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Weakening of large-scale tropical circulation for different SST pattern in CMIP6

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MOTIVATION

- Large-scale tropical circulation, like the meridionally-oriented Hadley circulation and the zonally-oriented Walker circulation, is expected to weaken with warming
- Weakening is explained both thermodynamically and dynamically (Held and Soden, 2006; Knutson and Manabe, 1995)
- Trend in tropical circulation strength differs between reanalysis dataset and global climate models
- This work analyses trend in large-scale tropical circulation for near-past decades using the recent suite of models from the Coupled Model Intercomparison Project Phase 6 (CMIP6)

DATA AND METHODS

- CMIP6 amip + historical experiments (r1i1p1f1)
- RSS Merged 1-deg Monthly Mean Total Precipitable Water
- GISS Surface Temperature Analysis (GISTEMP v4)
- ECMWF Reanalysis v5 (ERA5)
- **3 strength indices:**
  - upward component of mid-tropospheric vertical velocity
  - spatial variance of mid-tropospheric vertical velocity
  - tropical mean convective mass flux
- **Convective mass flux estimation:**

$$M_c^* = \frac{P}{q}$$

P = precipitation
q = near-surface specific humidity

TEMPERATURE AND ω_{500} TREND

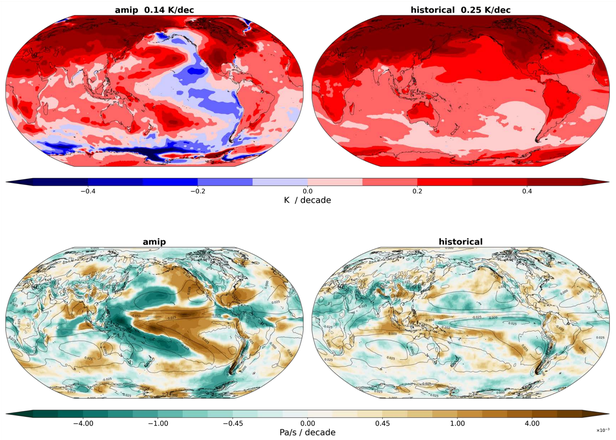

Fig.1: Decadal trend in near-surface temperature and ω_{500} for 1979-2014.

- global mean increase in temperature in both datasets
- La Niña – like warming pattern in amip
- zonal gradient in ω_{500} trend along the equatorial Pacific with opposite signs in amip and historical simulations

STRENGTH INDICES FOR LARGE-SCALE TROPICAL CIRCULATION

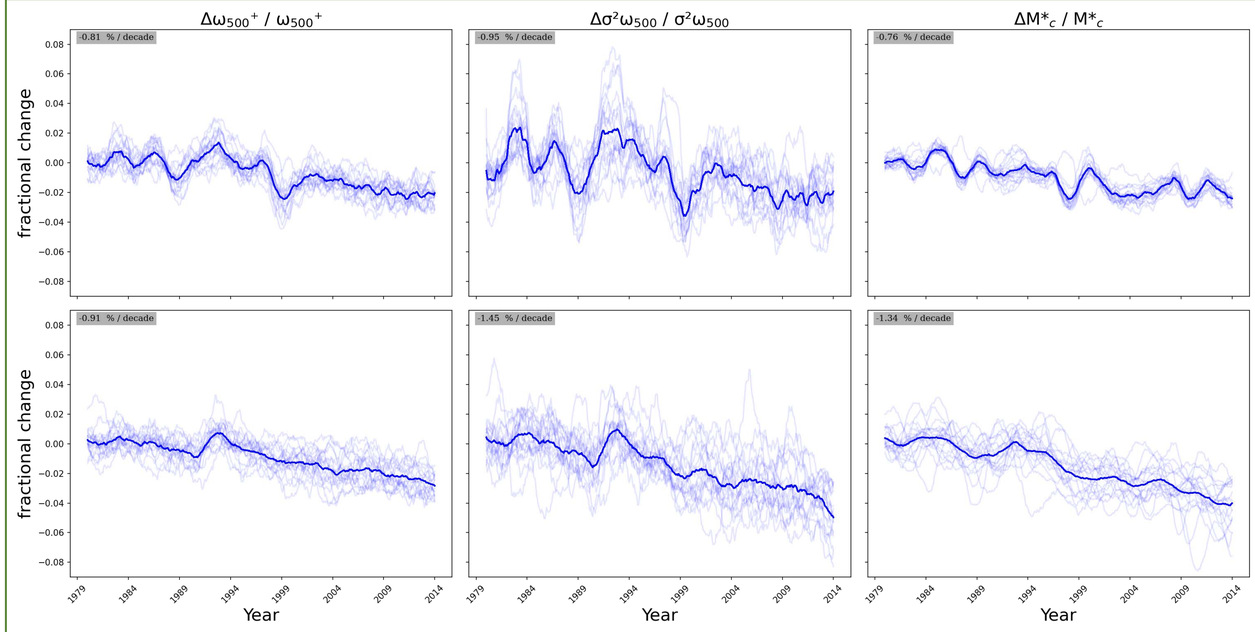

Fig. 2: Time series of the strength indices for (top) amip and (bottom) historical simulations. Bold blue line denotes the ensemble mean. A 2-year running mean has been applied to the time series.

- decrease in all three strength indices, signifying a decrease in tropical-mean large-scale circulation
- weakening of the circulation stronger in the historical simulations compared to the amip simulations
- similar magnitude of weakening per 1 K of global warming in both the simulations (~5.44 %/ K for historical and ~5.0 %/K for amip)
- Anomalous high temperatures during major El Niño (1982-23, 1997-98) are followed by a weakening of the tropical mean circulation. Similarly, anomalous low temperatures during major La Niña events (1988-89, 1999-00, 2007-2008) are followed by a strengthening of the tropical circulation
- ensemble mean (bold blue line) for both the simulations capture the temporary cooling effect of aerosols following the 1991 Mt. Pinatubo explosion

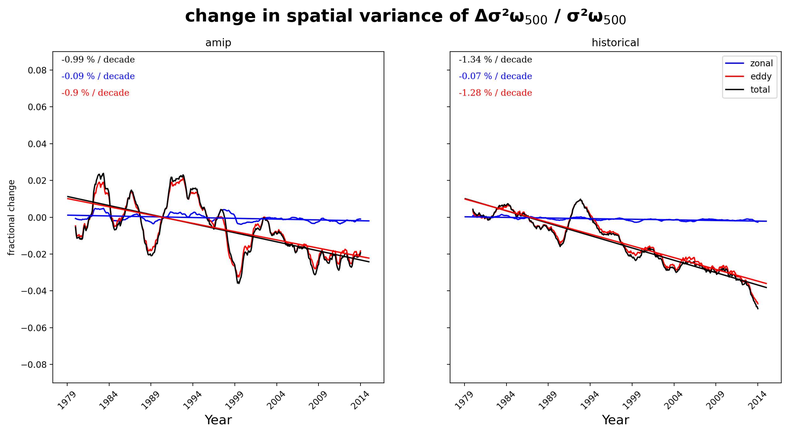

Fig. 3: Fractional change in spatial variance of ω_{500} for total (black), eddy (red) and zonal (blue) components.

- total weakening dominated by the eddy-component of tropical circulation
- weakening of the zonal-component, representative of the Hadley circulation, stronger in the amip simulation ensemble mean.

	$\Delta\omega_{500}^{+} / \omega_{500}^{+}$	$\Delta\sigma^2_{\omega_{500}} / \sigma^2_{\omega_{500}}$	$\Delta M_c' / M_c'$
amip	-0.81 +/- 0.23	-0.95 +/- 1.13	-0.76 +/- 0.2
historical	-0.91 +/- 0.11	-1.45 +/- 1.03	-1.34 +/- 0.09
ERA5	2.92 +/- 0.46	7.32 +/- 1.37	1.38 +/- 0.28
observation	-	-	-0.47 +/- 2.28

Table 1: Decadal trend (%/decade) in tropical mean large-scale circulation.

SPATIAL PATTERN OF WEAKENING

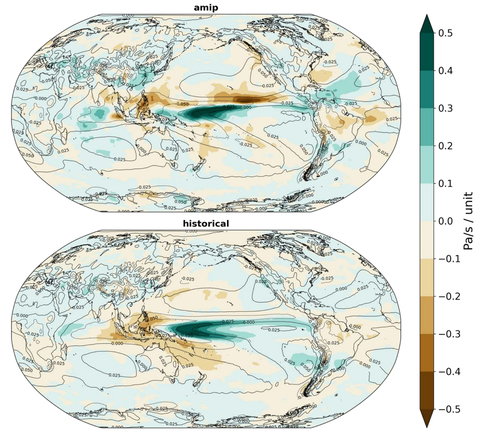

Fig.3: Interannual ω_{500}regressed on tropical mean fractional change in convective mass flux

- anomalous subsidence (convection) in climatological convection (subsidence) zones
- weakening of convection along the ITCZ stronger in the amip simulations

SUMMARY

- **weakening of tropical-mean large-scale circulation in CMIP6 models, irrespective of the pattern of SST warming and ω_{500} trend.**
- **global mean warming plays a bigger role than the pattern effect in the weakening of large-scale tropical circulation**
- **weakening of tropical mean circulation corresponds to a weakening of climatological subsidence/ convective zones and an eastward shift in the Pacific Walker cell.**
- **weakening dominated by changes in the eddy-component compared to the zonal-component.**

REFERENCES AND ACKNOWLEDGEMENT

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- Knutson, T. R., and S. Manabe, 1995: Time-mean response over the tropical Pacific to increased CO2 in a coupled ocean–atmosphere model. J. Climate, 8, 2181–2199, doi:10.1175/1520-0442(1995)008,2181:TMROTT.2.0.CO;2.

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