A Study of AR-, TS-, and MCS-Associated Precipitation and Extreme Precipitation in Present and Warmer Climates

Ming Zhao
Geophysical Fluid Dynamics Laboratory
NOAA

EarthCARE Modeling Workshop
February 16-18, 2022

Paper published in Journal of Climate DOI:10.1175/JCLI-D-21-0145.1

Motivation

- How much of the present-day climatological precipitation and extreme precipitation may be attributed to ARs, TSs, and MCSs?

- How well are AR-, TS-, and MCS-associated precipitation and extreme precipitation simulated in the latest GFDL moderately high resolution (50km) GCM?

- How may AR-, TS-, and MCS-associated precipitation change in a warmer climate?

- How may we understand the change in AR-, TS-, and MCS-associated extreme precipitation in a warmer climate?

Observational Data

- **Precipitation**: Multi-Source Weighted-Ensemble Precipitation (MSWEP-v2, Beck et al. 2019 BAMS, 1980-2014)

- **Atmospheric Rivers**: Integrated Vapor Transport from ERA-Interim reanalysis (1980-2014)

- **Tropical Storms**: International Best Track Archive for Climate Stewardship (IBTrACS) (1980-2014)

- **Mesoscale Convective Systems**: Multi-Satellite Infrared Brightness Temperature from CLoud Archive User Service (CLAUS) (1985-2008)

Model and simulations

- GFDL HighResMIP participating model: C192AM4 (50km resolution) (Zhao 2020: AR, Murakami et al. 2020: TS, Dong et al. 2021: MCS)

- PRESENT (1980-2014): present-day simulation with C192AM4 forced by observed SSTs, SICs, radiative gases and aerosol emissions

- CLIMO (100 years): climatological simulation with C192AM4 forced by observed monthly varying climatological (1980-2014 average) SSTs and SICs with radiative gases and aerosol emissions fixed at 2010 condition

- P4K (100 years): As in CLIMO except with the SSTs increased uniformly by 4K

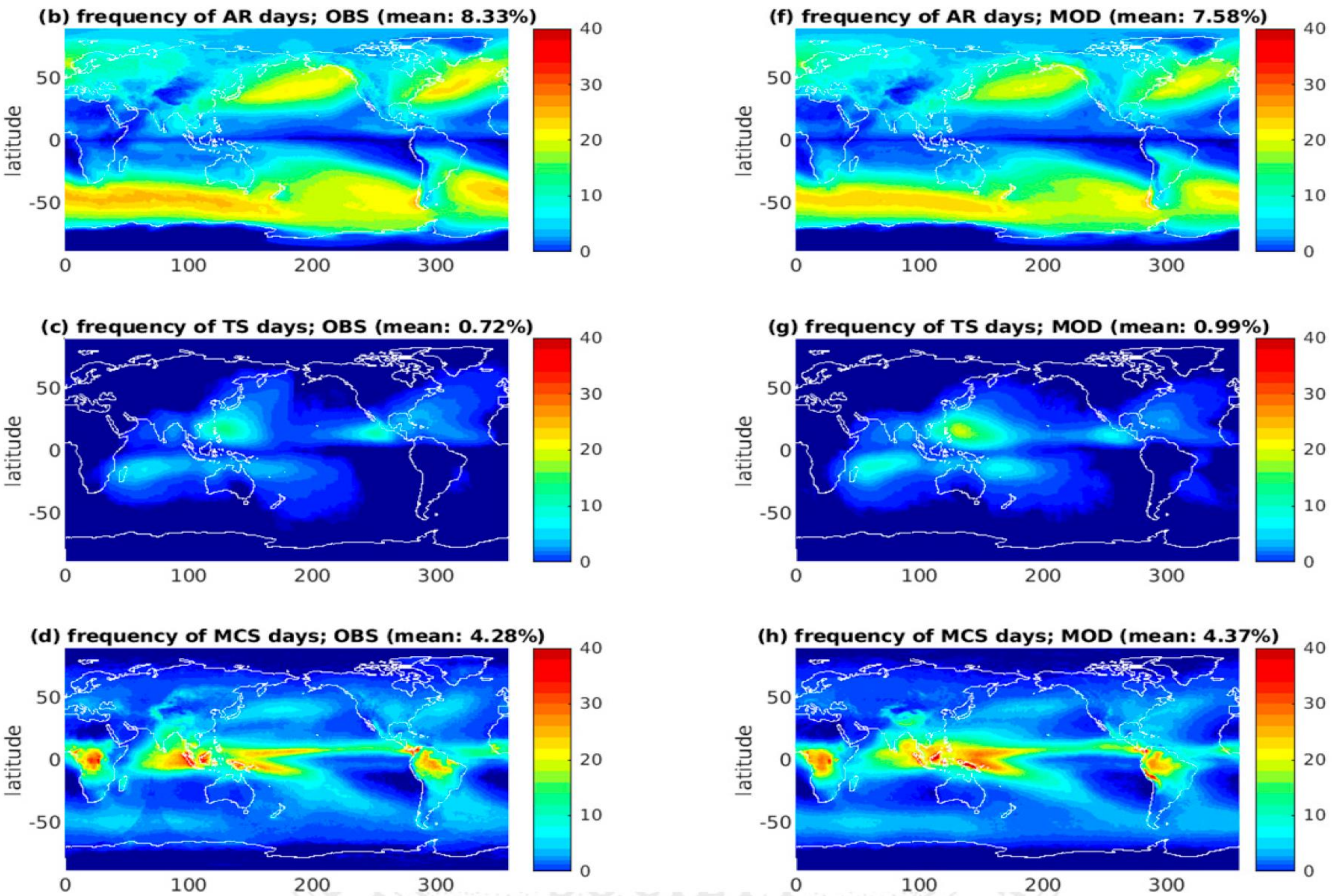
Storm detection methods

- Atmospheric Rivers (Guan & Waliser 2015, Zhao 2020)
  - Integrated Vapor Transport (IVT) Method, $IVT_{th} = \max(IVT^{85th}$, 100kg/m/s)
  - Geometry requirement: Length $\geq$ 2000km, Length/Width $\geq$ 2
  - Poleward water transport $\geq$ 50 kg/m/s
  - Coherence of IVT direction $\geq$ 0.5
- Tropical Storms (Zhao et al. 2009, 2012)
  - Locate local maximums of 850-hPa relative vorticity exceeding a threshold
  - Define their nearby local minimum of SLP as cyclone centers
  - Track individual TCs using 6-hourly cyclone locations
  - Check track with criteria (maximum windspeed, relative vorticity, warm-core, duration)
  - 12˚x12˚ centered at each TC center considered as TS region
- Mesoscale Convective Systems (Dong et al. 2020, Huang et al. 2018)
  - Derive Brightness temperature (T_b) using OLR (Ellingson and Ferraro 1983)
  - Remove grid cells with $T_b(\lambda, \phi, t) \geq$ 233 K and $T_b(\lambda, \phi, t) \geq \overline{T_b(\lambda, \phi, t)}$-30 K
- AR, TS and MCS days
  - For a given grid cell and calendar day if at least one AR/TS/MCS condition identified from 6-hrly data and daily precipitation $\geq$ 1mm/day
  - Priority for overlap conditions: 1) TS → 2) AR → 3) MCS (mutually exclusive)

Annual occurrence frequency of AR, TS, and MCS days (%)

Observation (AR+TS+MCS=13.3%)

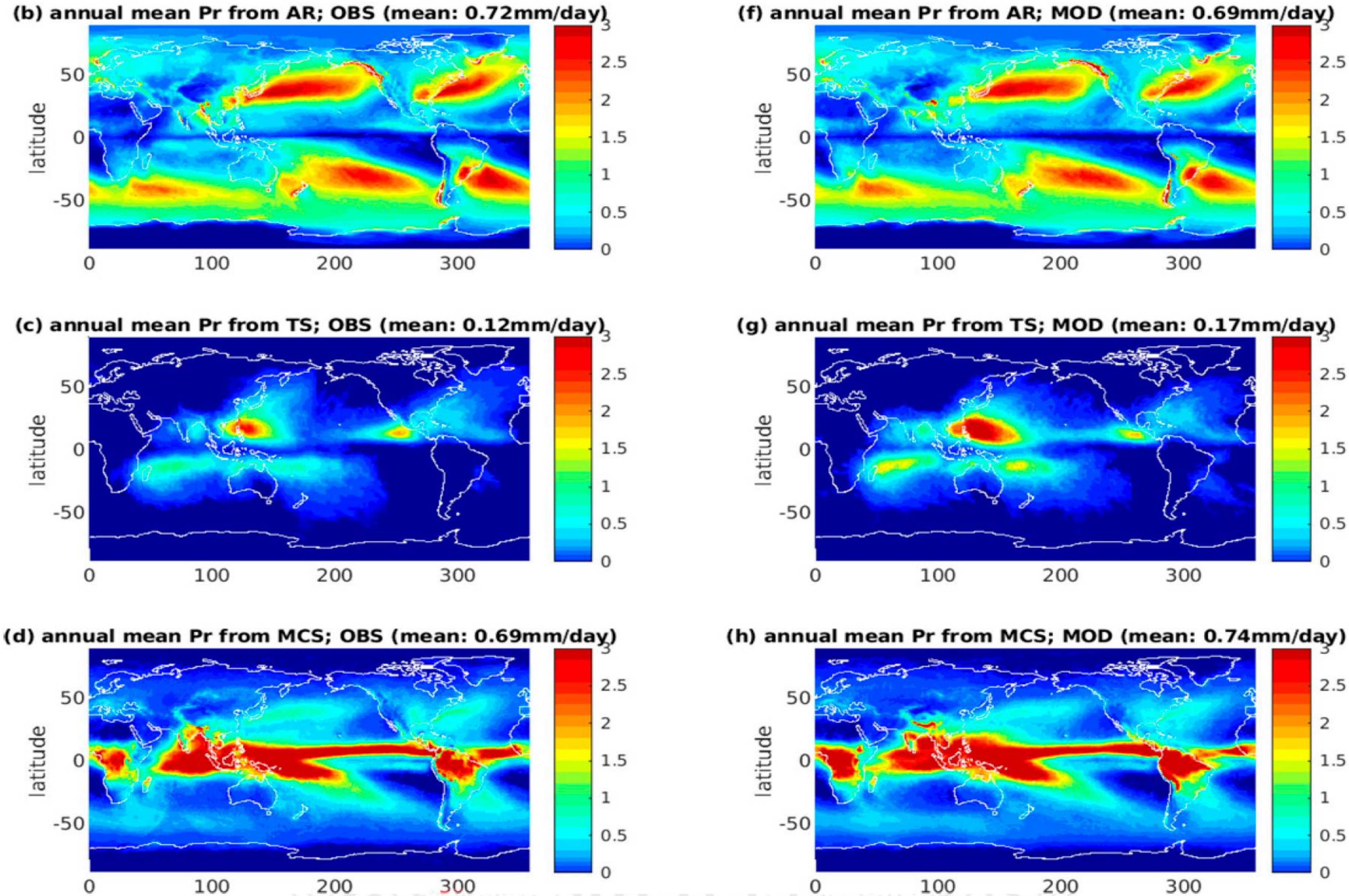
C192AM4 (AR+TS+MCS= 12.9%)



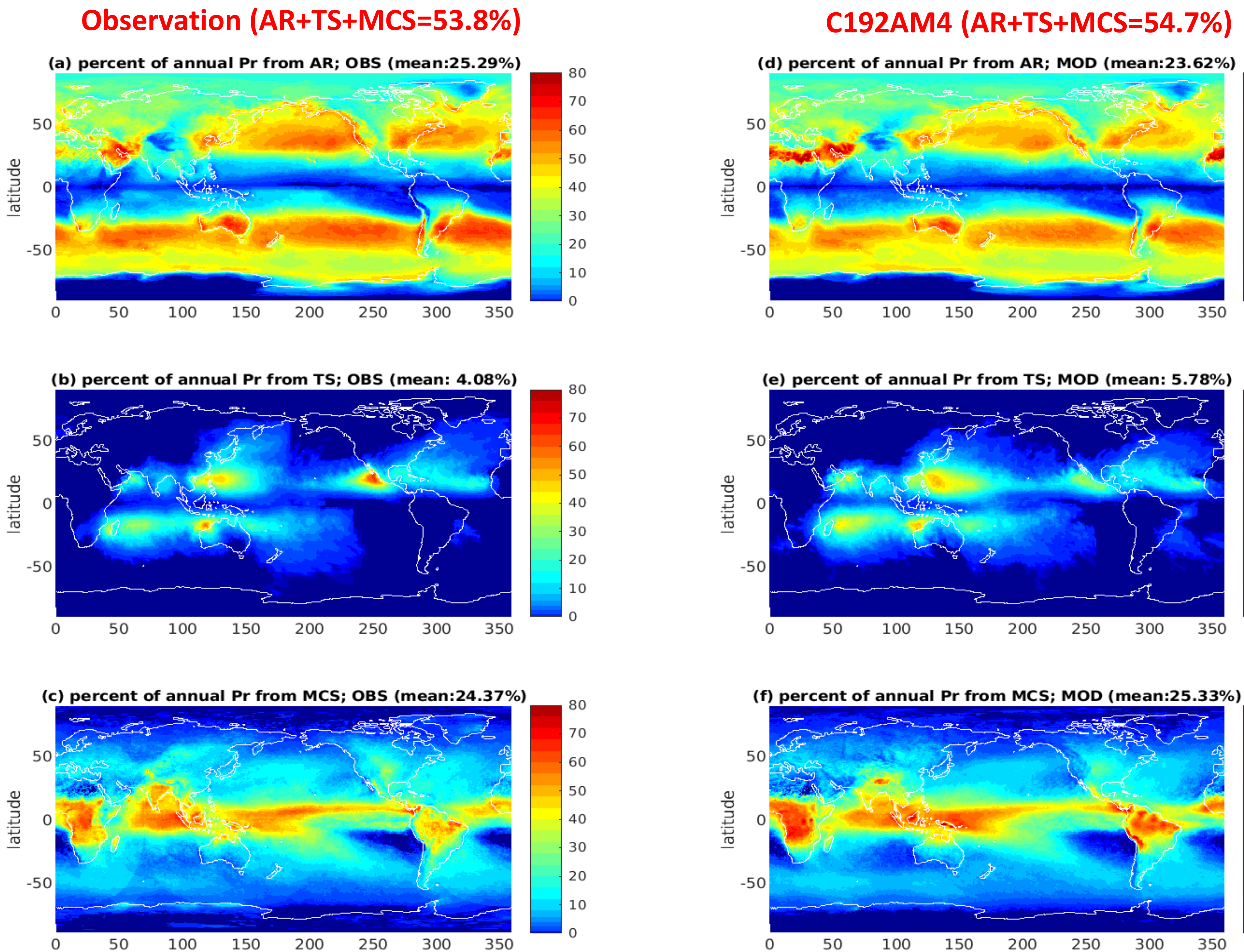
Annual mean precipitation from AR, TS, and MCS days

Observation (AR+TS+MCS=1.53mm/day)

C192AM4 (AR+TS+MCS=1.6mm/day)

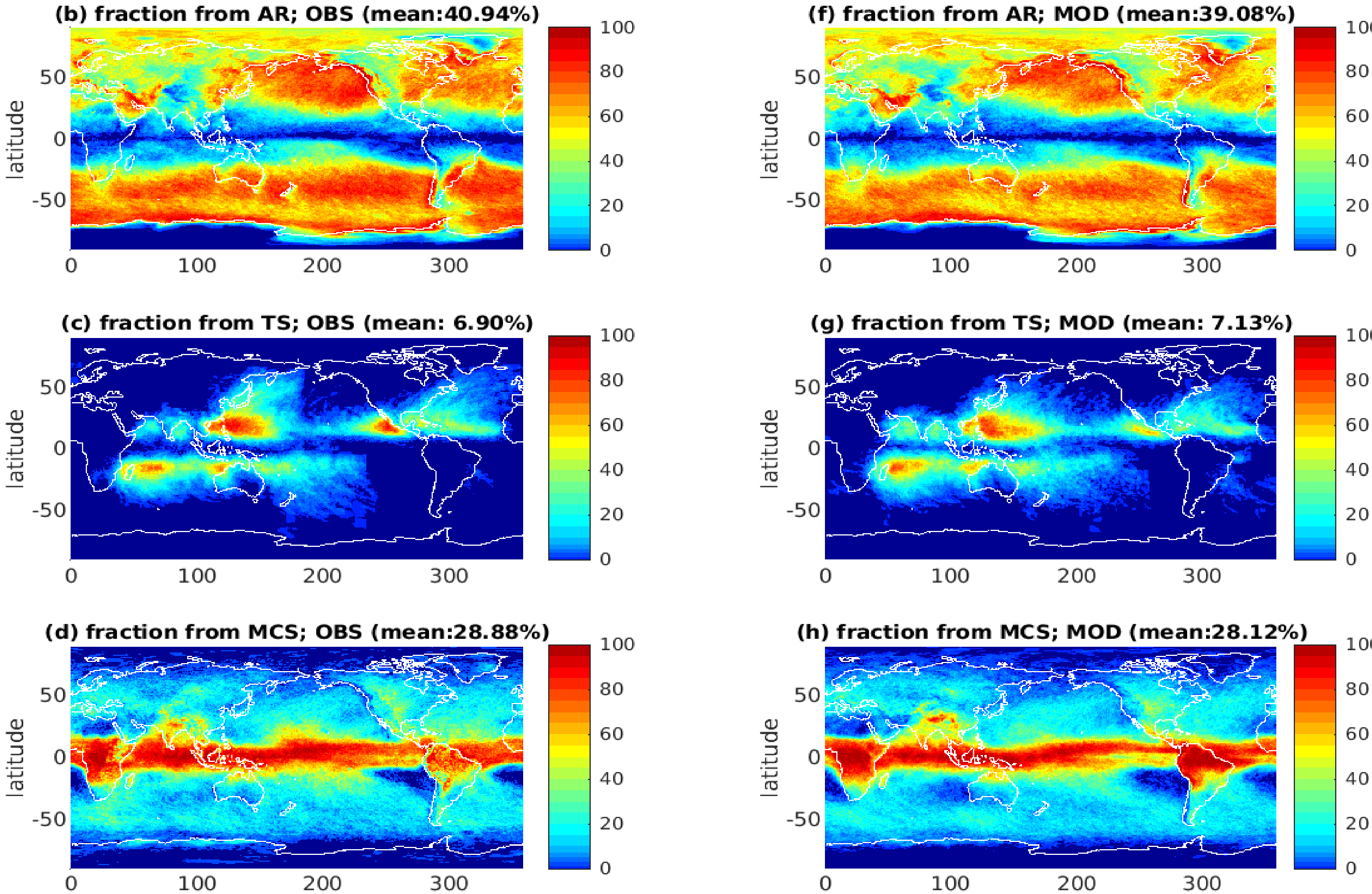


Percent of annual precipitation from AR, TS, and MCS days



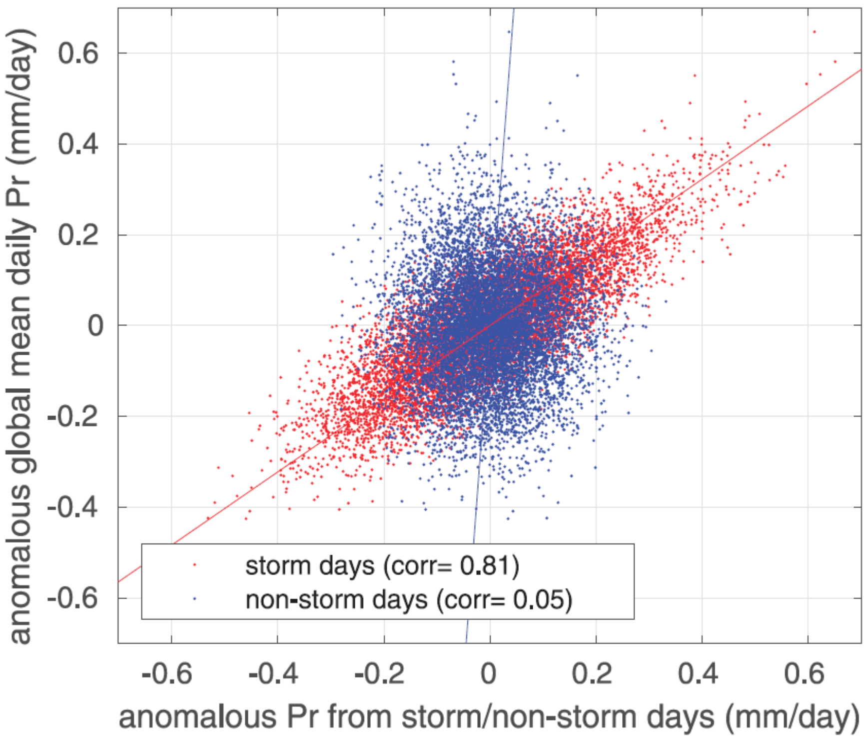
Percent of extreme daily precipitation events (local 1% heaviest daily precipitation) from AR, TS, and MCS days

Observation (AR+TS+MCS=76.7%) **C192AM4 (AR+TS+MCS=74.3%)**

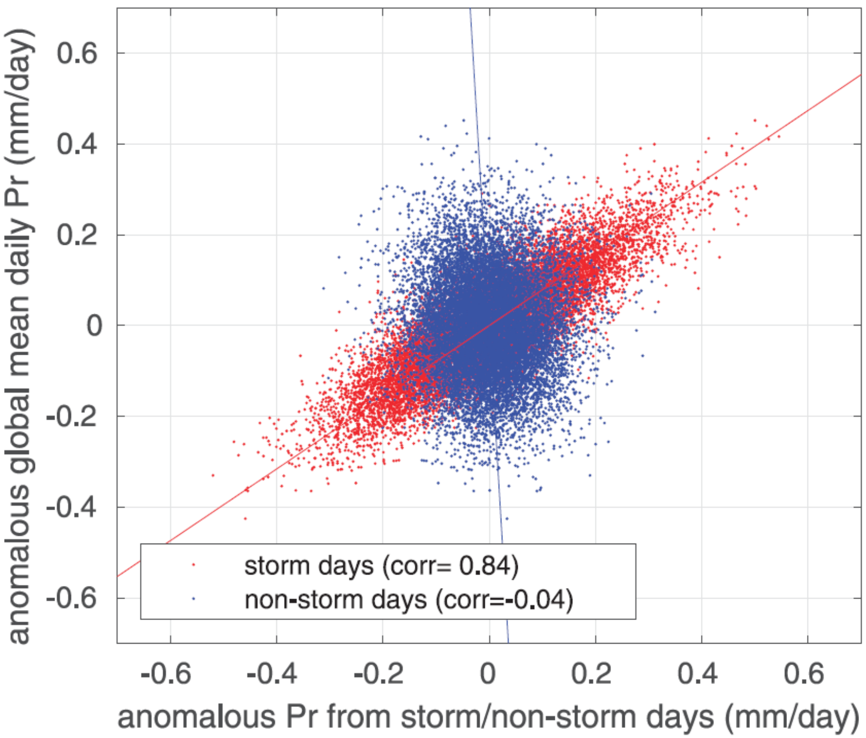


Interannual variation of global mean daily precipitation is dominated by storm (AR+TS+MCS) days

Observation



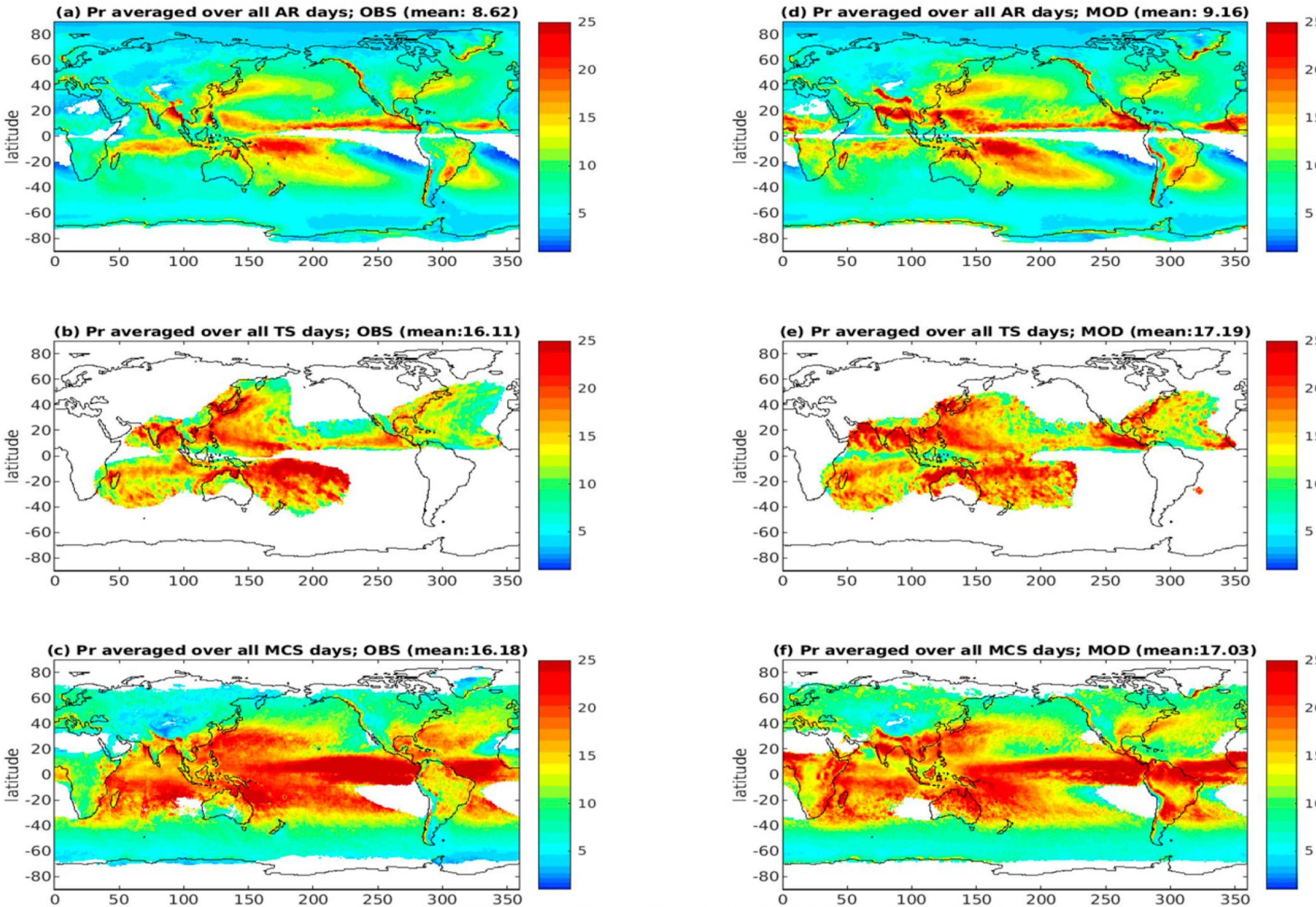
C192AM4



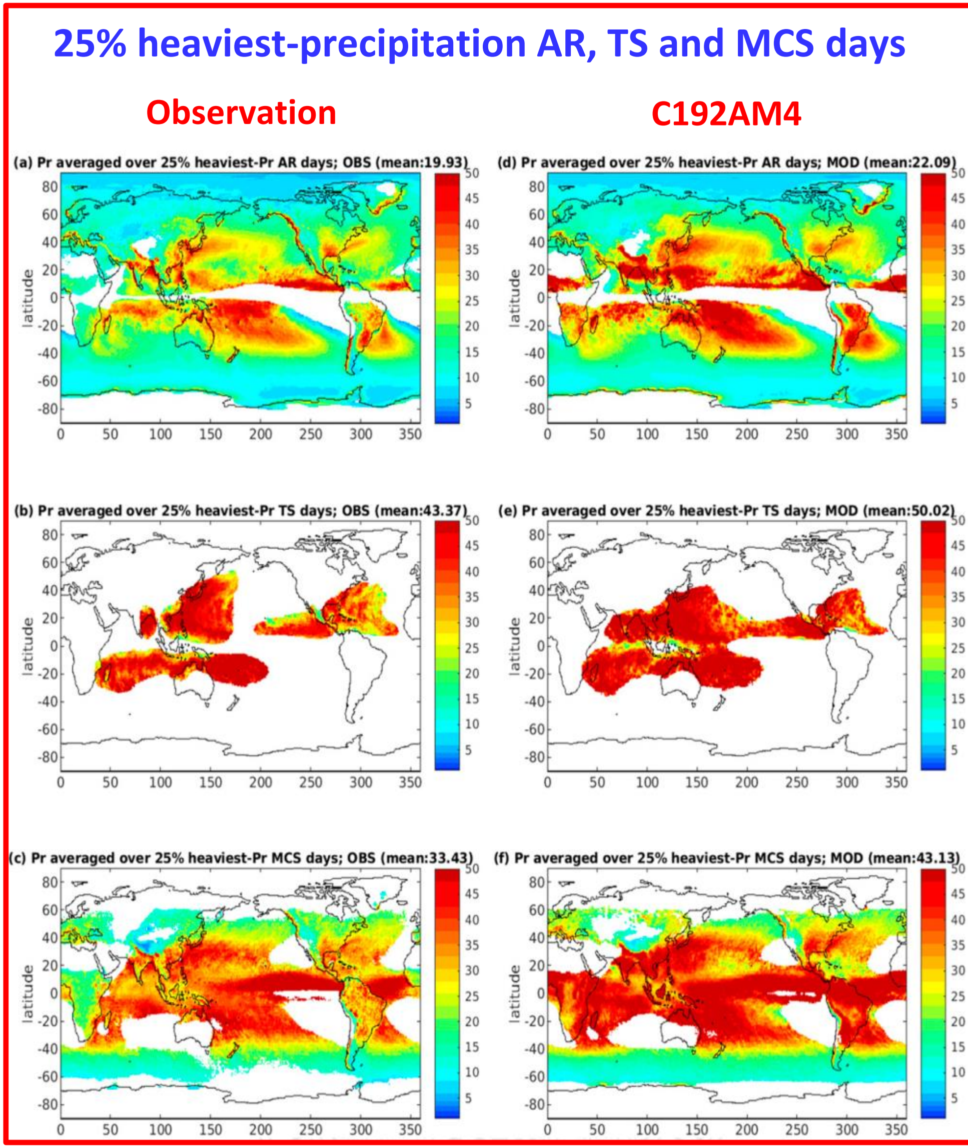
Interannual anomalous global mean daily precipitation vs interannual anomalous global mean daily precipitation from storm (AR+TS+MCS) and non-storm days

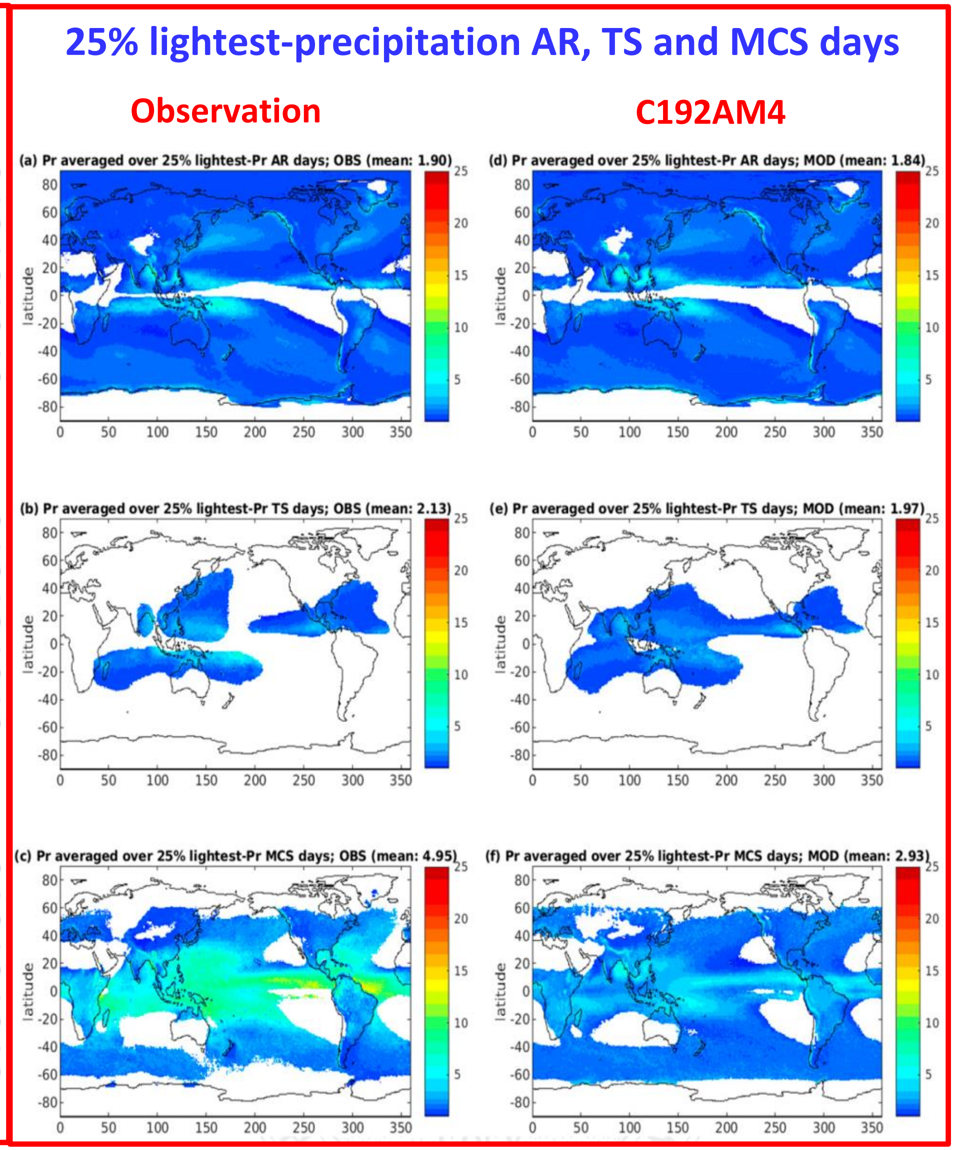
Precipitation intensity averaged from all AR, TS, and MCS days

Observation **C192AM4**



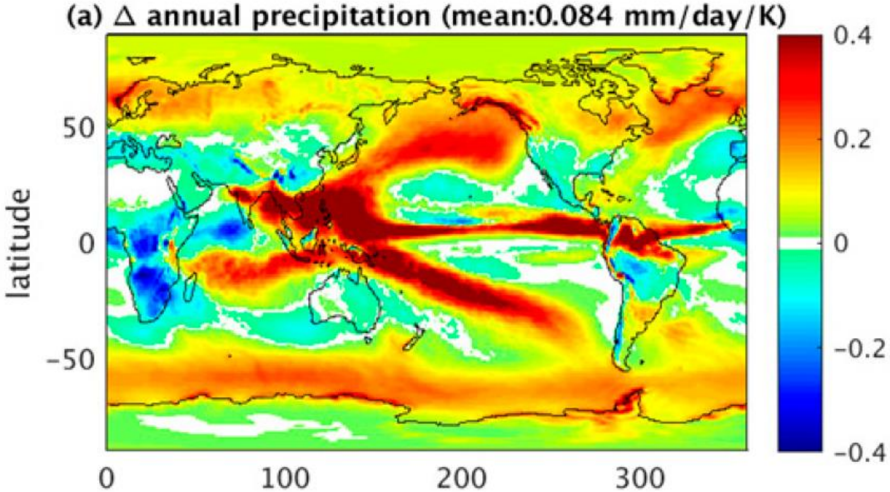
Precipitation intensity averaged over the 25% heaviest-precipitation vs. the 25% lightest-precipitation AR, TS, and MCS days



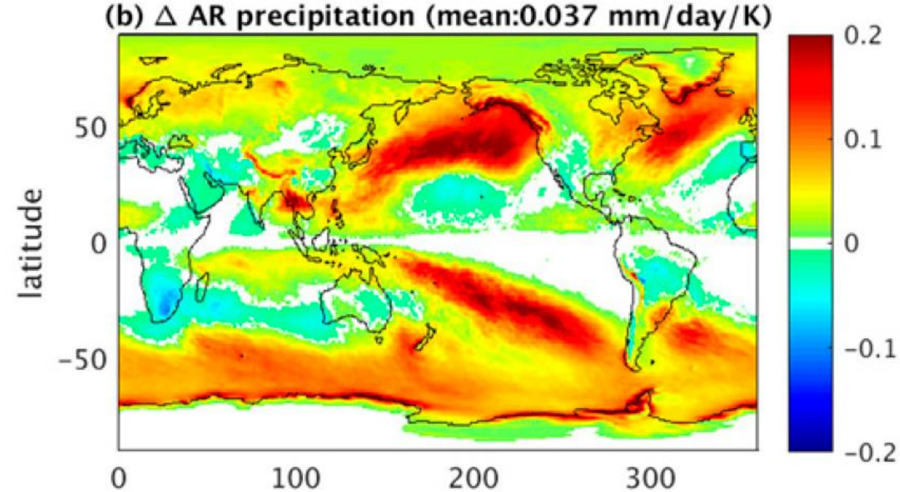


Change in annual mean precipitation between P4K and CLIMO and its contributions from AR, TS, and MCS days

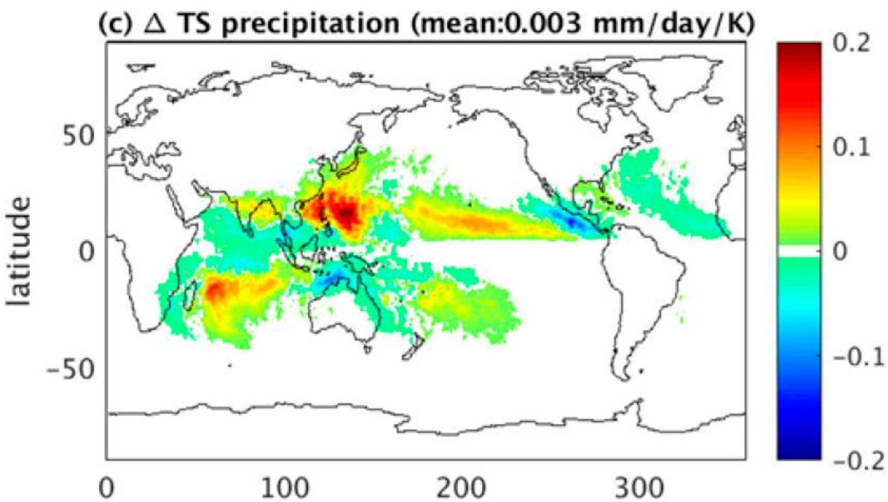
$\Delta P_r / P_r$ = 0.084/2.94 = 2.85%/K



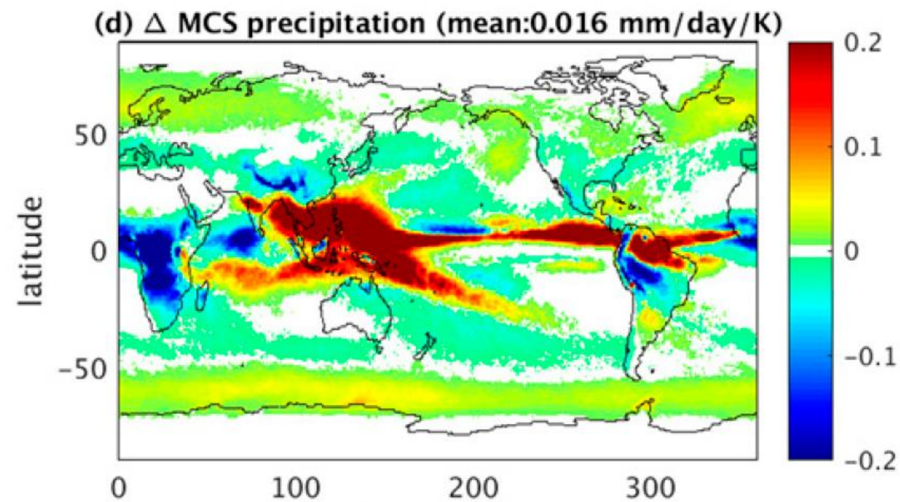
$\Delta P_{AR} / P_{AR}$ = 0.037/0.69 = 5.4%/K



$\Delta P_{TS} / P_{TS}$ = 0.0026/0.17 = 1.5%/K

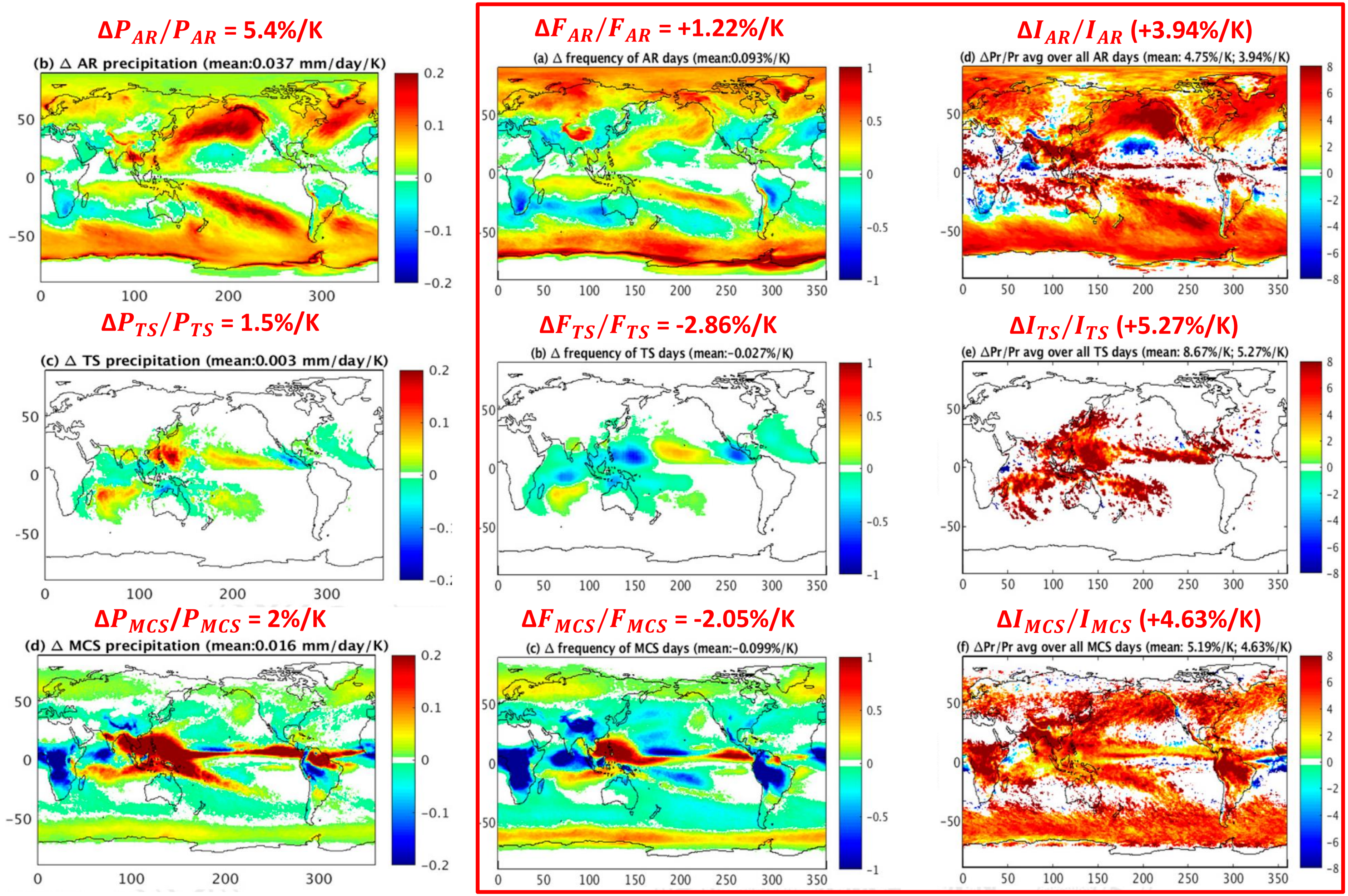


$\Delta P_{MCS} / P_{MCS}$ = 0.016/0.74 = 2%/K



(0.037+0.0026+0.016)/0.084 = 44%(AR) + 3%(TS) + 19%(MCS) = 66%

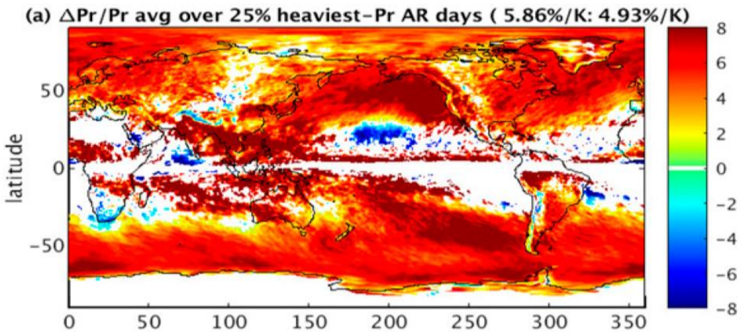
Change in annual frequency of AR/TS/MCS days and the percentage change in precipitation intensity averaged over all AR/TS/MCS days



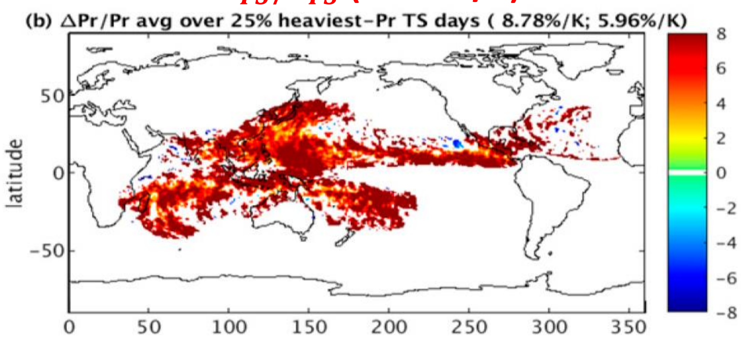
Change in precipitation intensity averaged over the 25% heaviest-precipitation vs the 25% lightest-precipitation AR, TS, and MCS days

25% heaviest-precipitation AR, TS and MCS days

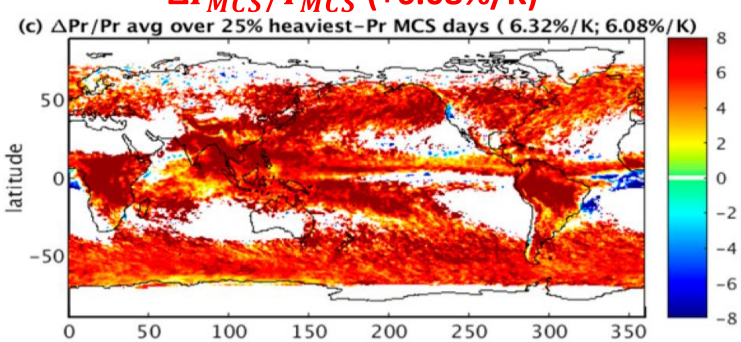
$\Delta I_{AR}/I_{AR}$ (+4.93%/K)



$\Delta I_{TS}/I_{TS}$ (+5.96%/K)

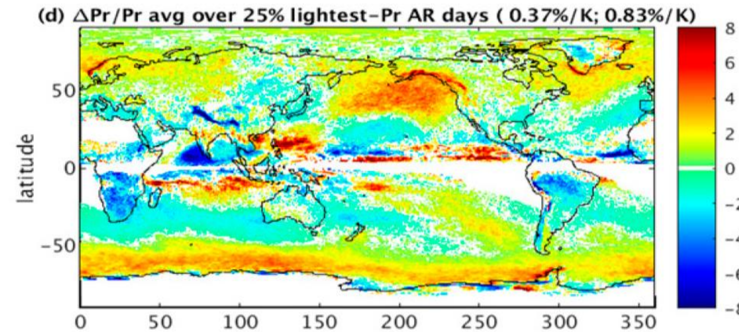


$\Delta I_{MCS}/I_{MCS}$ (+6.08%/K)

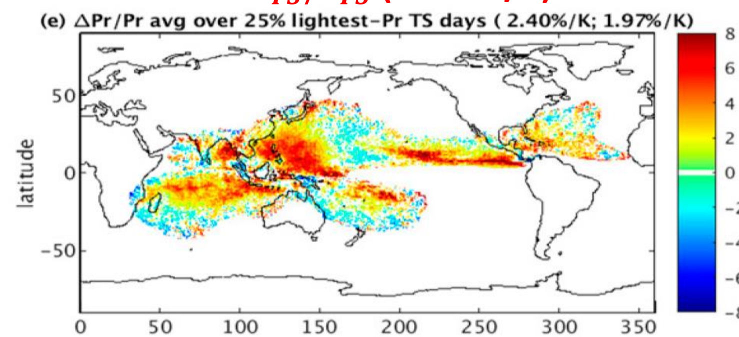


25% lightest-precipitation AR, TS and MCS days

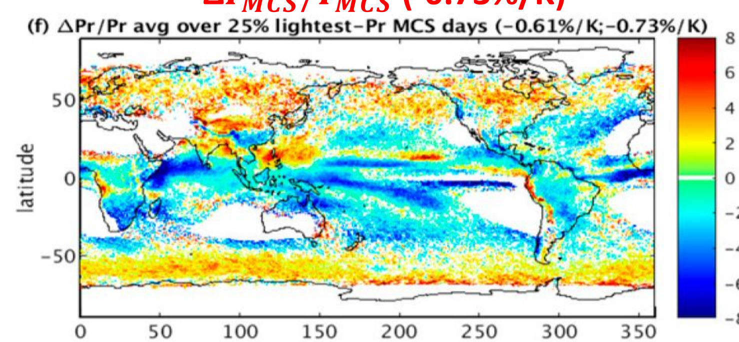
$\Delta I_{AR}/I_{AR}$ (+0.83%/K)



$\Delta I_{TS}/I_{TS}$ (+1.97%/K)



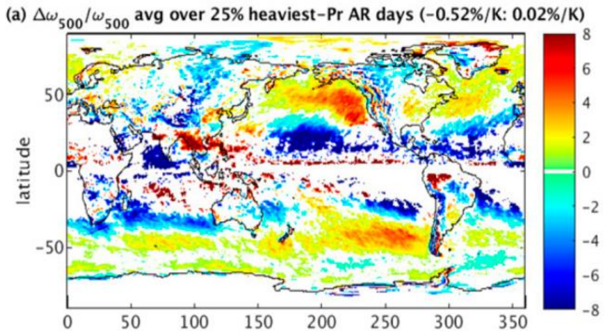
$\Delta I_{MCS}/I_{MCS}$ (-0.73%/K)



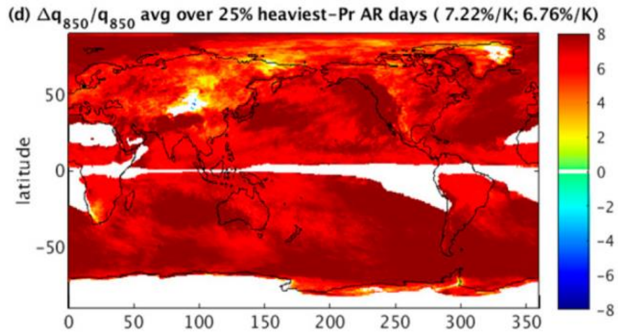
Change in dynamic and thermodynamic environment averaged over the 25% heaviest-precipitation AR, TS, and MCS days (P4K – CLIMO)

$$\Delta P_r/P_r \approx \Delta\omega_{500}/\omega_{500} + \Delta q_{850}/q_{850} + \Delta\varepsilon/\varepsilon$$

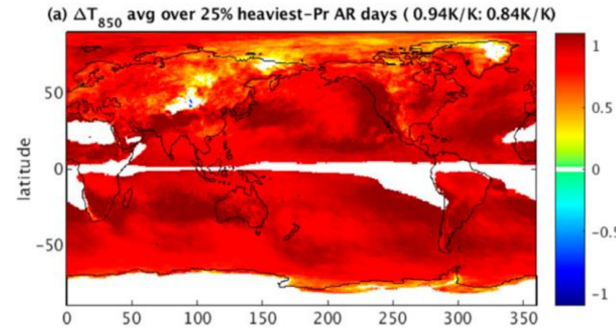
AR: $\Delta\omega_{500}/\omega_{500}$ (+0.02%/K)



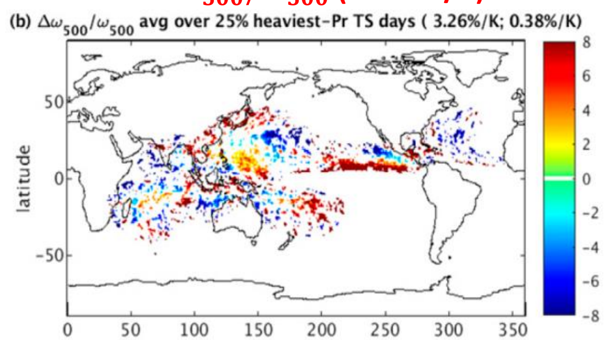
AR: $\Delta q_{850}/q_{850}$ (+6.76%/K)



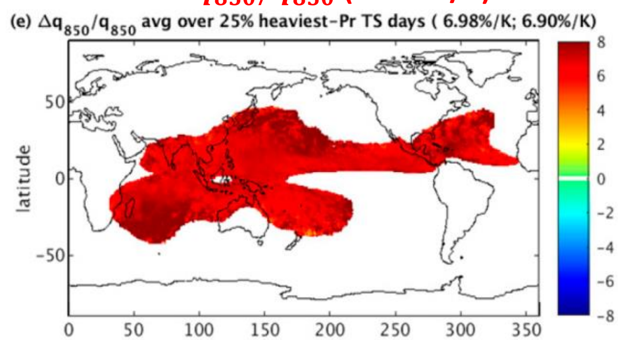
AR: ΔT_{850} (+0.84 K/K)



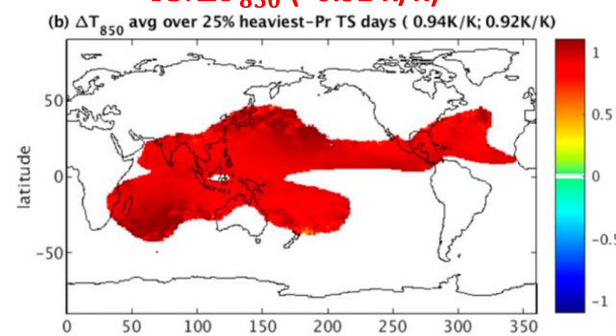
TS: $\Delta\omega_{500}/\omega_{500}$ (+0.38%/K)



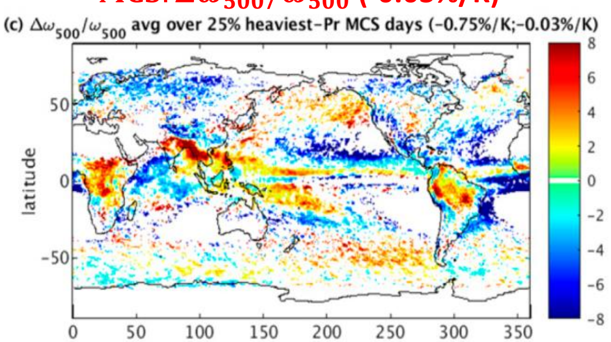
TS: $\Delta q_{850}/q_{850}$ (+6.90%/K)



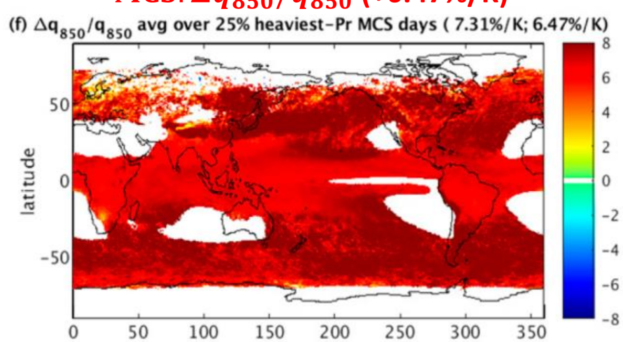
TS: ΔT_{850} (+0.92 K/K)



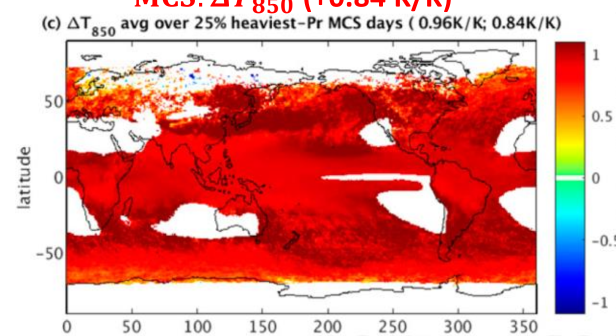
MCS: $\Delta\omega_{500}/\omega_{500}$ (-0.03%/K)



MCS: $\Delta q_{850}/q_{850}$ (+6.47%/K)



MCS: ΔT_{850} (+0.84 K/K)



Summary

- Despite their occasional (13%) occurrence globally, AR, TS, and MCS days together account for ~55% of global mean precipitation and ~75% of extreme precipitation with daily rates exceeding its local 99th percentile.
- GFDL C192AM4 reproduces well the observed percentage of mean and extreme precipitation associated with AR, TS, and MCS days. But the model overestimates precipitation intensity in the 25% heaviest-precipitation AR, TS, and MCS days.
- In an idealized global warming simulation, the modeled changes in global mean and regional distribution of precipitation correspond well with changes in AR/TS/MCS precipitation.
- Globally, the frequency of AR days increases slightly and migrates toward higher latitudes while the frequency of TS days increases over the central Pacific and part of the south Indian Ocean with a decrease elsewhere. The frequency of MCS days increase over parts of the equatorial western and eastern Pacific warm pools and high latitudes and decreases over most part of the tropics and subtropics.
- The AR/TS/MCS mean precipitation intensity increases by ~5%/K due primarily to precipitation increases in the top 25% of AR/TS/MCS days with the heaviest precipitation, which are dominated by the thermodynamic component with the dynamic and microphysical components playing a secondary role.