Shifting Mechanisms for the Tropical Pacific Surface Warming Pattern

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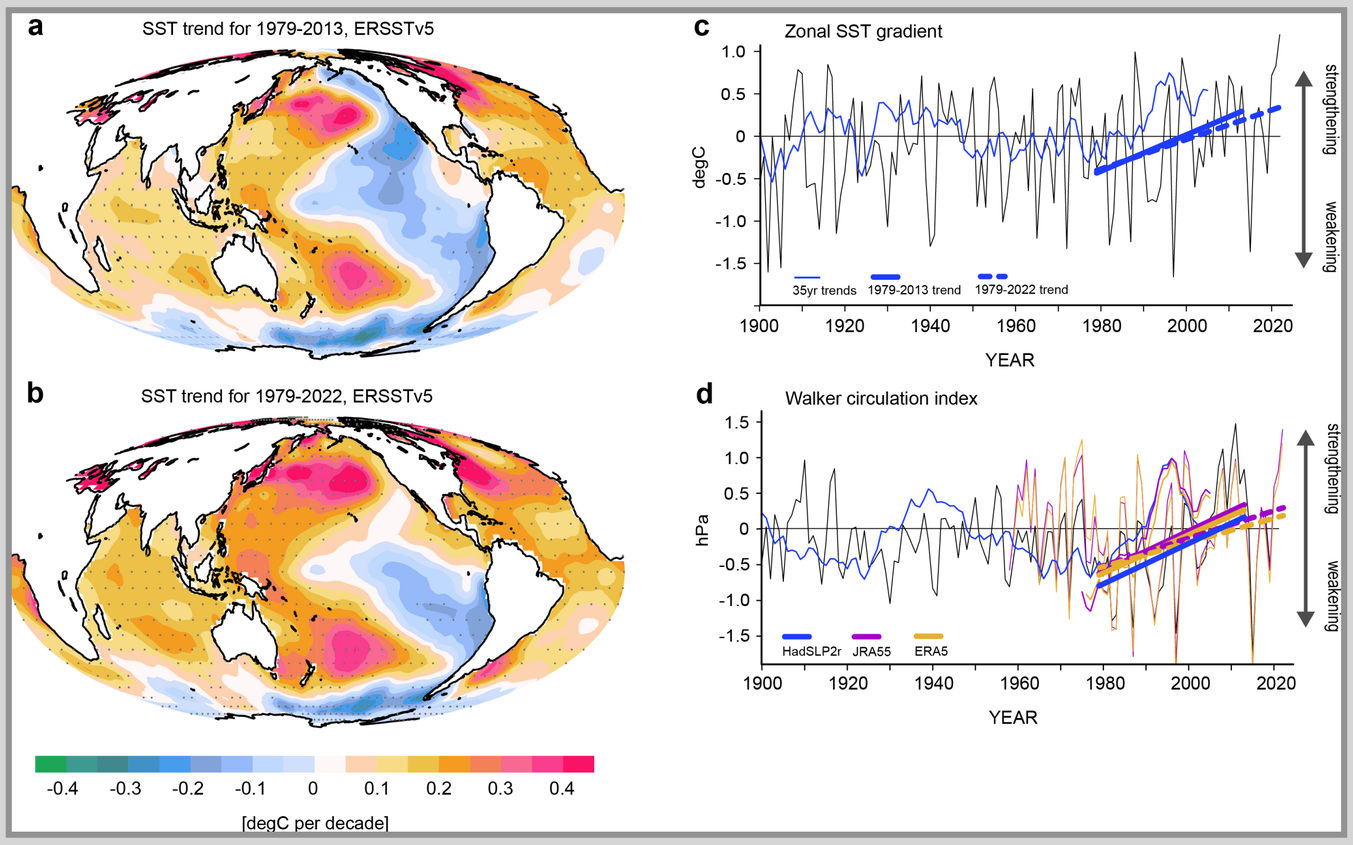
My group website:



	Mechanism	Direction for the zonal SST gradient and PWC	Role in the past (1979-2013) [possible model bias]	Role in the future (by 2100)
Global energy budget constraint	Energy budget constraint on the hydrological cycle (Held and Soden)/ Anomalous GMS mechanism (Chou and Neelin 2004)	Weakening	Inefficient (Watanabe et al. 2023)	More important (Vecchi and Soden 2007, Collins et al. 2010, Chadwick et al. 2013, Wills et al. 2017, Duffy et al. 2023, Fan et al. 2023)
Local mechanism	Differential evaporative damping (Knutson et al. 2023)	Weakening	Not identified	Important (Xie et al. 2010, Heede et al. 2020)
	Rainfall-induced freshwater forcing (Kim et al. 2023)	Weakening	Inefficient (Watanabe et al. 2014)	More important (Power et al. 2013, Huang et al. 2015, Yu et al. 2021)
	Ocean thermostat (Clement et al. 1996)	Strengthening	Potentially important (Zeller et al. 2021)	Less important (Heede et al. 2021, Sun et al. 1996, Luo et al. 2017)
	ENSO nonlinear rectification (Jin et al. 2003, Sun et al. 2006)	Strengthening/ Weakening	Not identified	Important if ENSO skewness changes (Kohyama and Hartmann 2017, Hayashi et al. 2020, Cai et al. 2014)
Remote teleconnection	Oceanic tunnel (Heede et al. 2020, Liu et al. 1998)	Weakening	Potentially important (Kleeman et al. 1999, Gu and Philander 1997, Imada et al. 2016)	More important (England et al. 2020, Wang et al. 2011, Graffino et al. 2021, Stellema et al. 2022)
	Relative warming of the tropical Atlantic/ Indian Ocean	Strengthening	Important (McGregor et al. 2018, Li et al. 2016, Ruprich-Robert et al. 2017, Kajtar et al. 2017) [Underestimated (Cai et al. 2019)]	Remains equally important (Cai et al. 2019)
	Aerosol forcing (Hwang et al. in press, Kang et al. 2020, Tseng et al. 2023, Allen et al. 2015, Hwang et al. 2013)	Strengthening	Important (Smith et al. 2016, Takahashi and Watanabe 2016, Heede and Fedorov 2021)	Less important
	Southern Ocean cooling (Kang et al. 2023, Dong et al. 2022)	Strengthening	Important [Underestimated (Kang et al. 2023, Kim et al. 2022)]	Reverses in sign (Bronselaer et al. 2018, Schloesser et al. 2019, Li et al. 2023)

Despite uncertainties, the balance of evidence suggests that the mechanisms leading to strengthening the zonal SST contrast have been efficient in the past but will not last over a century. Meanwhile, those leading to a weakening were less efficient but will become dominant in a future climate. We have high confidence in concluding that the weakening gradient will emerge. The question is when.

Timescales!

CLIVAR Climate Dynamic Panel Working Group:
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An example of understanding mechanisms with different timescales: When will the effect of aerosols diminish?

Probably longer than what you have expected

Contribution of Anthropogenic Aerosols to Persistent La Niña-like Conditions in the Earth 21st Century

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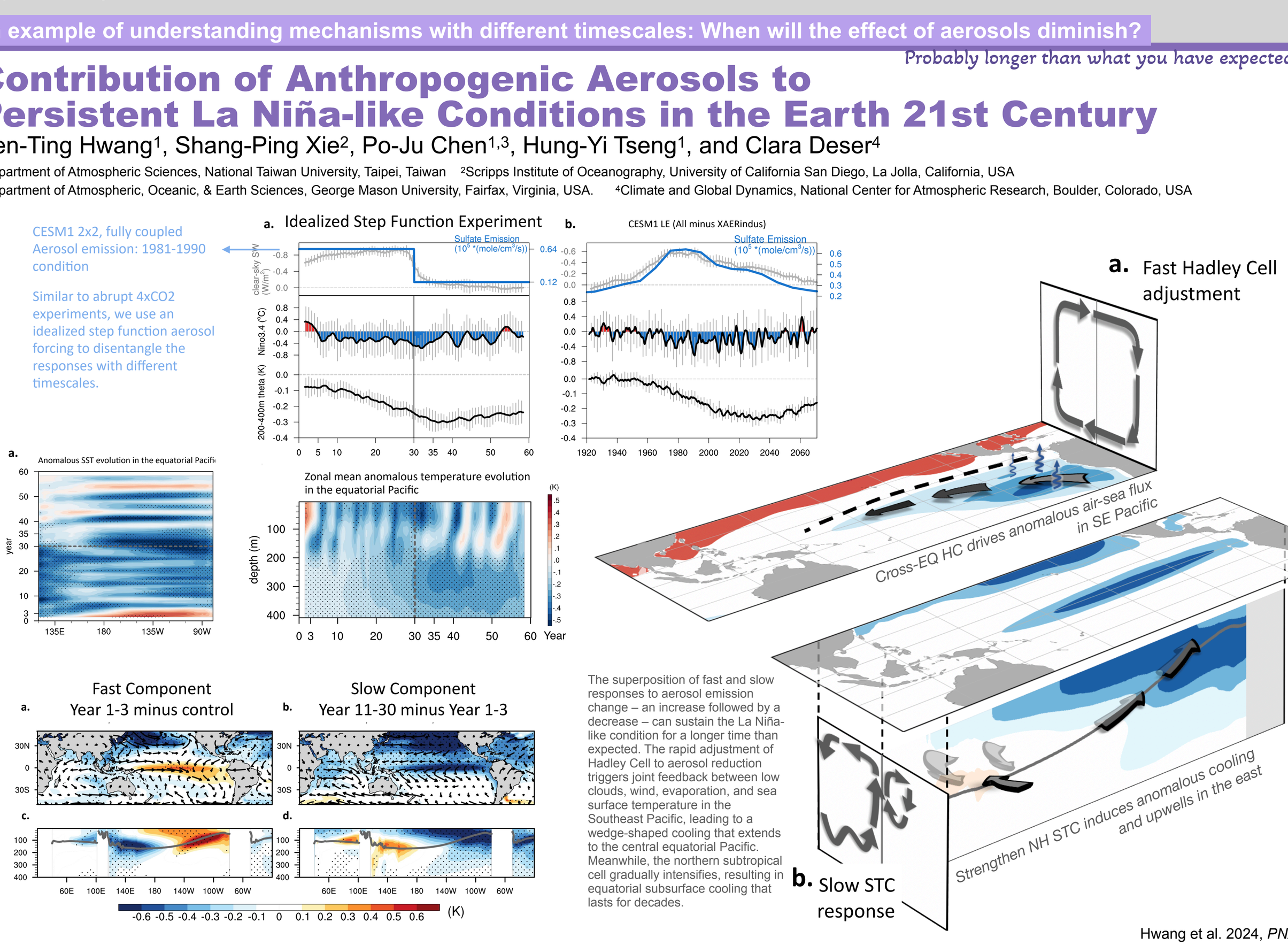
CESM1 2x2, fully coupled Aerosol emission: 1981-1990 condition

Similar to abrupt 4xCO2 experiments, we use an idealized step function aerosol forcing to disentangle the responses with different timescales.



The superposition of fast and slow responses to aerosol emission change – an increase followed by a decrease – can sustain the La Niña-like condition for a longer time than expected. The rapid adjustment of Hadley Cell to aerosol reduction triggers joint feedback between low clouds, wind, evaporation, and sea surface temperature in the Southeast Pacific, leading to a wedge-shaped cooling that extends to the central equatorial Pacific. Meanwhile, the northern subtropical cell gradually intensifies, resulting in equatorial subsurface cooling that lasts for decades.

Hwang et al. 2024, *PNAS*