Crucial Role of Sea Surface Temperature Warming Patterns in Projections of High-Impact Weather, Hydrologic and Climate Sensitivity

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Take-Home Messages

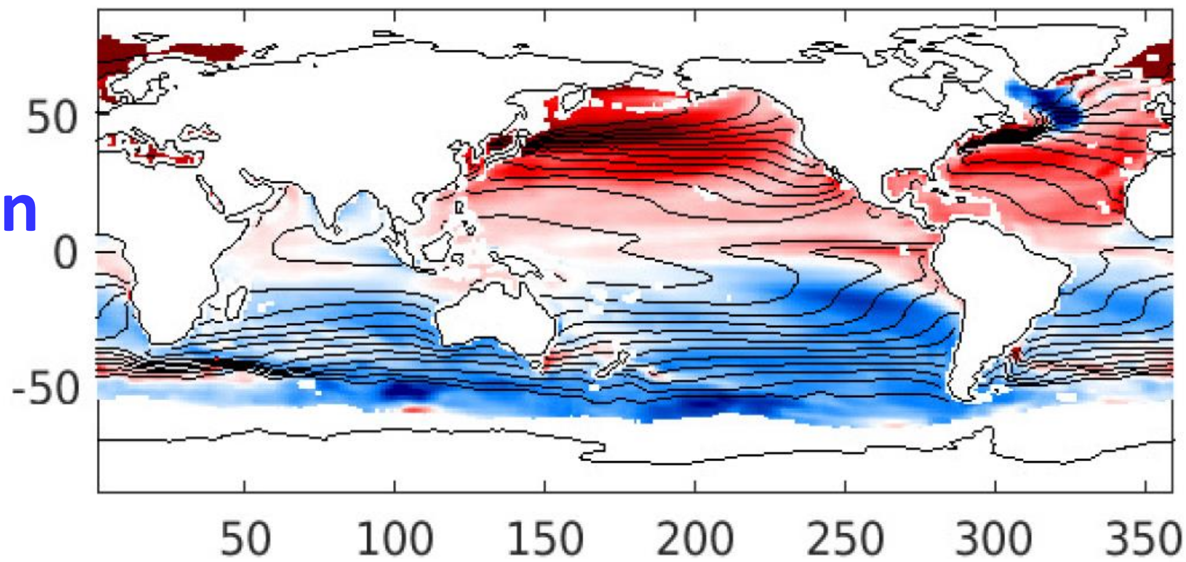
- **GFDL SPEAR has difficulty simulating recent SST trend patterns**
  - **excessive relative warming in the E. Pacific and Southern Ocean**
  - **insufficient relative warming over the Indo-Pacific Warm Pool**
  - **biases are correlated and significant considering internal variability**
- **The biases have profound implications for near-term projections of extreme storms (AR, TS, MCS) as well as global hydrological and climate sensitivity.**
- **If future SST warming pattern continues to resemble the observed pattern rather than model simulated patterns, our results suggest:**
  - **a drastically different future projection of high-impact storms and associated hydroclimate changes**
  - **a stronger global hydrological sensitivity to warming**
  - **substantially less global mean warming due to more negative feedback and lower climate sensitivity**
- **Thus, it is imperative to understand and improve the model biases in SST trend patterns for more confident future projections.**

1979-2020 SST trend patterns in GFDL SPEAR & observation

SPEAR LE ensemble mean

$\overline{SST_A}$ = 0.18 K/decade

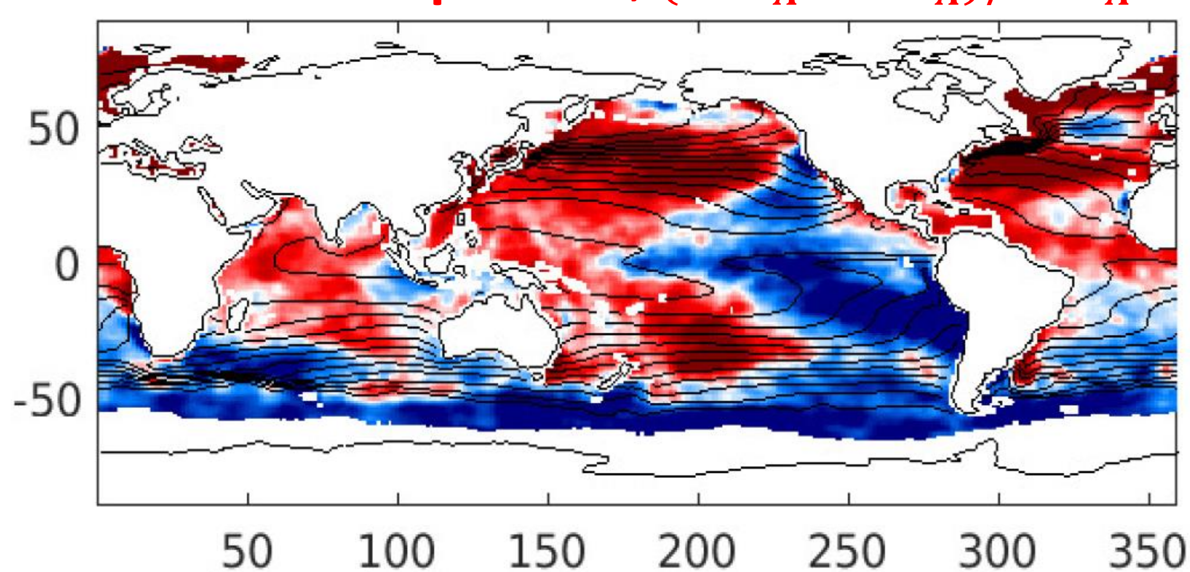
SPEAR−pattern; $(SST_A - \overline{SST_A})/\overline{SST_A}$

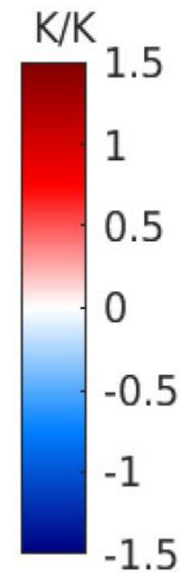


HadISST

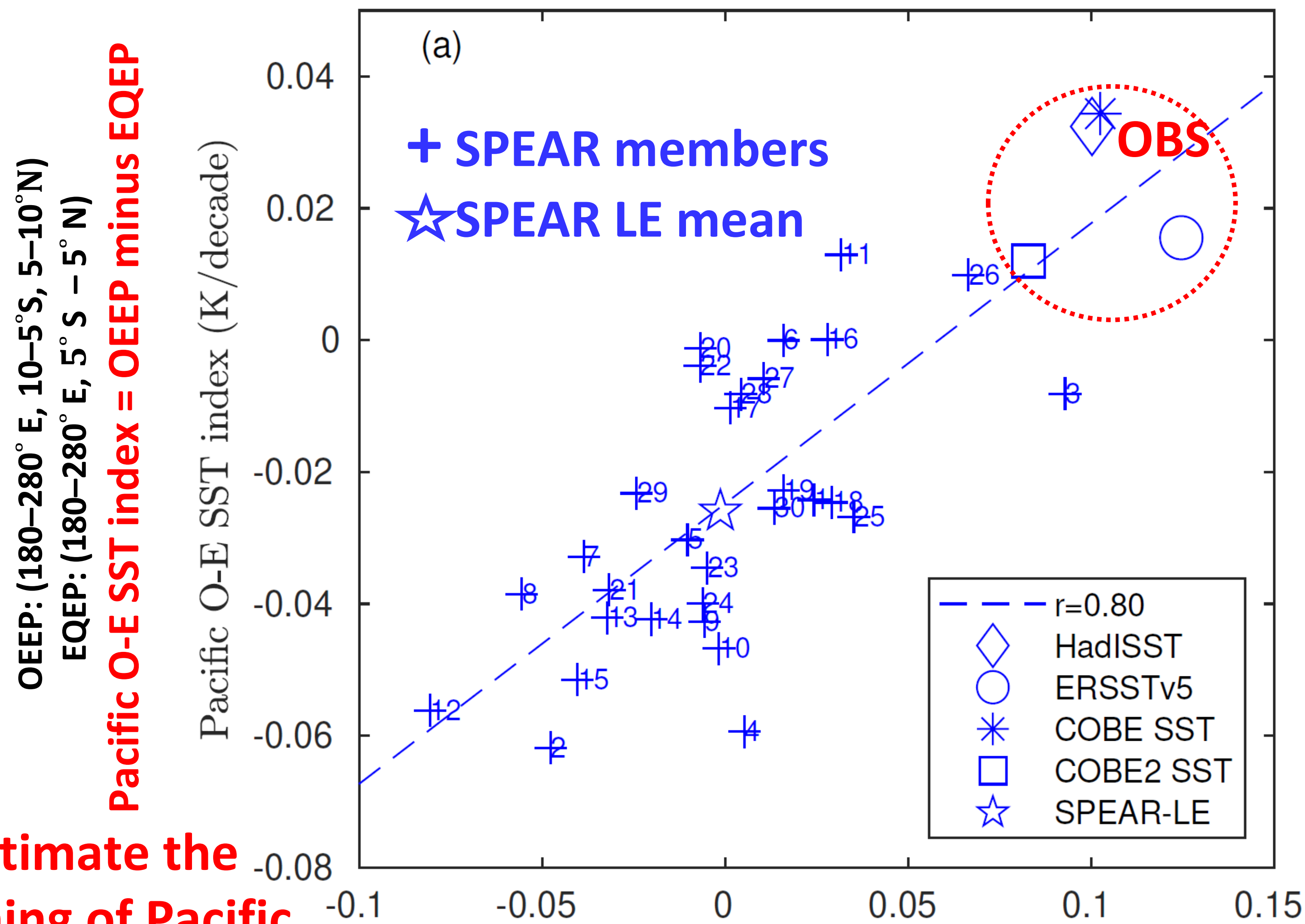
$\overline{SST_A}$ = 0.09 K/decade

Observed−pattern; $(SST_A - \overline{SST_A})/\overline{SST_A}$





Scatter plot of tropical Pacific indices for SST trend patterns



Underestimate the strengthening of Pacific zonal and poleward SST gradient.

Pacific W-E SST index = WPAC minus EPAC

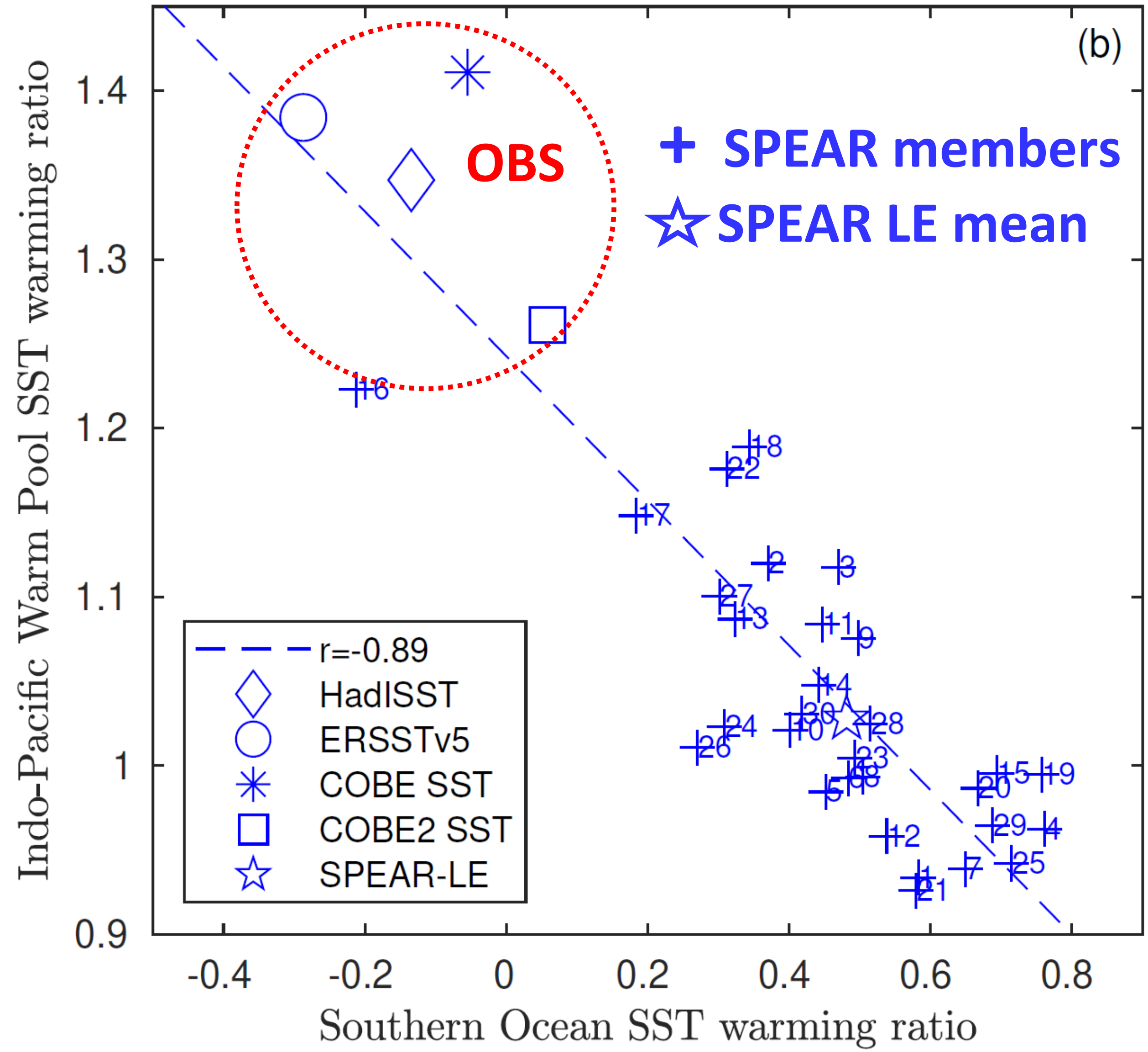
EPAC (180–280° E, 10° S–10° N); WPAC: (110–180° E, 10° S–10° N)

Scatter plot of SO and IPWP indices for SST trend patterns

IPWP: (50–180° E, 30° S – 30° N)

Indo-Pacific Warm Pool SST warming ratio

= IPWP / tropical ocean SST



Southern Ocean SST warming ratio = SO / global open ocean

SO: (0°–360° E, 45—75° S)

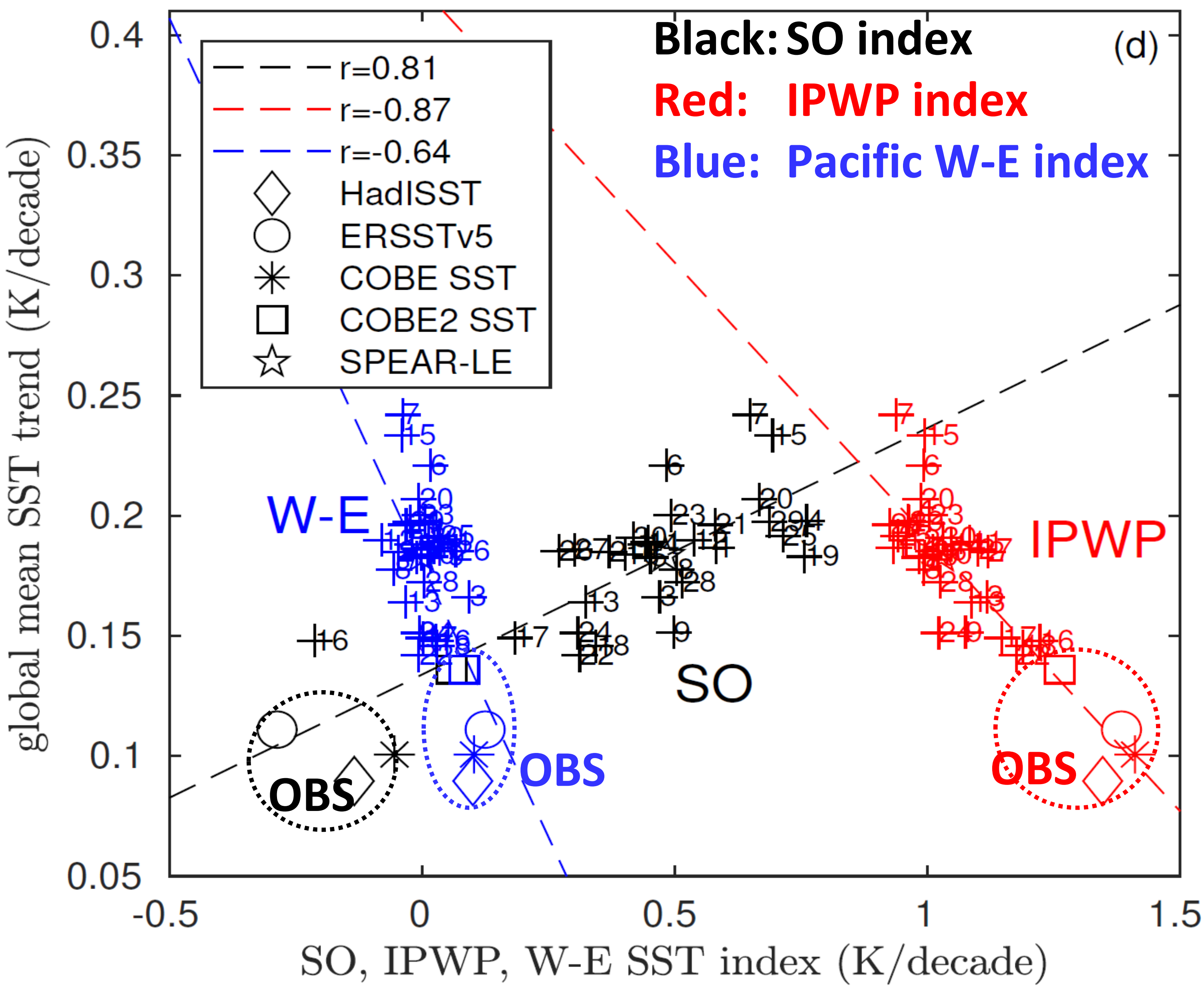
Underestimate

IPWP warming

Overestimate

SO warming ratio

Global mean SST warming and indices of SST trend patterns



Model, simulations, and storm detection methods

Model (GFDL C192AM4, Zhao et al. 2018a,b, Zhao 2020, 2022)

- GFDL CMIP6 HighResMIP participating model
- Atmospheric component of SPEAR-med (Delworth et al., 2020)

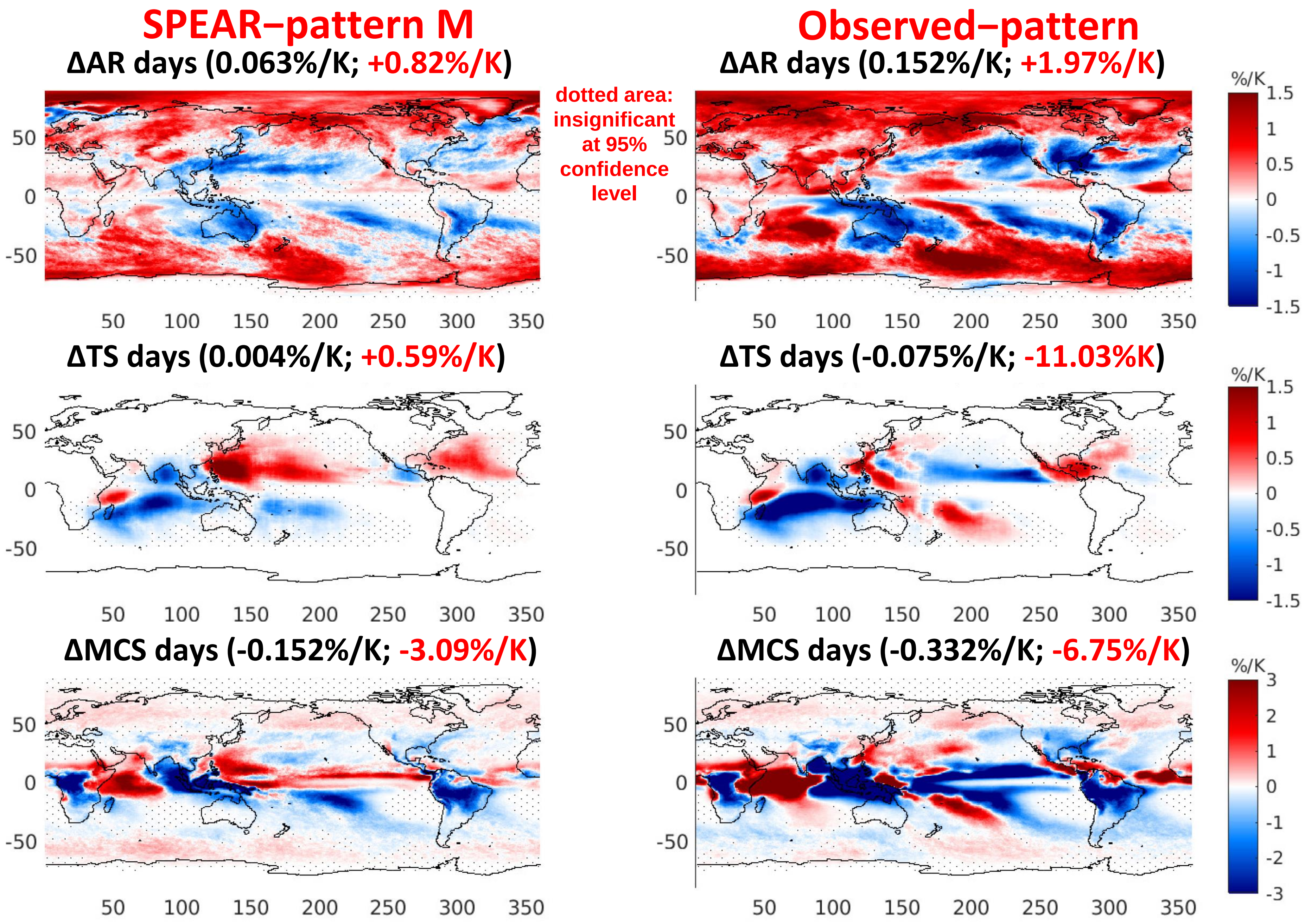
Simulations (101-year)

- **Control**: C192AM4 forced by observed climatological SSTs, sea-ice, fixed radiative gases and aerosol emissions at 2010 condition
- **SPEAR-pattern M**: As in Control except adding SST anomalies, assuming SPEAR pattern Mean will continue for the next 50 years
- **Observed-pattern:** As in Control except adding SST anomalies, assuming observed pattern will continue for the next 50 years

Storm detection method (Zhao 2022)

- Atmospheric Rivers (Guan & Waliser 2015, Zhao 2020)
- Tropical Storms (Zhao et al. 2009, 2012)
- Mesoscale Convective Systems (Dong et al. 2020, Huang et al. 2018)
- AR/TS/MCS days: if at least 1 AR/TS/MCS condition identified from 6-hr data and daily P $\geq$ 1mm/day; Priority: 1) TS → 2) AR→ 3) MCS

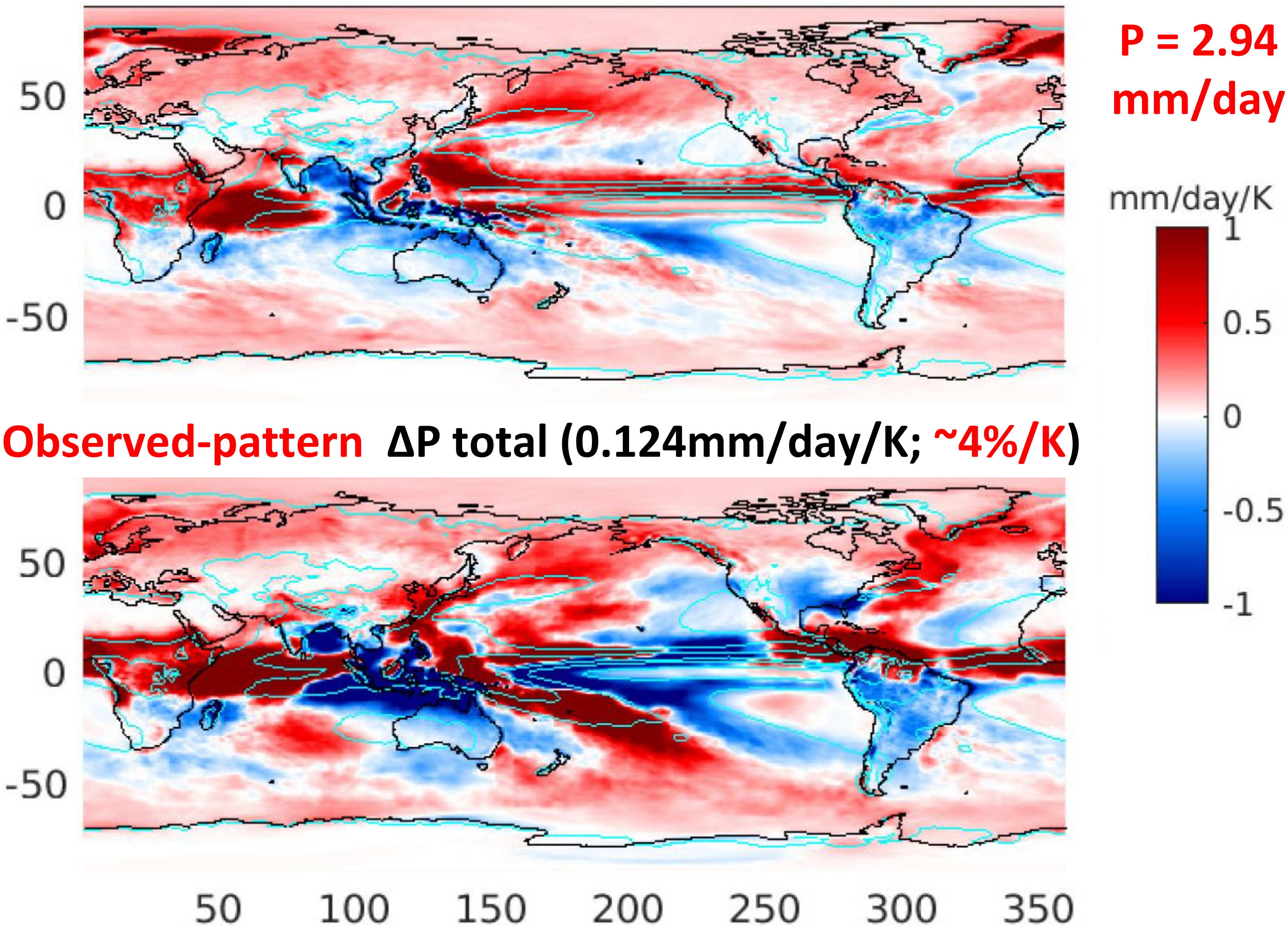
Future change in annual frequency of AR, TS and MCS days



Change in annual precipitation: SPEAR vs observed pattern

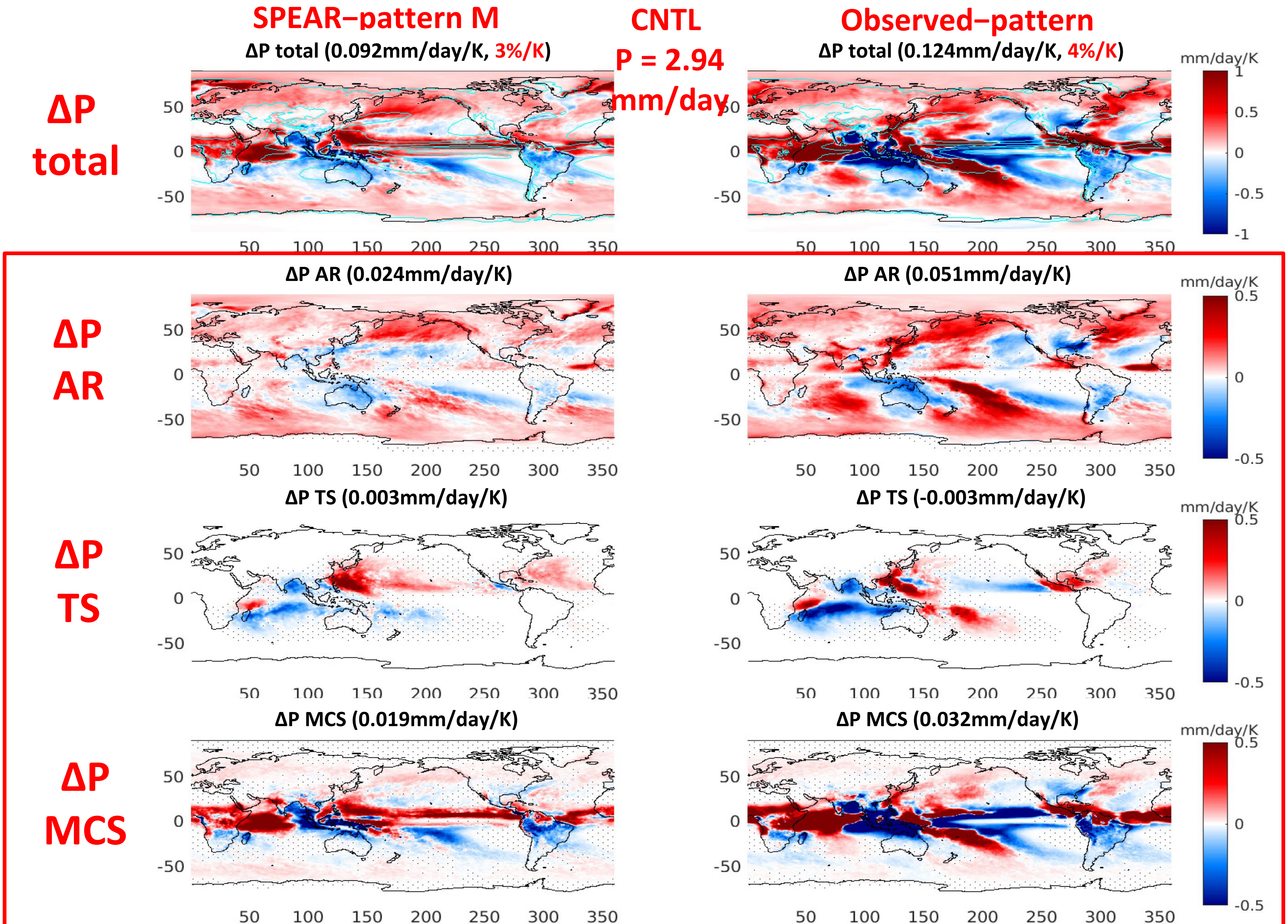
SPEAR–pattern M ΔP total (0.092mm/day/K; ~3%/K)

CNTL
P = 2.94
mm/day

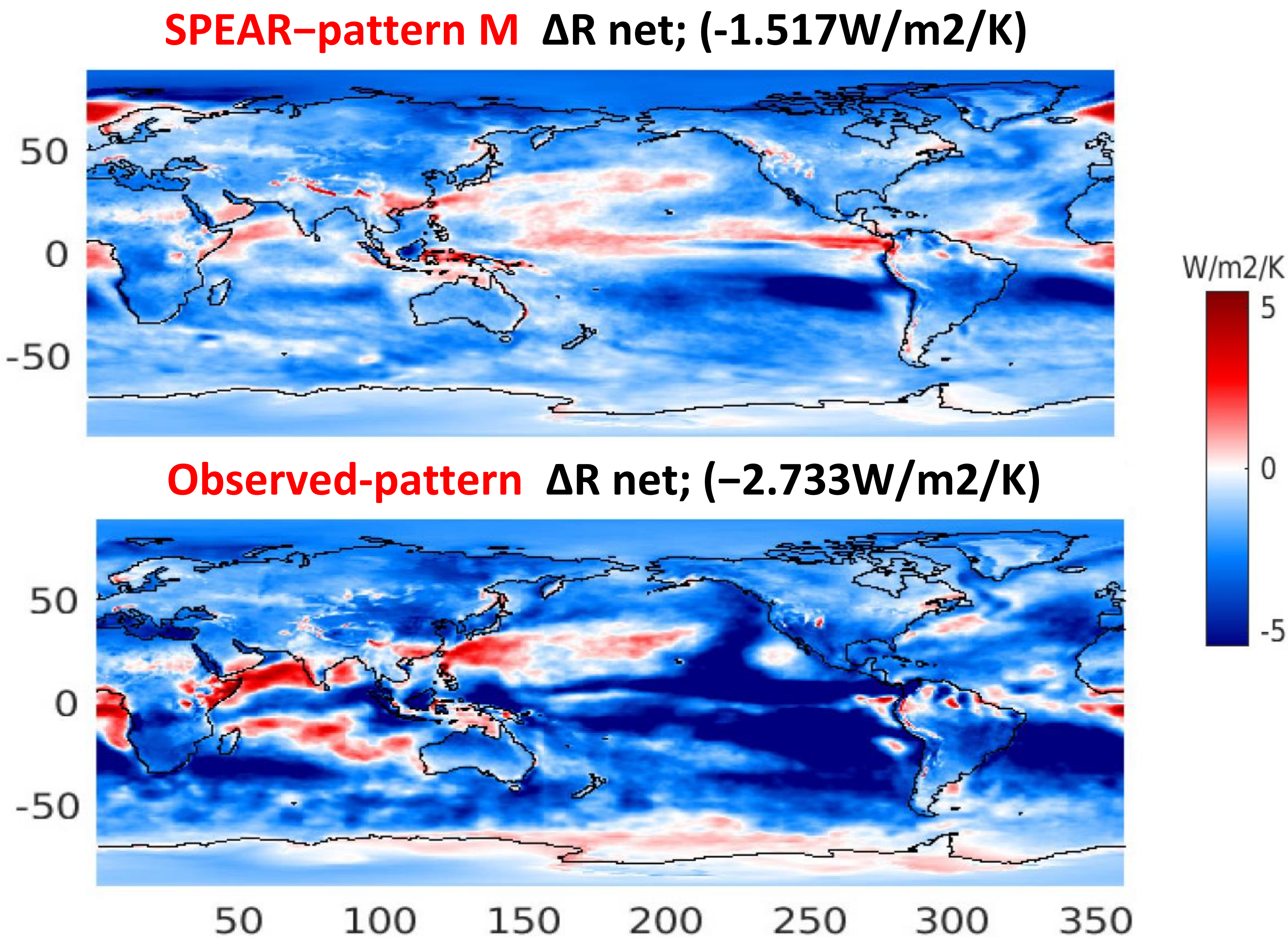


Observed-pattern ΔP total (0.124mm/day/K; ~4%/K)

Change in annual precipitation: SPEAR vs observed pattern



TOA radiative feedback SPEAR vs observed pattern



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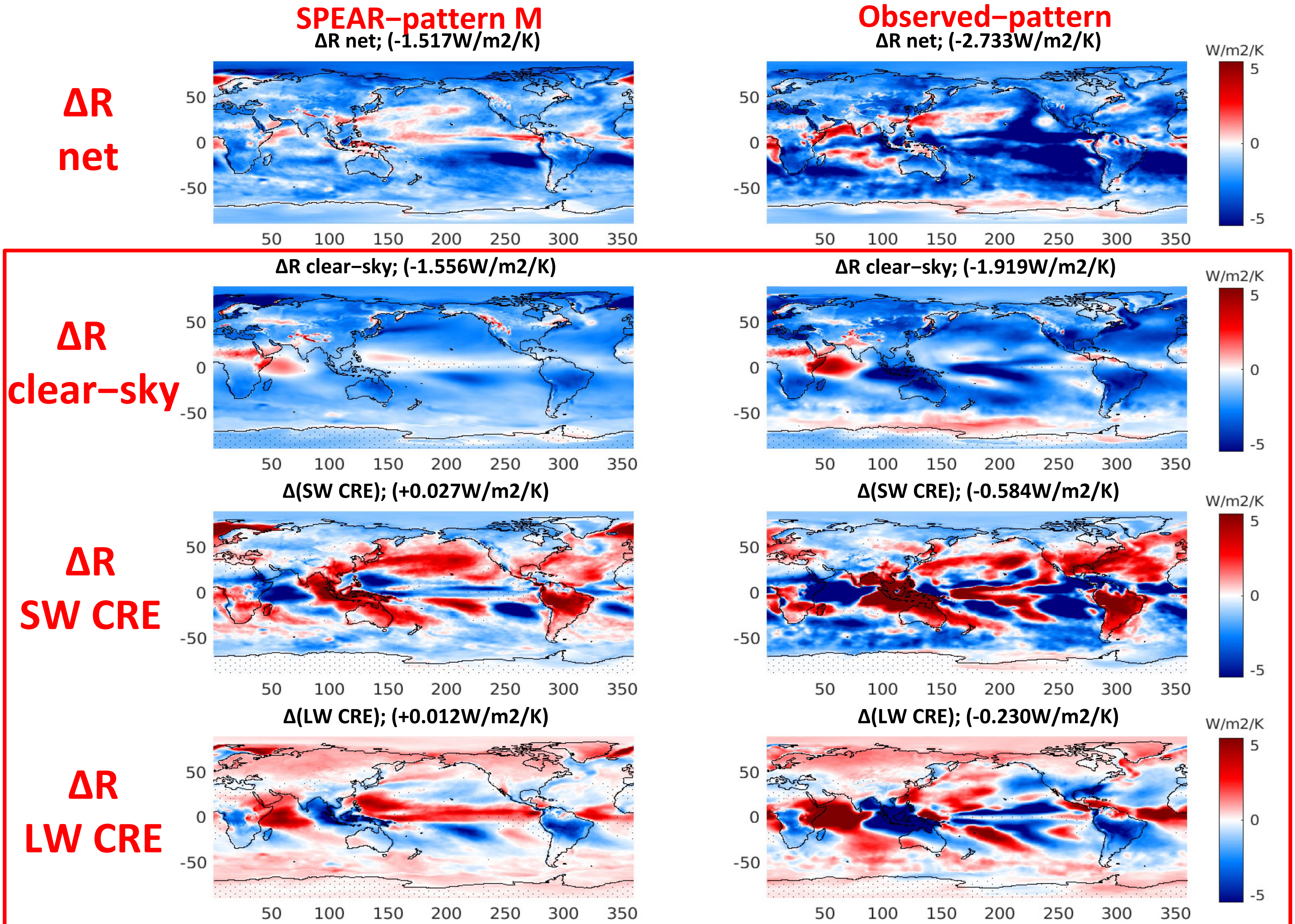
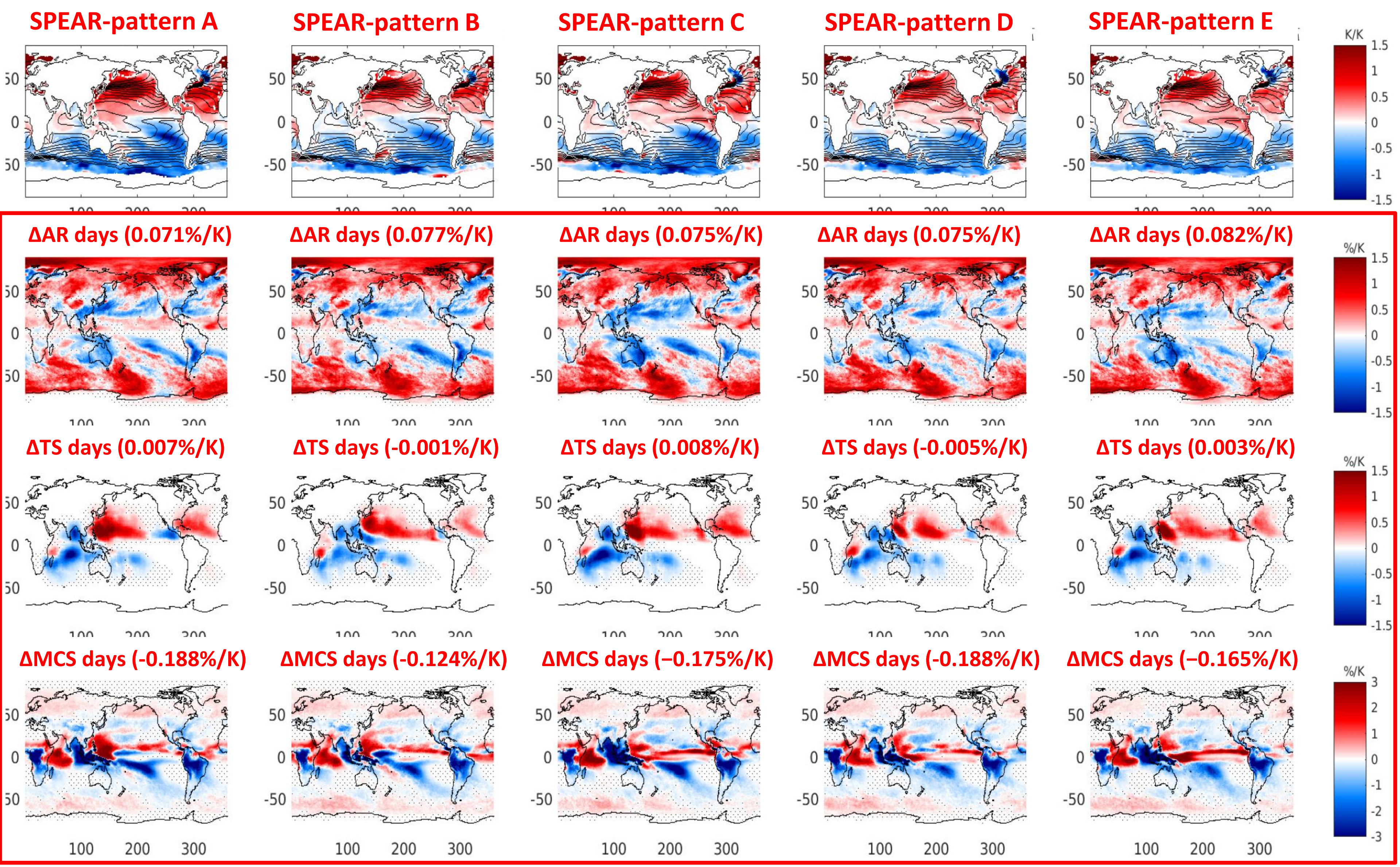


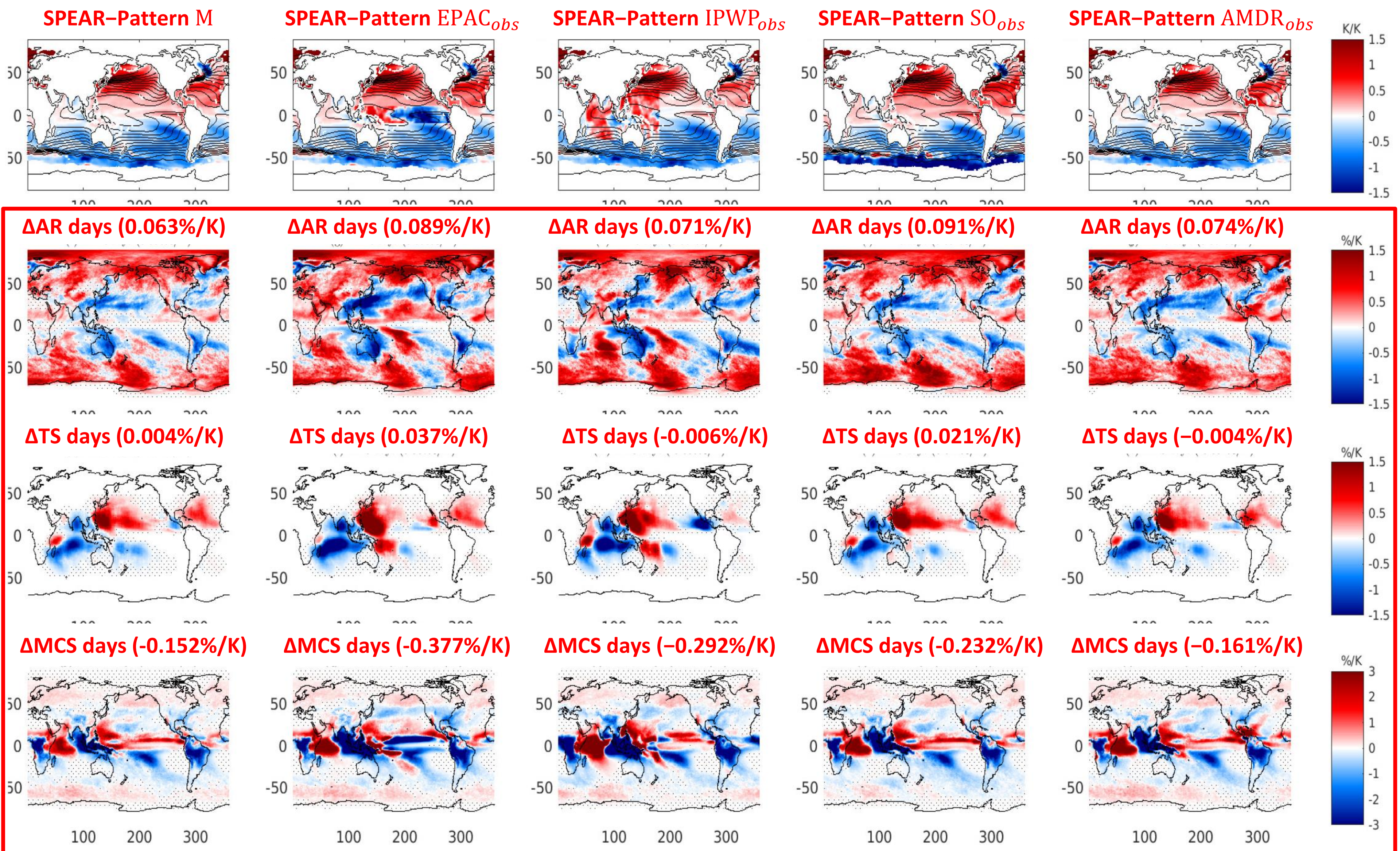
Sensitivity to internal variability of SPEAR LE

best performing ◄······ **Based on equatorial Pacific zonal SST gradient** ······► **worst performing**



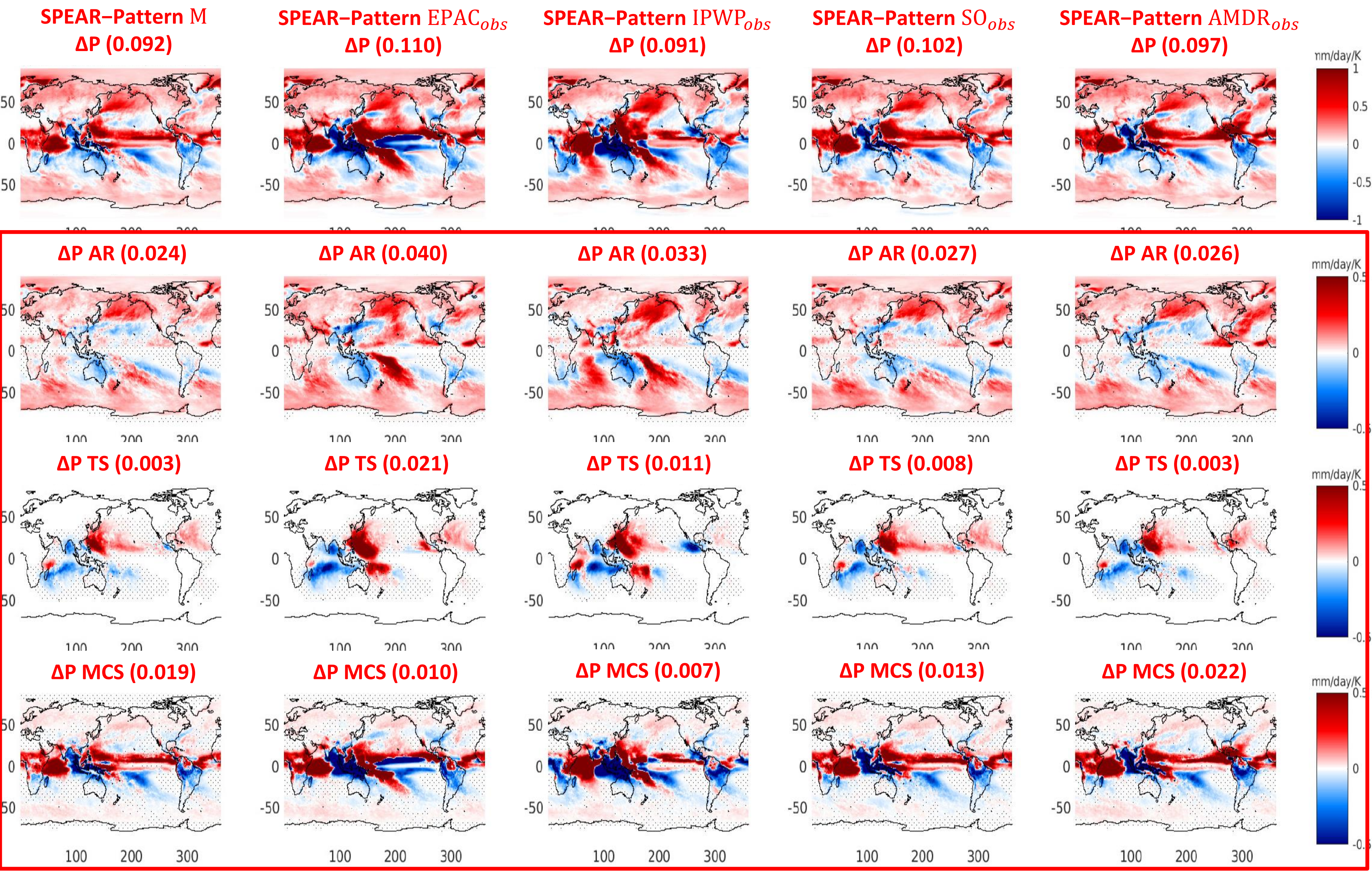
Sensitivity to regional trend of SST warming patterns

changes in annual frequency of AR, TS, and MCS days, unit: %/K



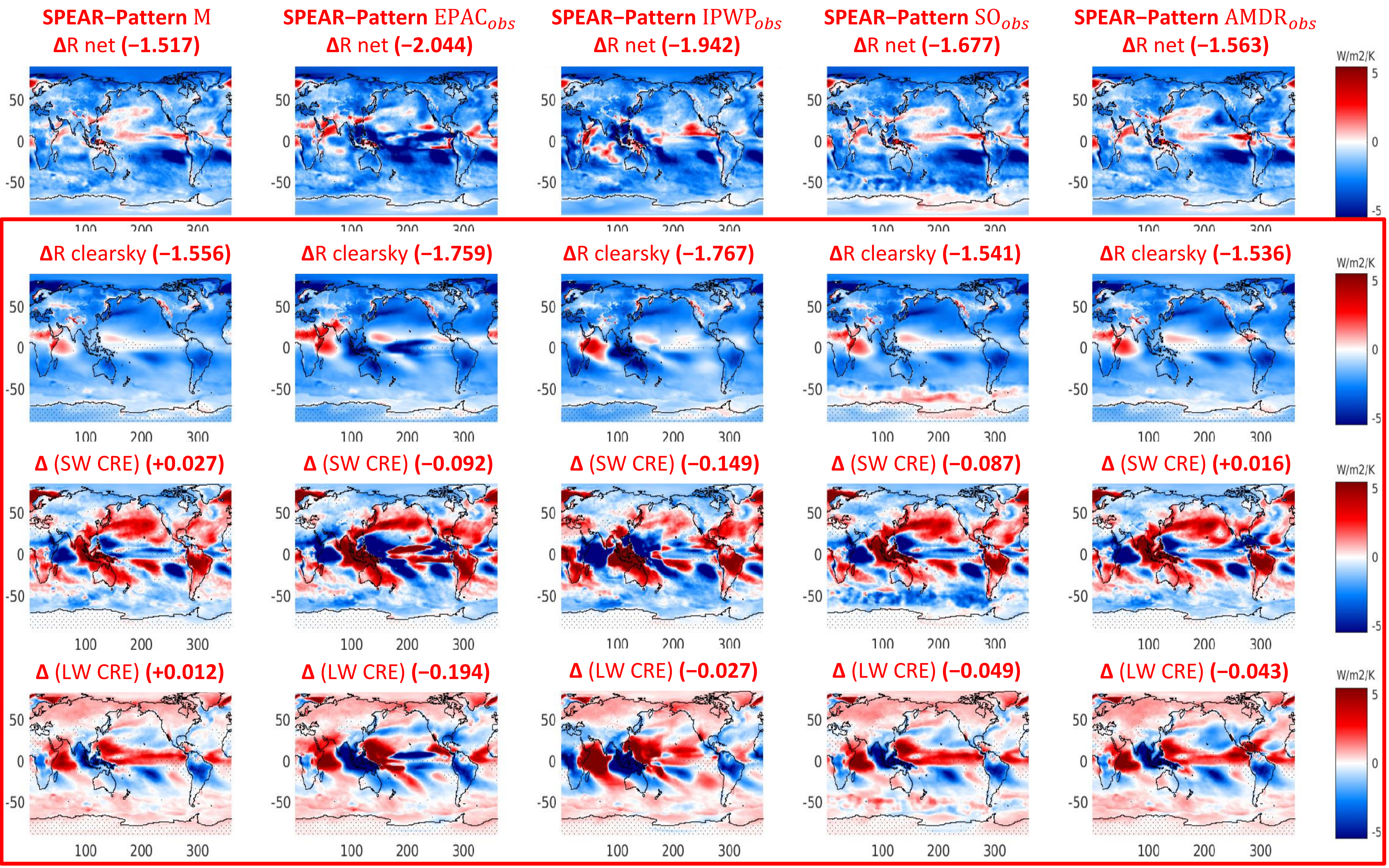
Sensitivity to regional SST trend patterns (precipitation)

changes in annual mean precipitation, unit: mm/day/K



Sensitivity to regional SST trend patterns (TOA radiation)

changes in TOA radiative feedback, unit: W/m2/K



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Open Questions

- **Uncertainties in SST pattern effects:**
  - **To what extent will the SST pattern effects (both global numbers and regional details) be verified in other models, including GSRM?**
  - **What can we do to quantify and assess the robustness of SST pattern effects through multi-model inter-comparisons (e.g., GFMIP) and observational analysis?**
- **What aspects of the coupled models' misrepresentations or omissions of important processes might be responsible for the biases in historical SST trend patterns?**
- **What can we do collectively to identify, test, and improve GCMs' representation of processes to reduce biases in historical SST trend patterns?**