Atlantic) in fall/winter
- Historical precipitation changes require consideration of moisture availability changes on seasonal/monthly timescales

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