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Correcting the double-ITCZ bias dials down future precipitation over Mediterranean climate regions in North Hemisphere

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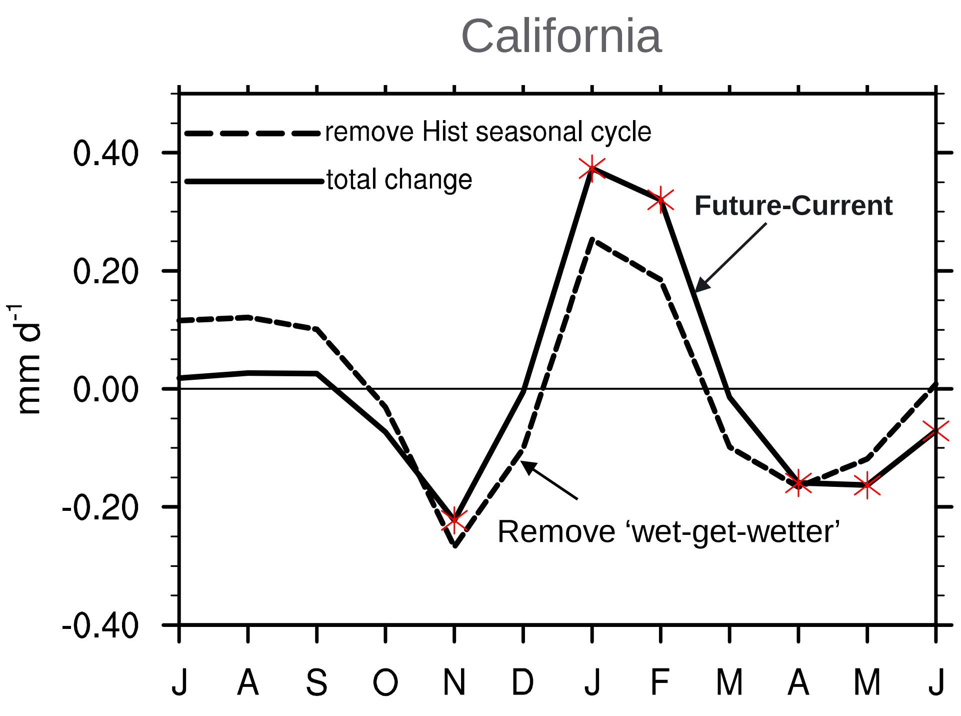
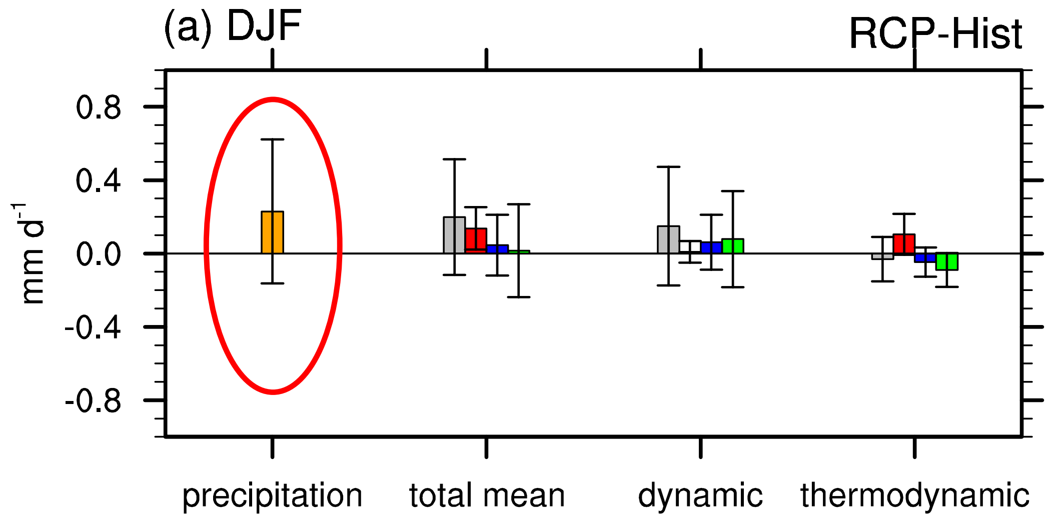
Motivation

- ✓Based on CMIP5, 80% models show a robust sharpening of precipitation seasonal cycle over California, with projecting wetter winters and drier fall and spring.
- ✓Despite the robust sharpening signal, projected magnitudes remain hugely uncertain, with inter-model spread comparable to the ensemble mean.
- ✓Based on multi-model ensemble, the wetter winter is mainly driven by the enhanced Pacific westerly jet and the deepened Aleutian low, which is tele-connected with the ITCZ over tropical Pacific (e.g., Neelin et al. 2013; Dong et al. 2019; Seager et al. 2019; McGee et al. 2018).

Question: What is the impact of the present-day double-ITCZ bias on the future projections of winter precipitation over the California?

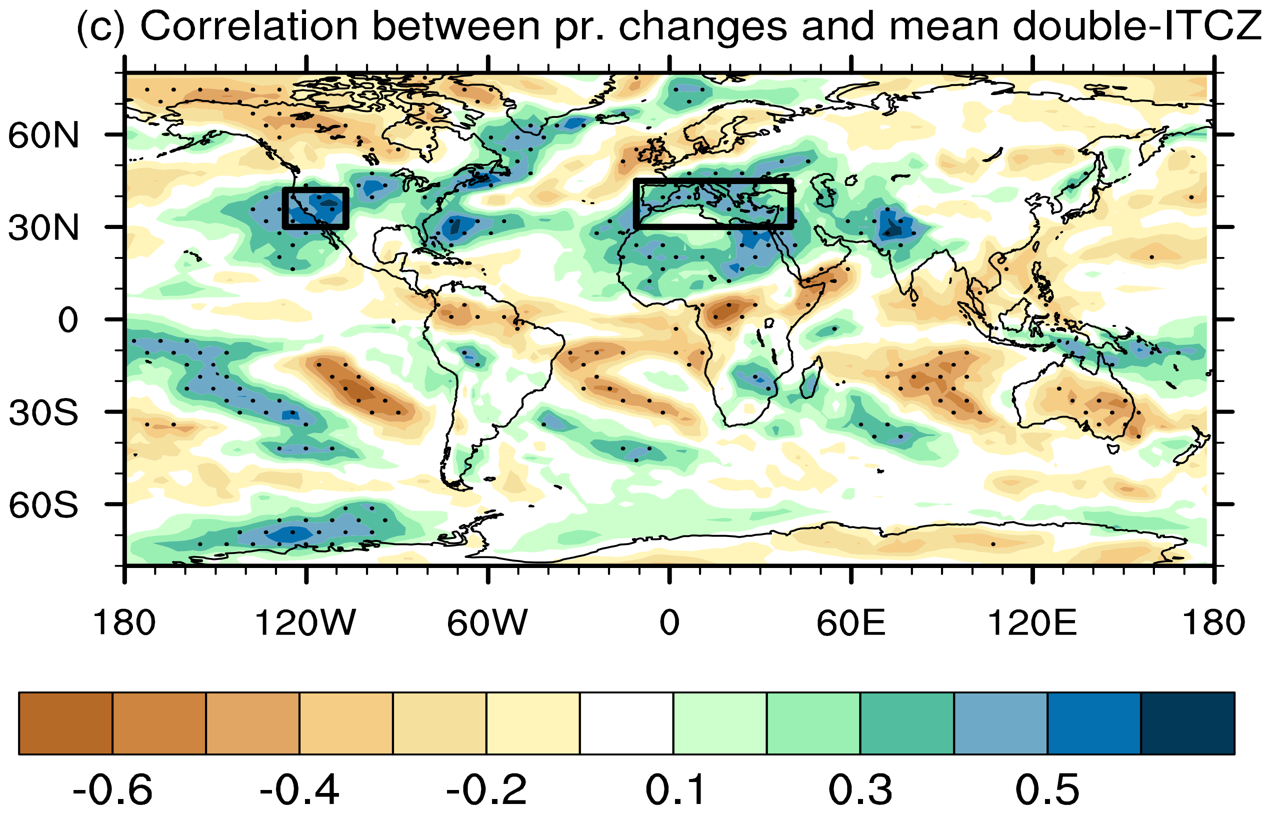


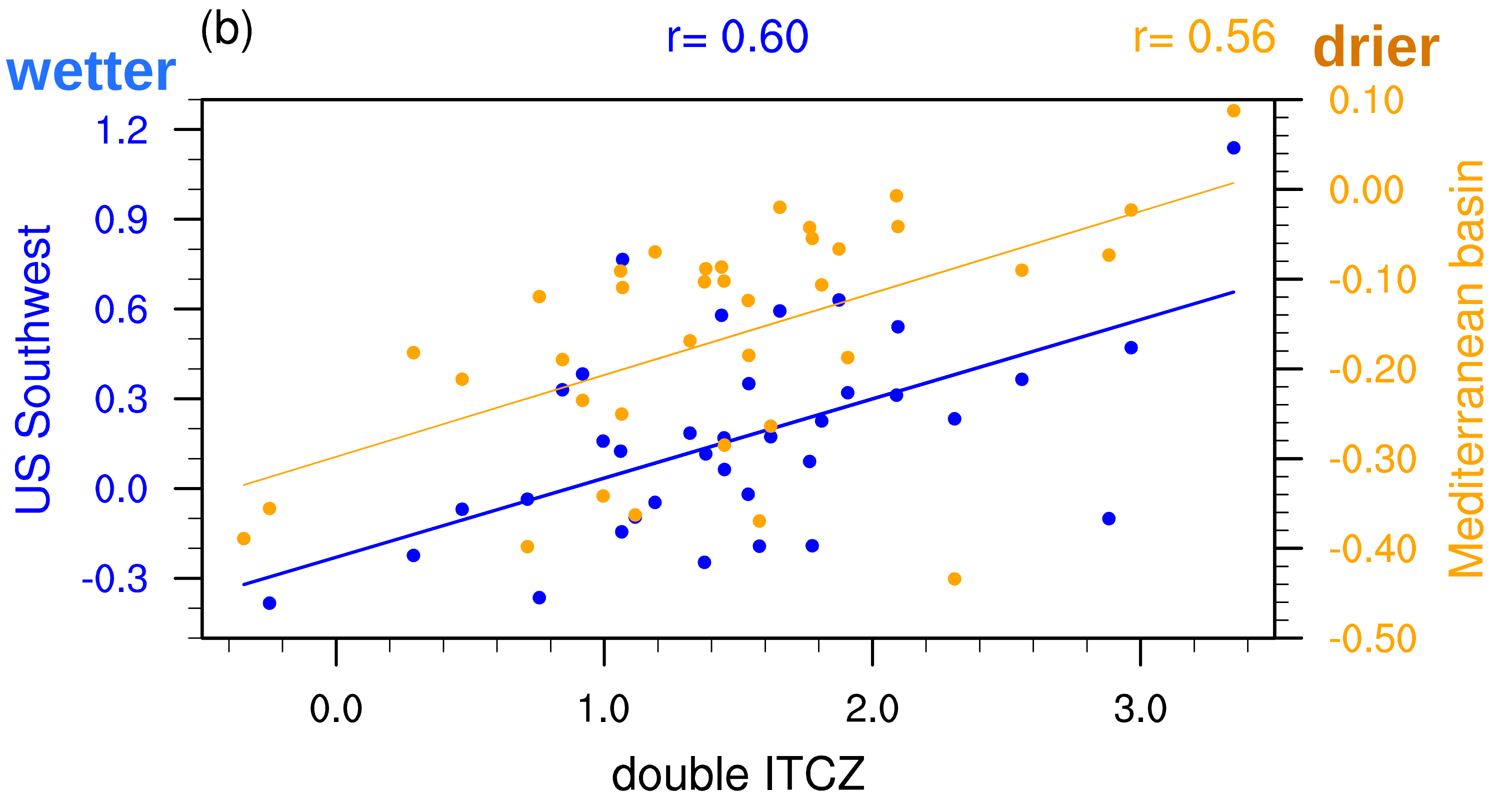


Dong et al. (2019, Journal of Climate)

Emergent constraint of double-ITCZ on winter precipitation changes

37 CMIP5 models





Double-ITCZ: inter-hemispheric difference in precipitation over tropical ocean: 0-20° S minus 0-20° N

Models with larger double-ITCZ biases tend to exaggerate the wetter winter over US Southwest and understate the drier winter over Mediterranean Basin in the warmer future.

The double-ITCZ spread in the CMIP5 models can explain around 36% and 31% of the inter-model spread in precipitation projections over the US Southwest and Mediterranean Basin, respectively.

Physical processes underpinning the constraints

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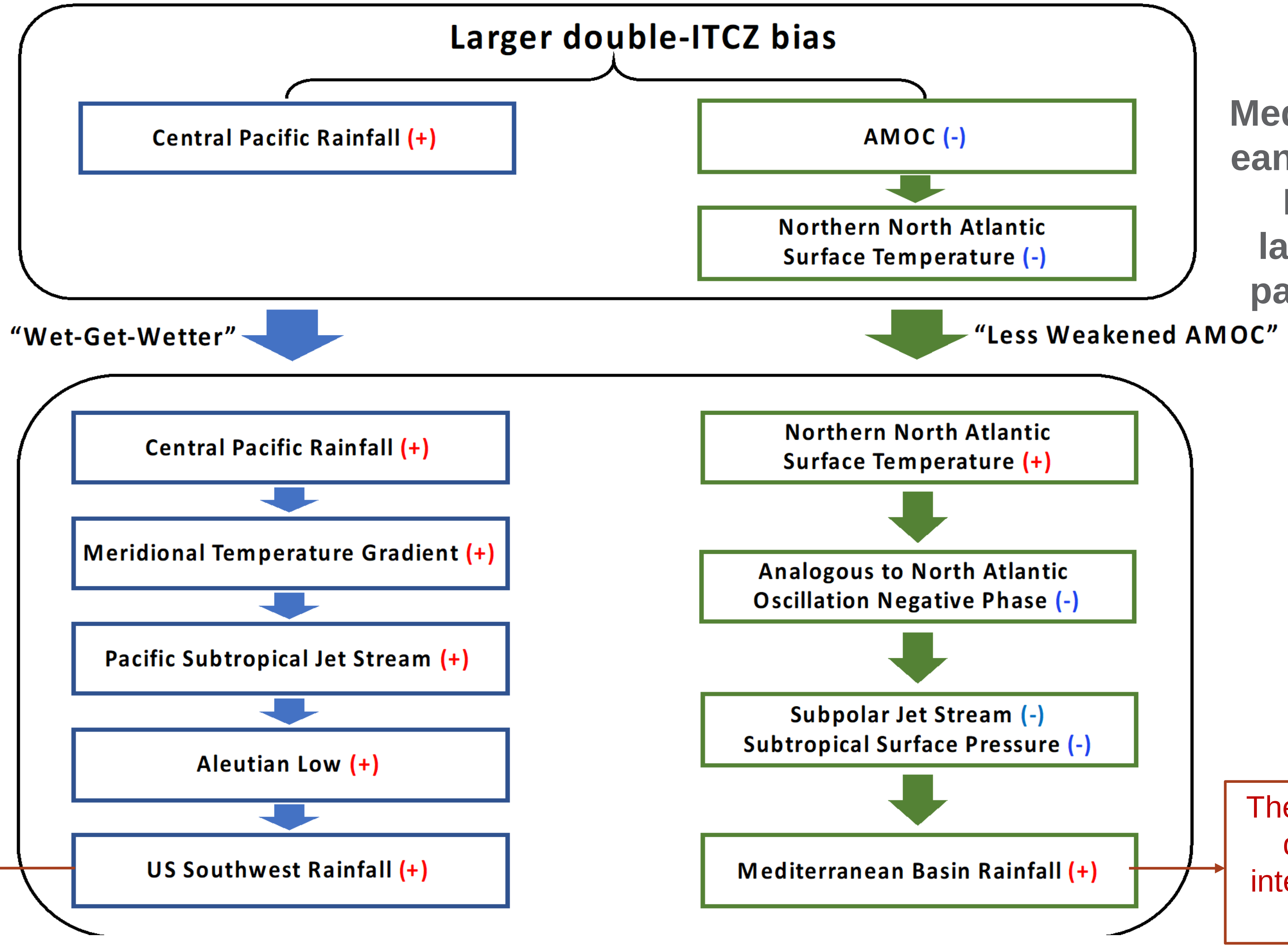
PRESENT

US Southwest: Tropical pathway

Mediterranean Basin: High latitude pathway

FUTURE



Constraining the double-ITCZ with observation, the projected wetting is reduced to no change.

The projected drying is intensified by 32%.

Research and opportunities in the future

- **3-5 years:** Since the corrected precipitation changes based on double-ITCZ bias over the two regions still show considerable spread among models, possible roles of other factors warrant further investigation, such as El Niño-like warming pattern, midlatitude ocean change.

- **5-10 years:** A systematic analysis to develop and understand the emergent constraints in multiple generations of models (with improved physics and increasing resolution) showing different biases will better inform uncertainties in projections of precipitation change over Mediterranean regions, which has profound societal and economic implications for these regions already under severe water stress.

Questions?

Thank you

Inter-model regressions onto the present-day double-ITCZ

Physical processes underpinning the projected precipitation in US Southwest

Larger double-ITCZ bias

⇩ "Wet-get-wetter"

Central Pacific rainfall (+)

⇩

Meridional temperature gradient (+)

⇩

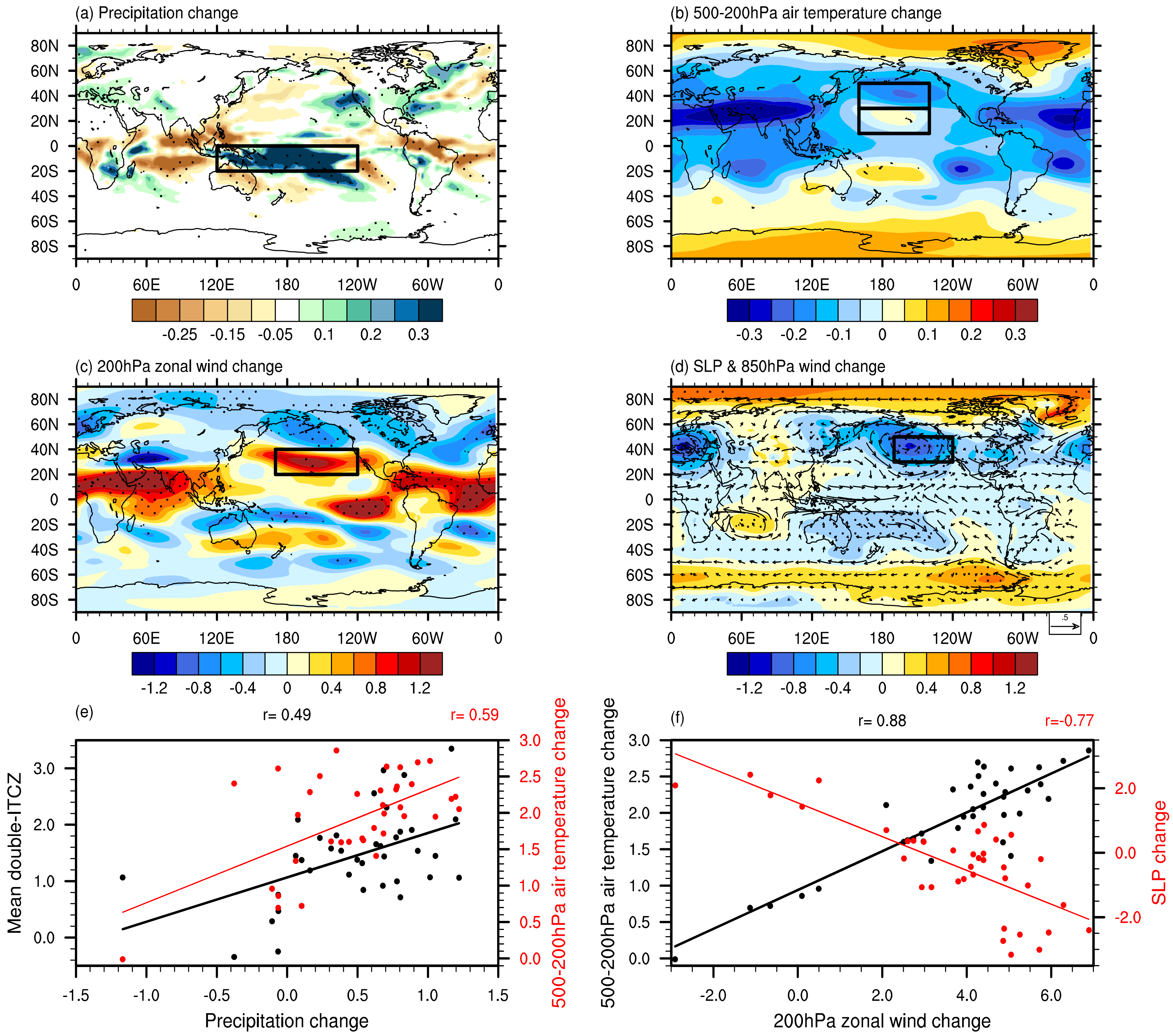
Pacific subtropical jet stream (+)

⇩

Aleutian Low (+)

⇩

US Southwest rainfall (+)



Physical processes underpinning the projected precipitation in Mediterranean Basin

Larger double-ITCZ bias

⇩ Weaker AMOC

Surface temperature in northern North Atlantic (-)

⇩ Weaker slowdown of the AMOC under warming

Surface temperature in northern North Atlantic (+)

⇩

North Atlantic Oscillation (-)

⇩

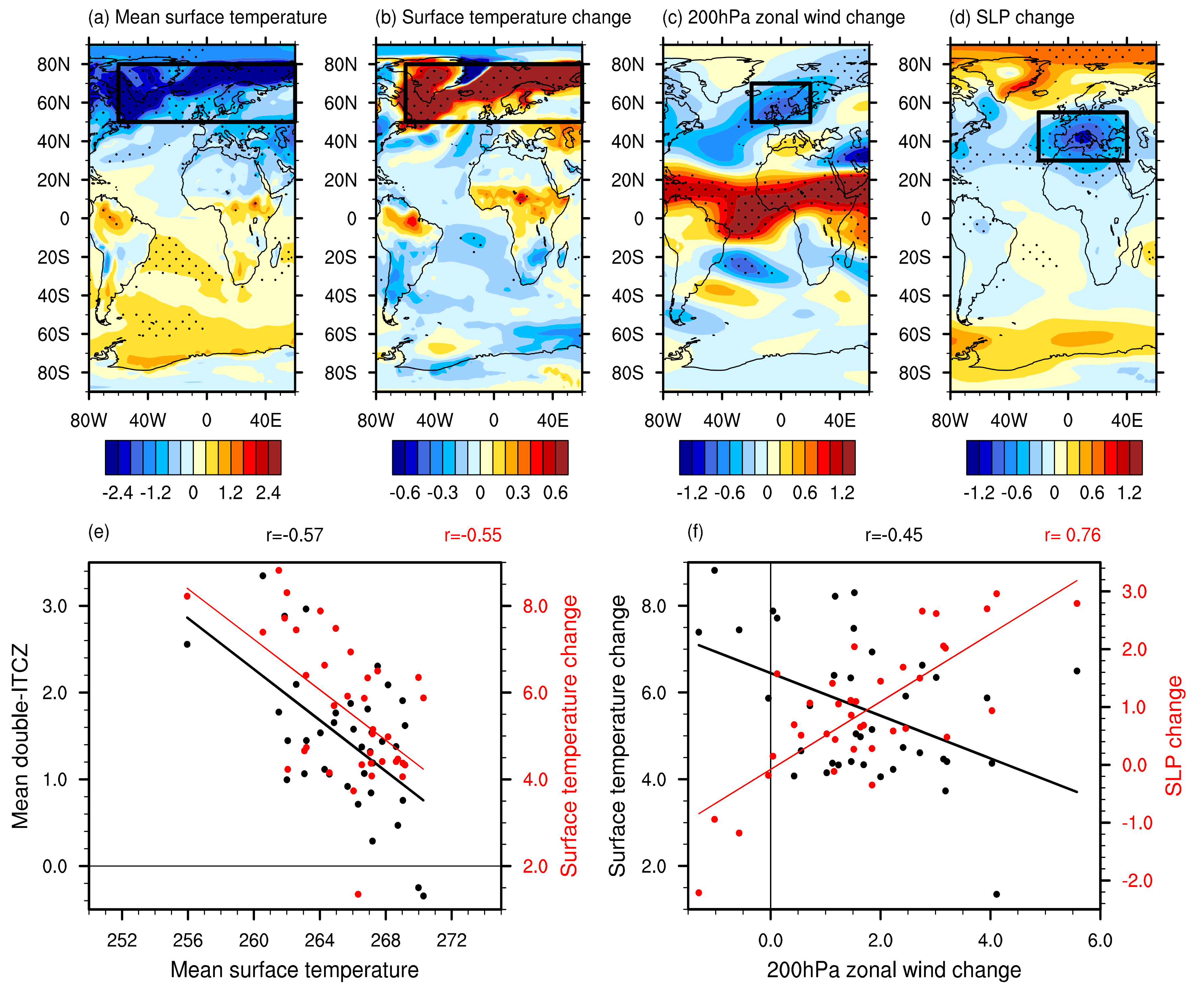
subpolar jet stream (-)
subtropical surface pressure (-)

⇩

Mediterranean basin rainfall (+)

Inter-model regressions onto the present-day double-ITCZ

PCC=-0.75



Correcting precipitation change using observed double-ITCZ

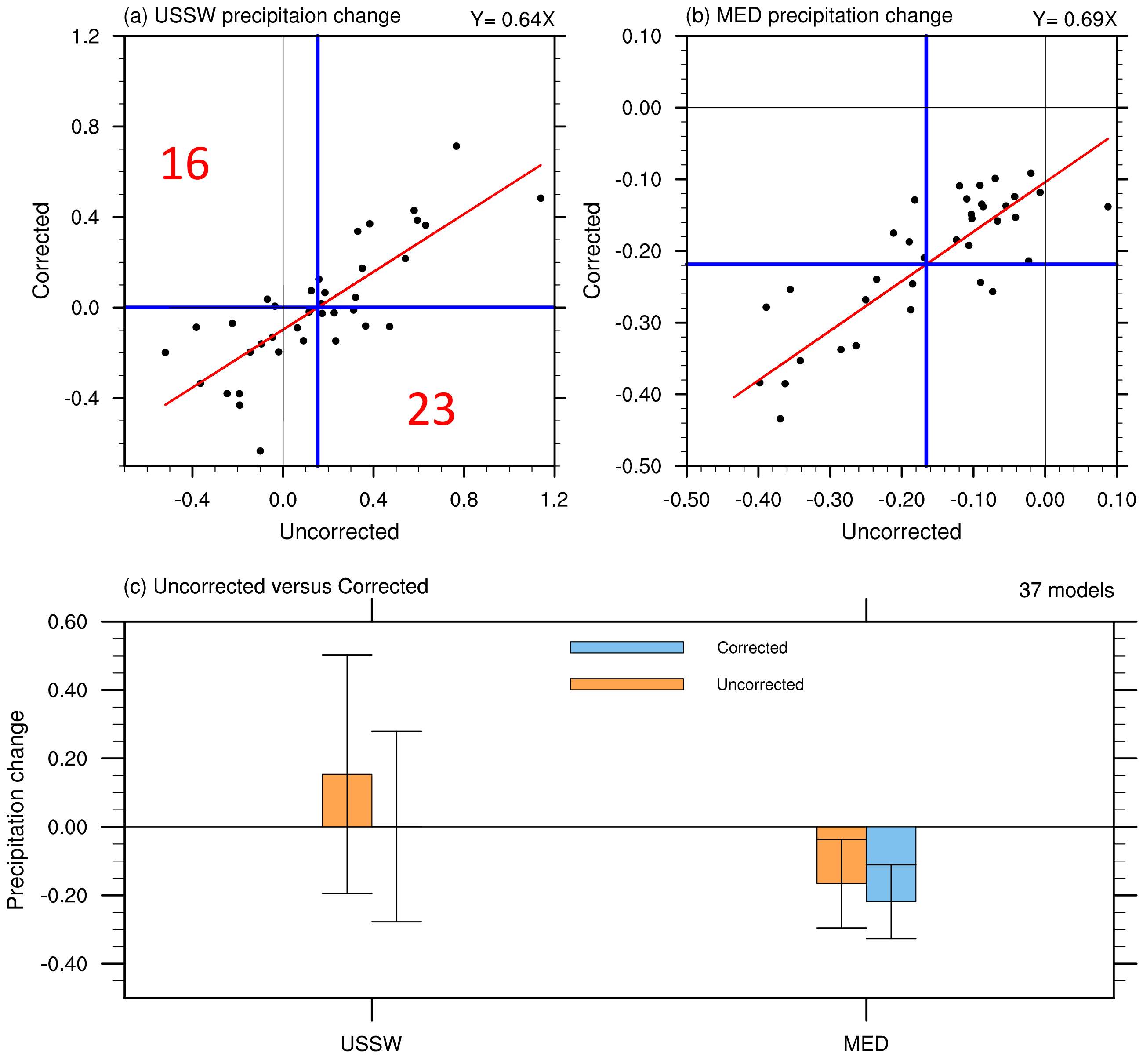
$$\Delta P_{corrected} = \Delta P_{uncorrected} - \Delta P'$$

$$\Delta P' = a(x,y) \times ITCZ_{bias}$$

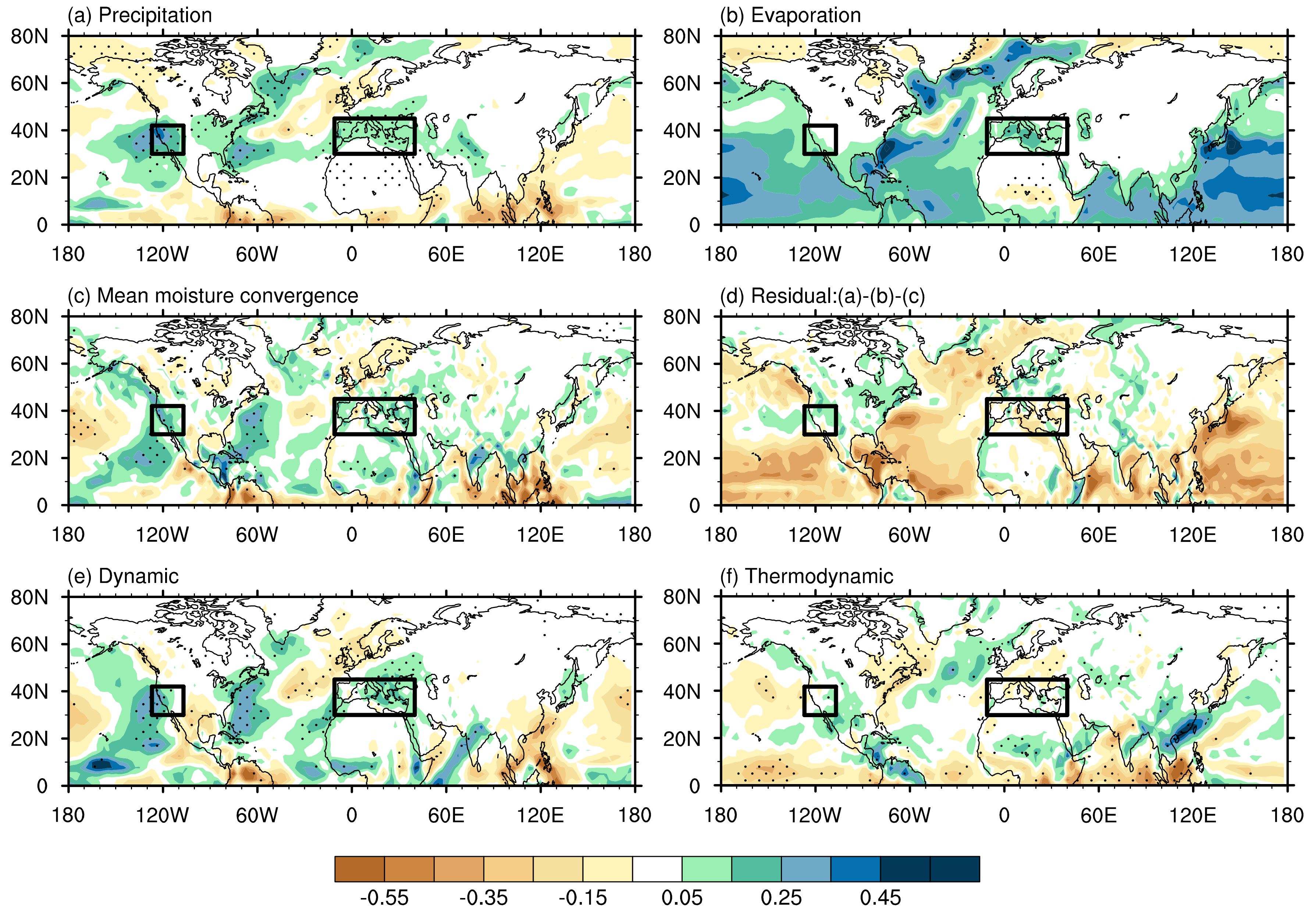
$a(x,y)$ is the regression pattern between the inter-model precipitation change and the historical mean double-ITCZ among 37 CMIP5 models, and $ITCZ_{bias} = ITCZ_m - ITCZ_{obs}$ is the ITCZ bias for model m.

Li et al. (2017)

Constraining the present-day simulated double-ITCZ with observation, the projected wetting over USSW is reduced to no change and the projected drying over MED is intensified by 32%.



Moisture budget analysis



Dynamic effect dominates the spread in precipitation changes associated with the double-ITCZ spread in both regions (Figs. a,e).

Inter-model regressions of moisture budget terms against the simulated present-day double-ITCZ among 37 CMIP5 models.

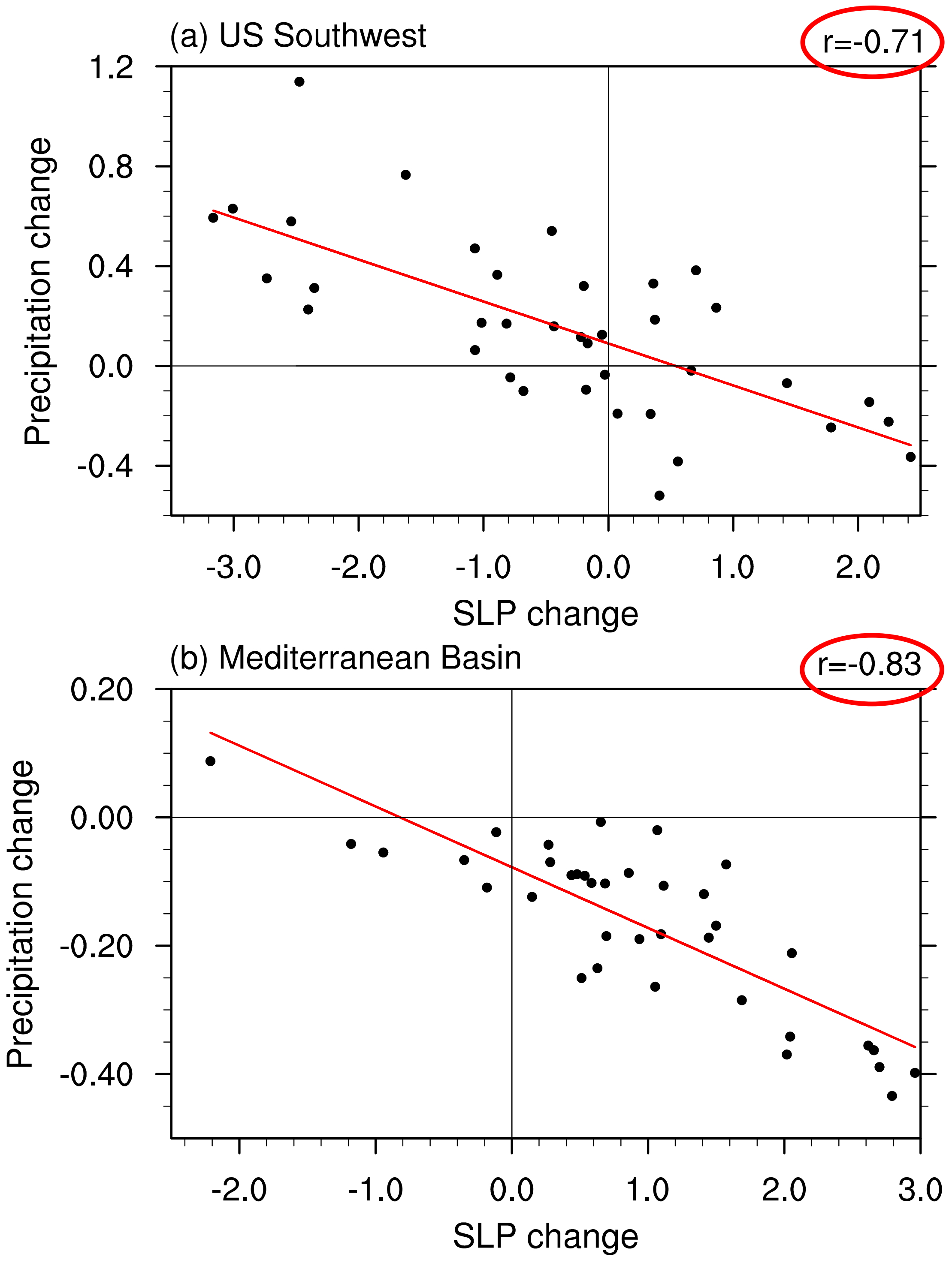
$$\Delta\overline{P} = \Delta\left(-\frac{1}{g\rho_w}\nabla\cdot\int_0^{p_s}\overline{\mathbf{u}}\,\overline{q}\,dp\right) + \Delta\left(-\frac{1}{g\rho_w}\nabla\cdot\int_0^{p_s}\overline{\mathbf{u}'q'}\,dp\right) + \Delta\overline{E}$$

Precipitation **Mean moisture convergence** **Transient (Residual)** **Evaporation**

$$\Delta\left(-\frac{1}{g\rho_w}\nabla\cdot\int_0^{p_s}\overline{\mathbf{u}}\,\overline{q}\,dp\right) \cong -\frac{1}{g\rho_w}\nabla\cdot\int_0^{p_s}\Delta\overline{\mathbf{u}}\,\overline{q}\,dp - \frac{1}{g\rho_w}\nabla\cdot\int_0^{p_s}\overline{\mathbf{u}}\,\Delta\overline{q}\,dp$$

Mean moisture convergence **Dynamic effect** **Thermodynamic effect**

Relationships between precipitation changes and sea level pressure changes in the two regions

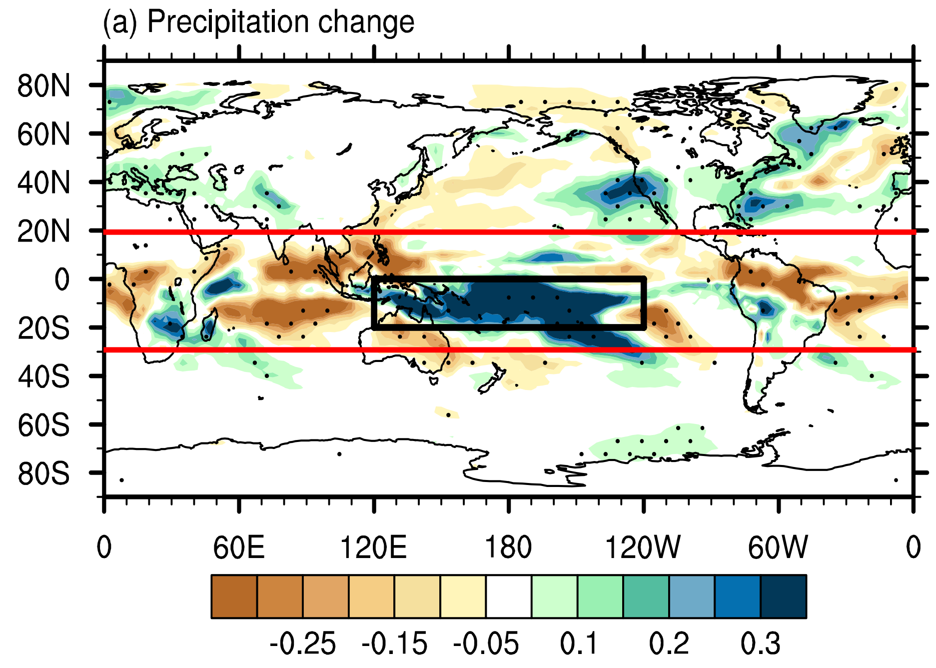


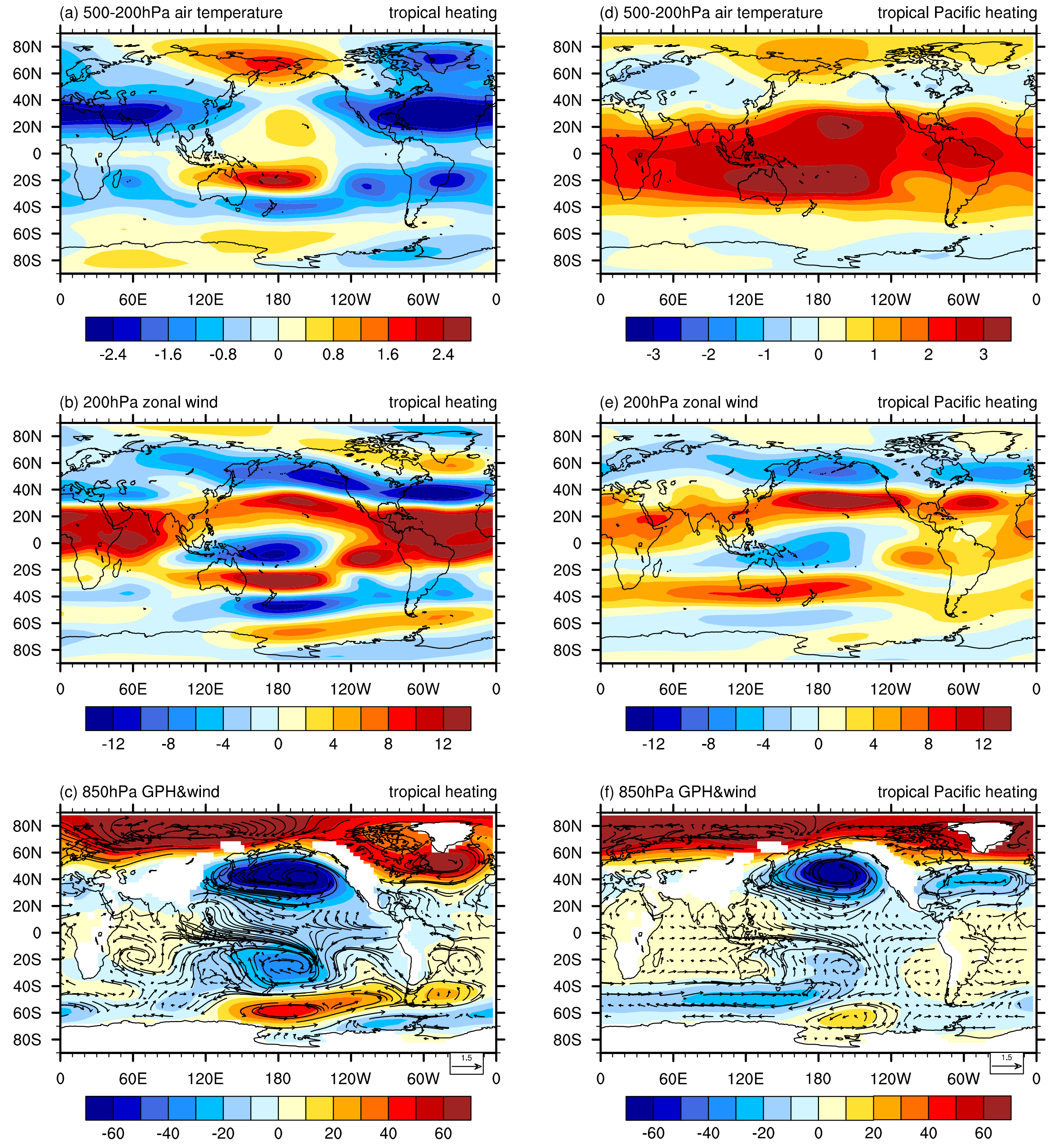
The good relationships confirm the dominant effect of the dynamic components in the spread of precipitation changes.

Hence, we will focus on understanding the dynamical processes behind the spread in precipitation changes in both regions.

Sensitivity experiments using GFDL dry atmosphere model

The dry atmospheric circulation responses over both tropics and North Pacific are quite similar to the full model responses related to the double-ITCZ bias in the CMIP5 models.





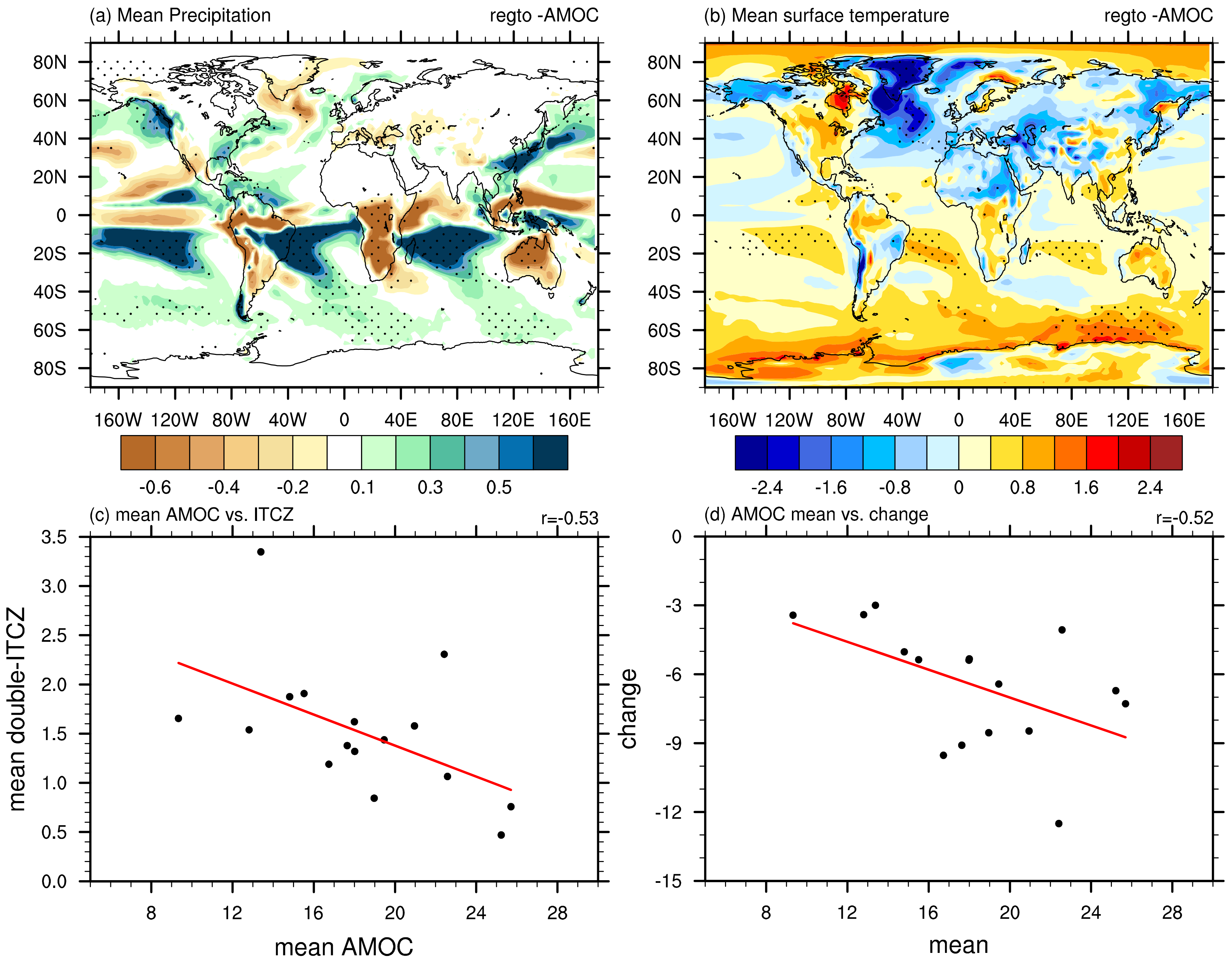
Differences between simulations with positive and negative heating patterns divided by two.

Relationship between mean precipitation and surface temperature with Atlantic Meridional Overturning Circulation (AMOC)

The relationship between double-ITCZ and AMOC can be understood as the result of an energetic framework: weaker AMOC, less (more) heat transport to NH in the ocean (atmosphere), southward shift of tropical rainfall, larger double-ITCZ bias.

The weaker present-day mean AMOC (colder northern North Atlantic) is associated with a weaker slowdown of the AMOC under warming (stronger warming in northern North Atlantic).

Inter-model regressions onto the negative AMOC



Relationships for extreme precipitation changes

The relationships with the present-day mean double-ITCZ for extreme precipitation changes in both regions are weaker but still significant.

In both regions, extreme precipitation is projected to increase under warming, and the corrected extreme precipitation changes are constrained to a weaker increase.

Extreme precipitation is defined as the maximum daily precipitation in winter at each grid based on 31 CMIP5 models with daily precipitation available.