Two-stage Tropical SST Responses to Extratropical Radiative Forcing

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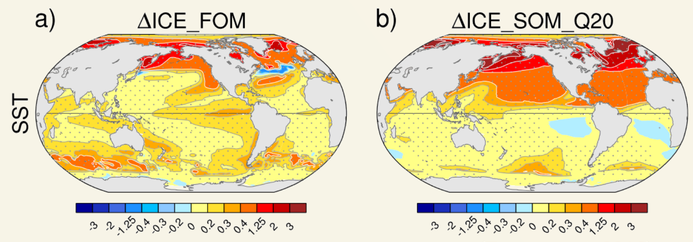
Introduction

Demonstrated by both paleoclimatic evidence and modeling experiments, variations in high latitudes would have the potential to impact remote tropical climates. It has been highlighted in some previous studies that the equilibrium responses to extratropical forcing between slab ocean models and coupled models are distinct. In this study, we investigate the transient responses in both slab ocean and fully coupled settings to understand the formation mechanisms of various timescales by perturbing the insolation in the northern extratropics in a fully-coupled global climate model CESM1.2.

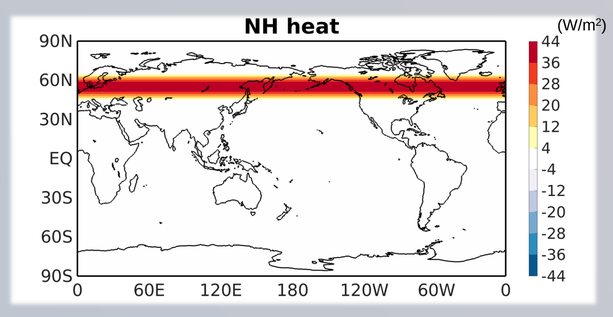


(Tomas et al. 2016)

Experiment Design

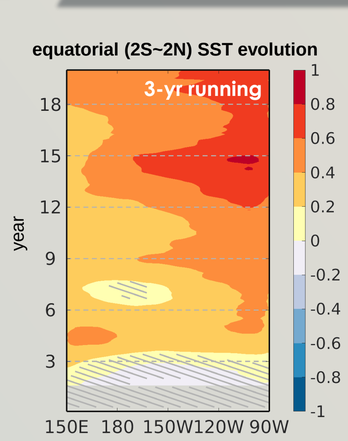
- **Community Earth System Model (CESM) 1.2**
- **compset: B1850C5 (fully coupled)**
- **resolution: 1.9°x2.5°(CAM5), gx1v6(POP2)**
- **seasonal cycled solar radiation**
- **30 ensemble members, 30 years**
- **forcing: modified incoming solar radiation**

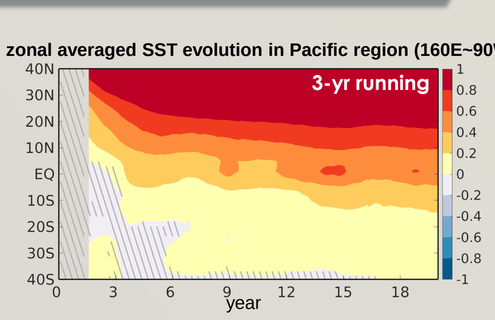
*The experiment design refers to ETIN-MIP (*Kang et al. 2019*), where insolation is reduced in the targeted regions to address the global implications of regional energy biases correction.



Linear Response = (NH heat – NH cool) / 2

Transient SST Evolution





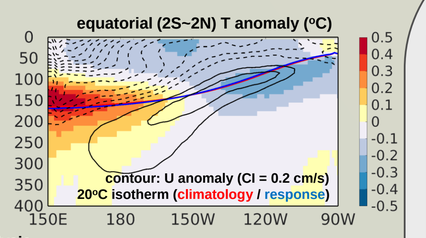
The temporal evolution of SST indicates a two-stage response of tropical SST to extratropical forcing: (1) a cooling response despite the heating imposed in the first three years, and (2) a warming response after then.

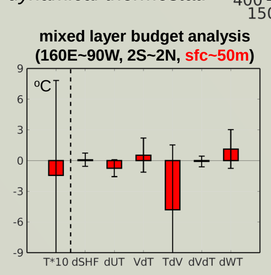
*Similar approach is adopted in *Hwang et al. (2021)*, where multiple ensembles are conducted to avoid noises from internal variabilities while examining the transient evolution of the tropical circulation. It is demonstrated that the tropical circulation experiences two distinct stages of adjustment, associated with momentum and energetics processes, respectively.

Fast and Slow Responses

Fast : Year 1~3

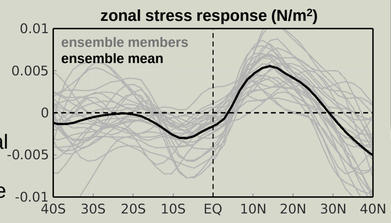
- Surface **cooling** is separated from the thermocline, indicating that the forming mechanism might be distinct from the *dynamical thermostat.*



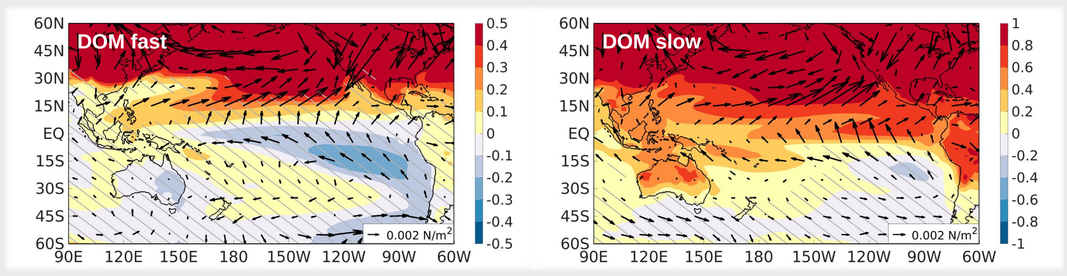


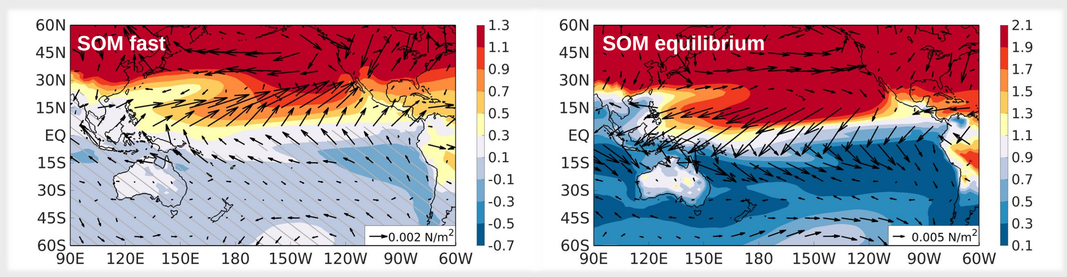
- Indicated by the budget analysis, the anomalous **meridional advection** due to ***velocity changes*** (TdV) is responsible for the surface cooling.

- The ***anomalous Ekman transport*** driven by ***anomalous equatorial easterlies*** could explain the changes in meridional velocity, and thus the divergence of heat on the equator.



SST & surface wind response

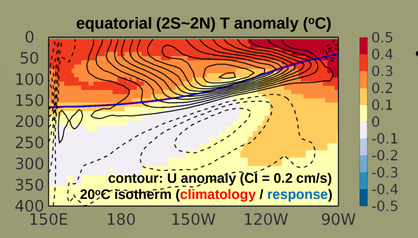




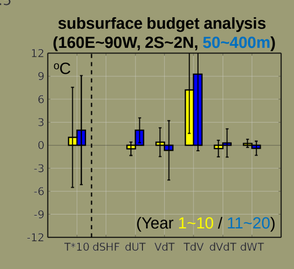
*** in SOM the SST response is centered on the tropical Pacific mean**

- **The responses demonstrated in the SOM experiment are similar to some previous studies (*Hwang et al. 2017*, *Hsiao et al. under revision*).**
- **It is suggested that the equilibrium responses in SOM could resemble the early-stage response in DOM, where the oceanic dynamics are absent.**

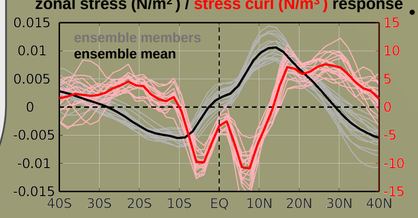
Slow : Year 10~20



- The **warming** peaking at the equatorial eastern region originates from the ***subsurface***, further suggested by the surface budget (not shown).



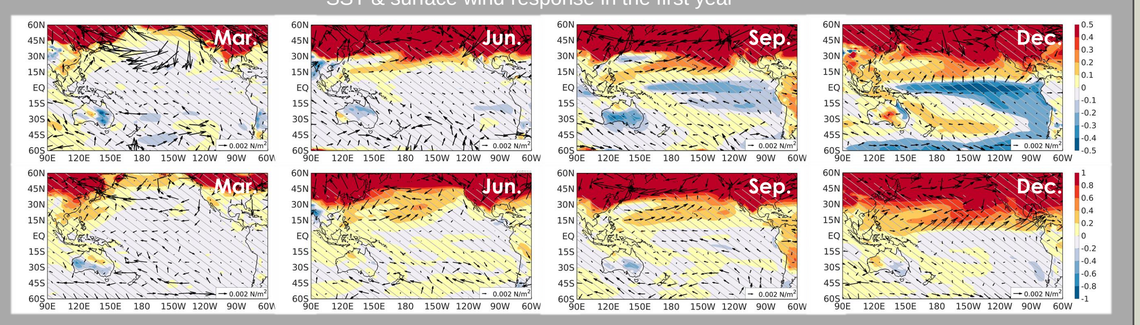
- The changes in **TdV** explain the SST warming during both *year 1~10* and year *11~20*, accounting for the development and the maintenance of the anomalous warming, respectively.



- The *zonal stress* (*stress curl*) *responses* result in anomalous **southward Ekman flow** (**northward Sverdrup flow**) at the surface (subsurface), which could be related to the anomalous heat convergence on the equator, as discussed below.

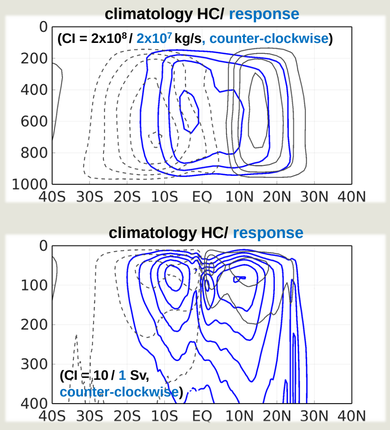
the establishment of the anomalous equatorial easterlies

SST & surface wind response in the first year



- The propagation of anomalous SST toward the equator from the NH (SH) initiates in June (September).
- Both SST anomalies from NH and SH strengthen the zonal SST gradient on the equator, and thus ***local easterlies***.
- The results in DOM and SOM are similar, indicating that the ***air-sea thermodynamics couplings*** might be important.
- In the DOM, the cooling on the equator is further amplified by the anomalous ***Ekman transport***.

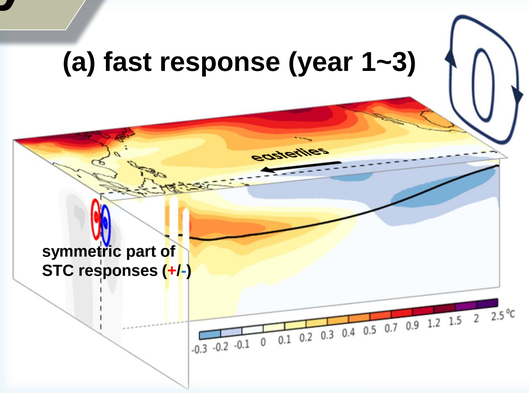
the cross-equatorial Hadley cell (HC) & subtropical cell (STC) responses



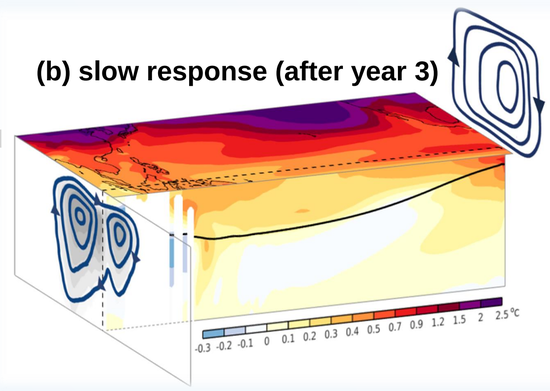
- An anomalous **counter-clockwise cross-equatorial HC** has established to compensate for the energy imbalance between the two hemispheres, consistent with the "*energetics framework*".
- The corresponding surface wind stress and surface wind stress curl responses drive **an anomalous cross-equatorial oceanic meridional overturning circulation**, in which direction is the same as the anomalous Hadley cell.
- In the **Northern Hemisphere** the response of STC is ***stronger***, indicating that the heat transport toward the extratropics is reduced, and excessive heat is thus *piled up on the equator*.

Summary

In this study, the transient evolution of tropical Pacific SST to extratropical forcing is summarized as a *two-stage* response:



(a) Fast response: the propagations of warmed (cooled) SST from NH (SH) toward the equator sharpen the equatorial zonal SST gradient and strengthen *local easterlies*. The resulted *Ekman transport* further amplified the cooling on the equator.



(b) Slow response: the hemispherically asymmetric counter-clockwise cross-equatorial STC response, driven by the anomalous cross-equatorial Hadley cell, tends to converge heat to the equator at the subsurface. The warming is eventually *upwelled* in the eastern equatorial Pacific region, shaping the Nino-like response pattern.

Reference

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- Hwang et al., 2017: https://doi.org/10.1002/2017GL074972
- Hwang et al., 2021: https://doi.org/10.1175/JCLI-D-20-0151.1
- Kang et al., 2019: https://doi.org/10.1175/BAMS-D-18-0301.1
- Tomas et al., 2016: https://doi.org/10.1175/JCLI-D-15-0651.1

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