A Likely Cause of Rapidly Developing Model Biases in the Western Tropical Pacific

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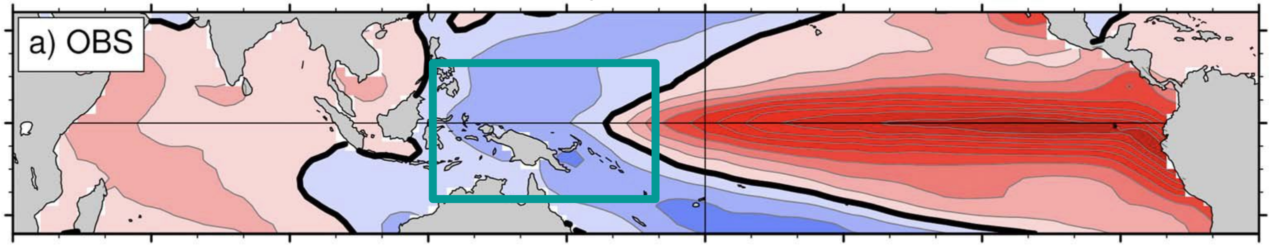
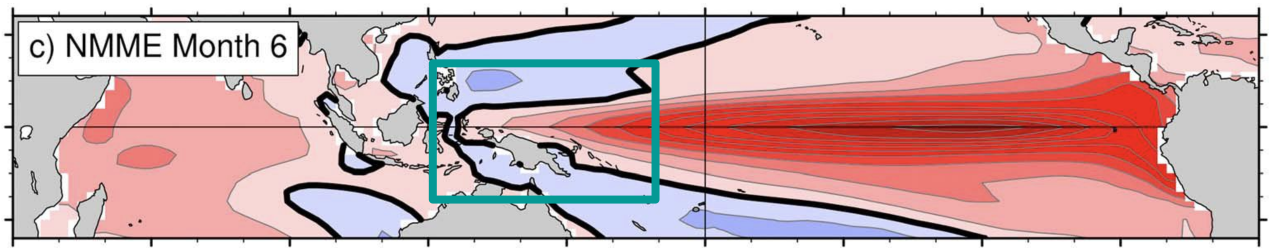
Some common biases of ENSO predictions and the mean Indo-Pacific climate

Dominant EOF of monthly SSTs in observations

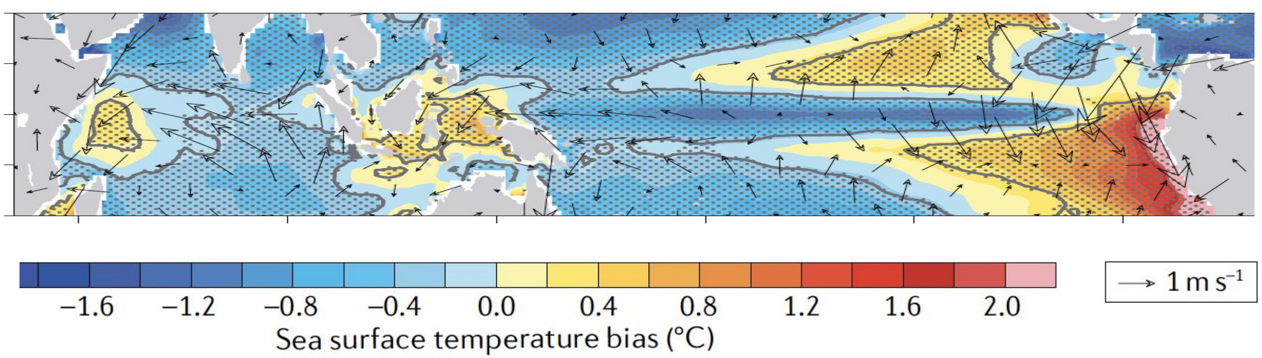


Dominant EOF of Month-6 SST predictions in the National Multi-Model Ensemble



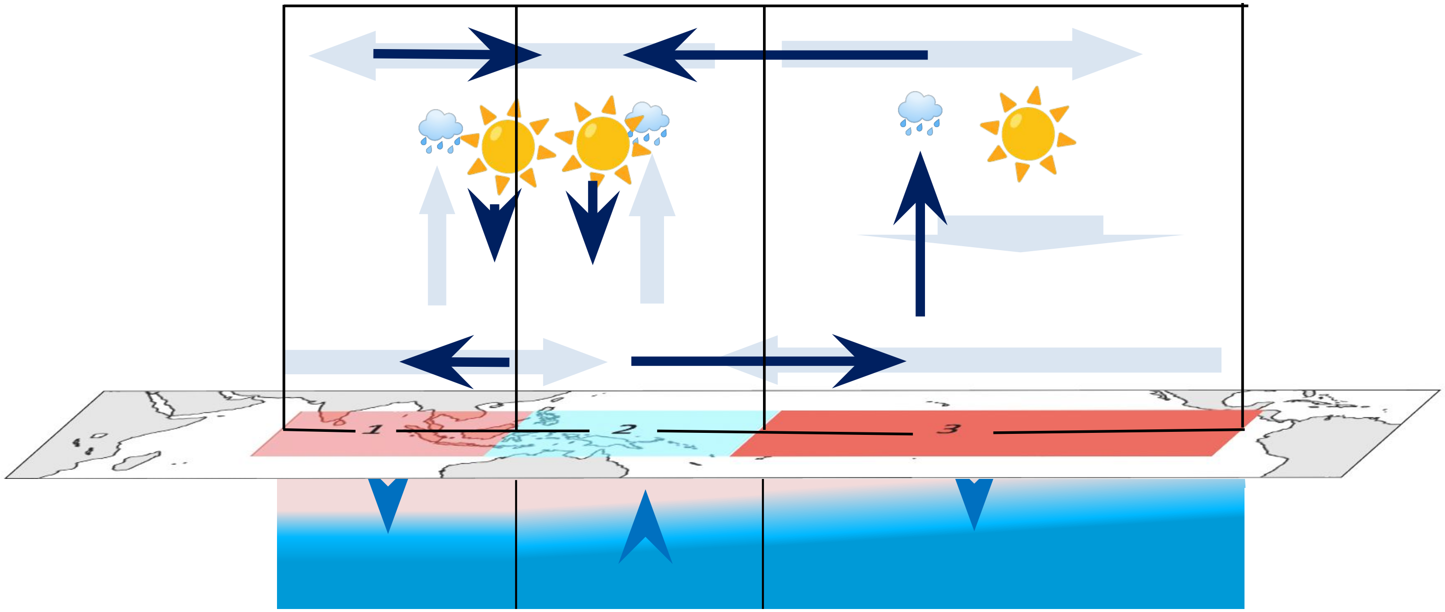
Newman and Sardeshmukh 2017

CMIP5 and CMIP6 mean climate biases



Cai et al 2021

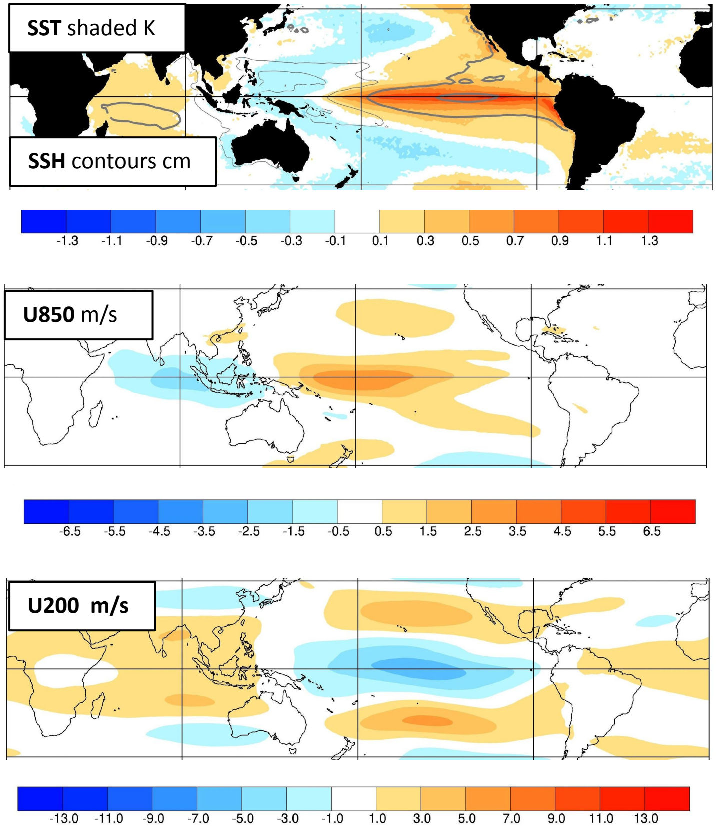
To identify the dominant feedbacks on predictable ENSO evolution from data, we constructed a 15-component Linear Inverse Model (LIM, *Penland and Sardeshmukh 1995*) of **deseasonalized, detrended, area-averaged anomalies of 5 variables (SST, SSH, U850, Omega500, and U200) in 3 areas (R1, R2, R3)** using reanalysis data (ERA5, ORAS5) for 1979-2018

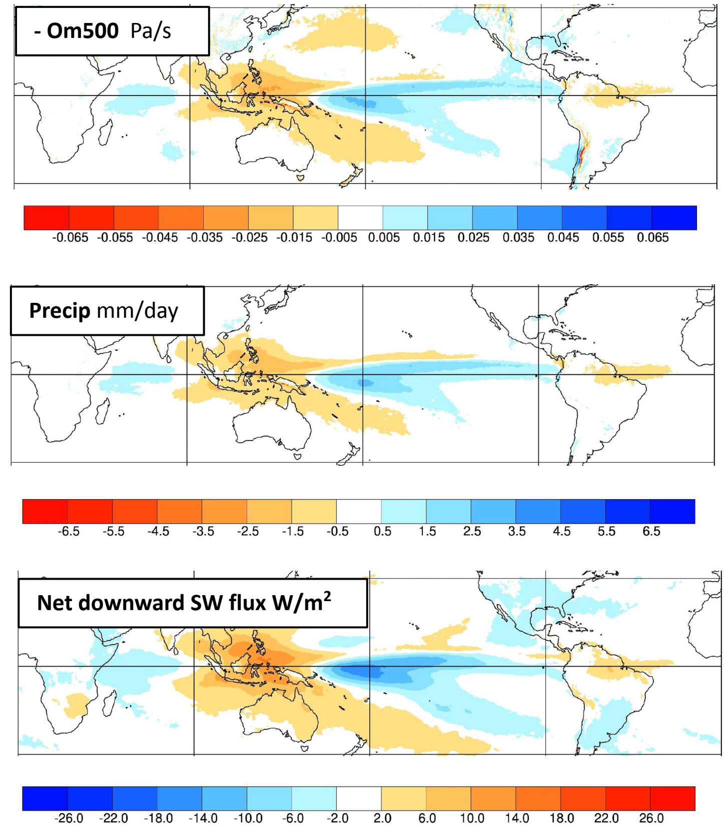


The LIM uses the observed 5-day lag-covariances of the 15 variables to estimate a 15x15 deterministic system feedback matrix ***M***. The predictable evolution of the system from an initial condition ***x(t)*** to time ***t+tau*** is ***G(tau)x(t)***, where ***G(tau)***= exp(***M tau***).

The dominant singular values and singular vectors of ***G*** identify the amplitudes and patterns associated with the maximum possible anomaly growth over the time interval ***tau.***

The first EOF of the 15-component LIM state vector captures the main features of ENSO



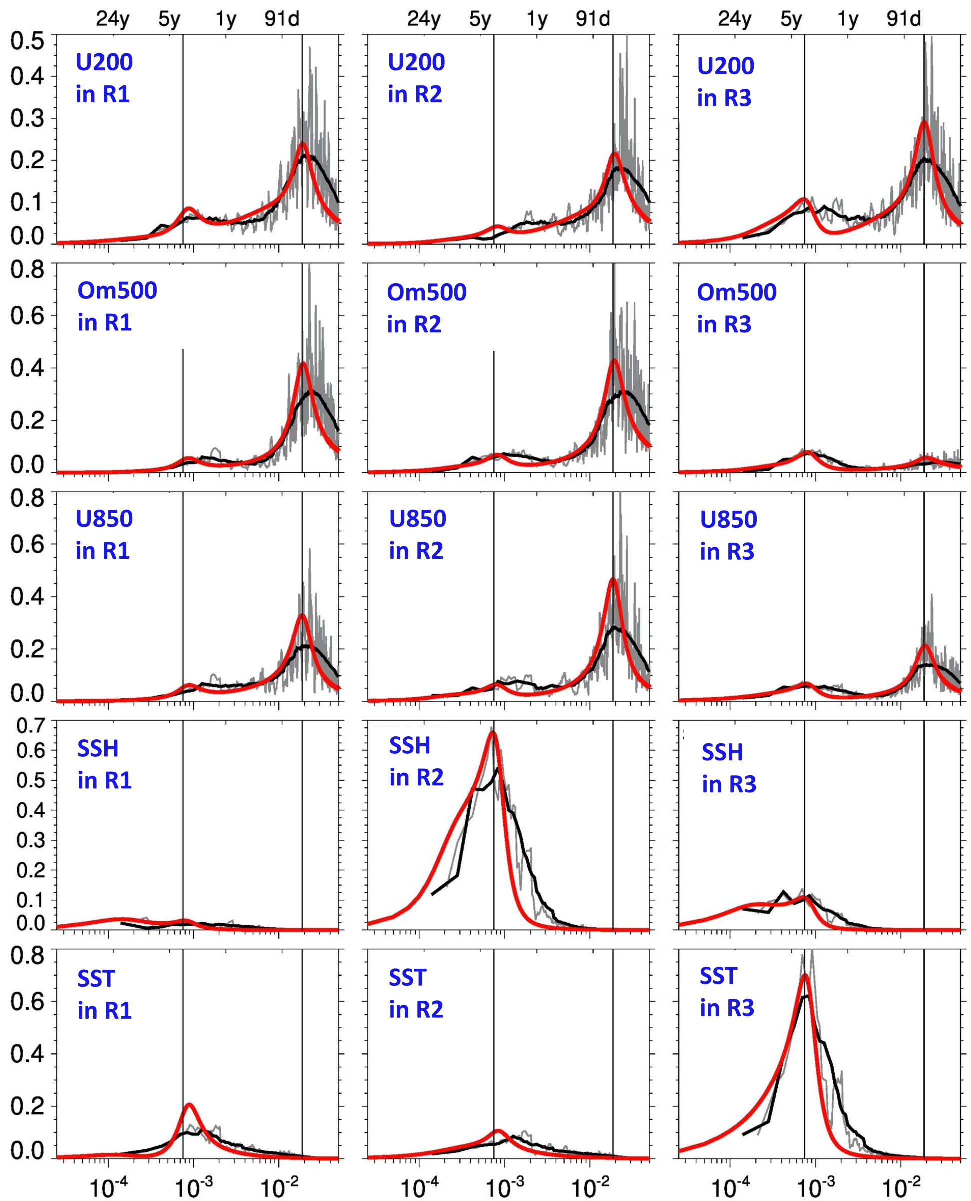


We regard the 500 hPa vertical velocity as a proxy for precip and the SW flux, since their maps are nearly identical

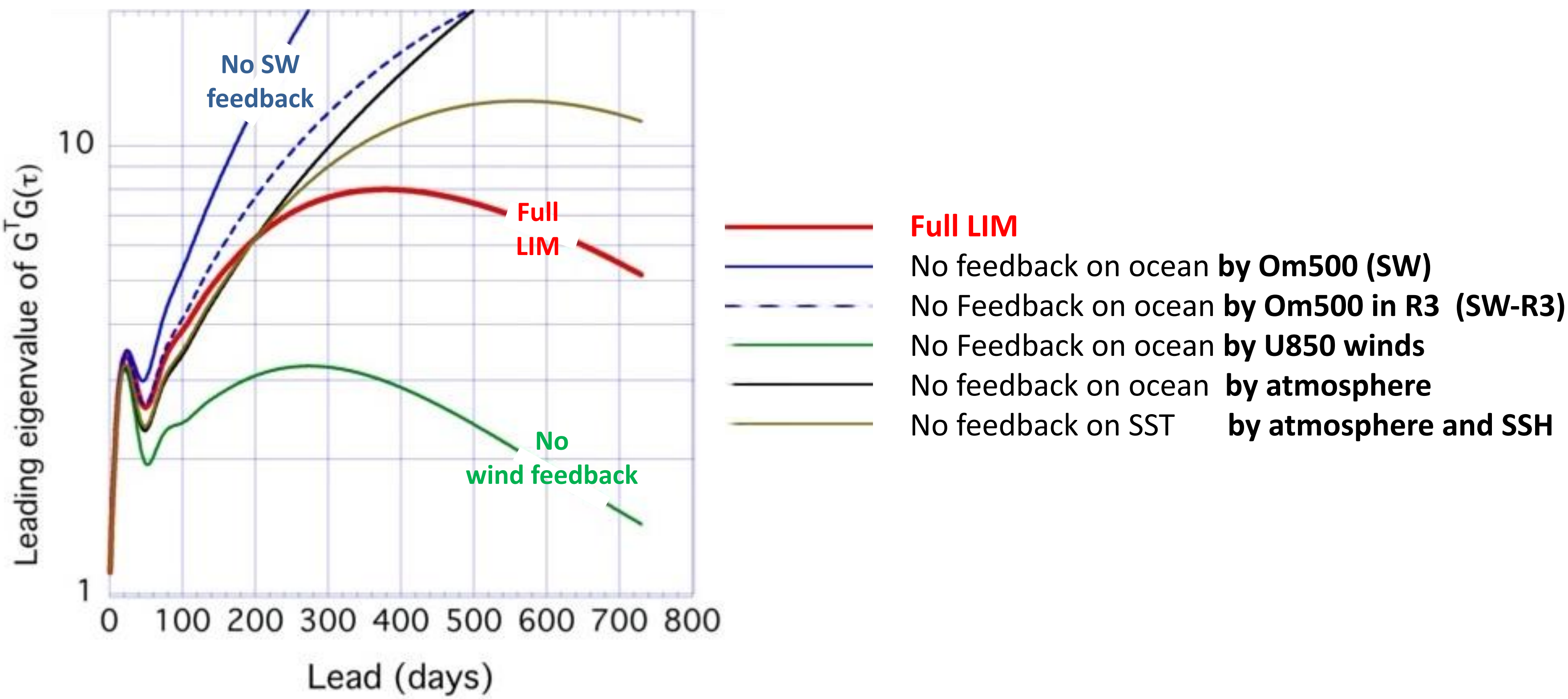
The observed power spectra of the 15 variables (Black)

are also well captured by the LIM (Red)

at both ENSO and MJO time scales



These **Maximum Amplitude (MA) growth curves** show the maximum possible predictable anomaly growth of the LIM's state vector over time when all the system feedbacks are included (as in the **Full LIM**), or when some of them are switched off in the feedback matrix ***M***

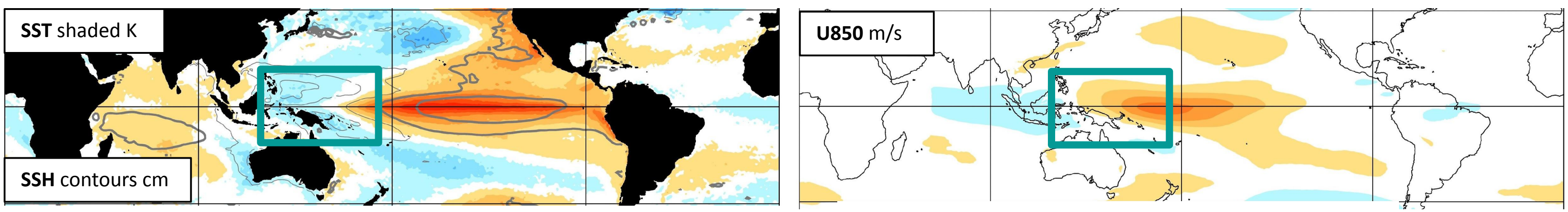


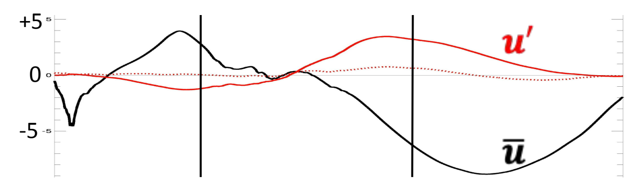
The wind feedback is *destabilizing*, so removing it stabilizes the system, as shown.
The SW feedback is strongly *stabilizing*, so removing it destabilizes the system, as shown.

In the SW feedback denial experiment, **ENSO is stronger** because of the removal of a strong damping mechanism (the cloud shielding effect).

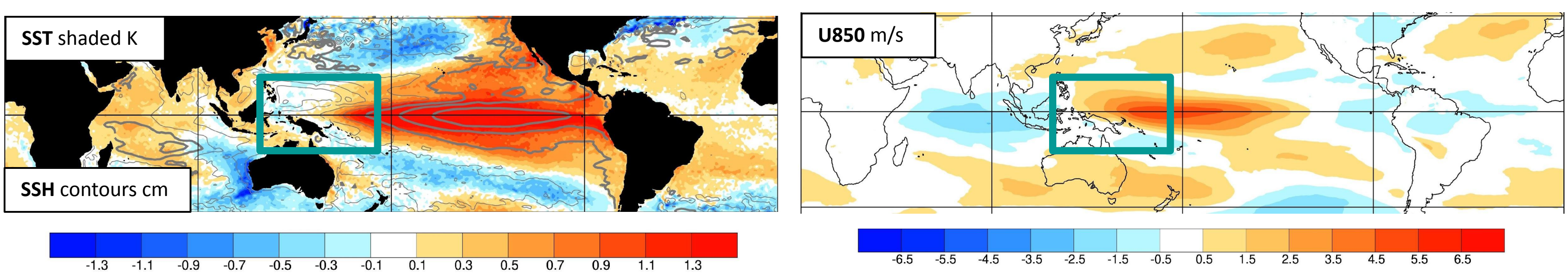
The warm SSTs also extend farther west. Recall that the equatorial zonal wind anomalies $\boldsymbol{u'}$ during El Nino reduce the total wind speed ($|u|' \approx (\bar{u}/|\bar{u}|)u' < 0,$ because the $\boldsymbol{u'}$ anomalies are nearly opposite to the mean $\bar{\boldsymbol{u}}$) thereby reducing the upward cooling turbulent surface heat fluxes and increasing the surface warming. This warming effect is stronger in the denial experiment, <u>throughout the equatorial Indo-Pacific</u>, because the $\boldsymbol{u'}$ anomalies in that experiment are stronger.

Full LIM



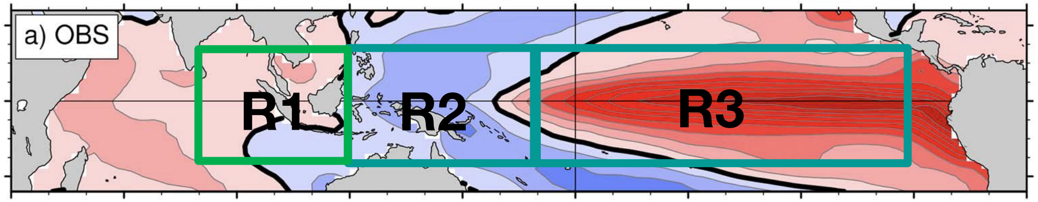


No Om500-R3 Feedback (SW feedback) on ocean

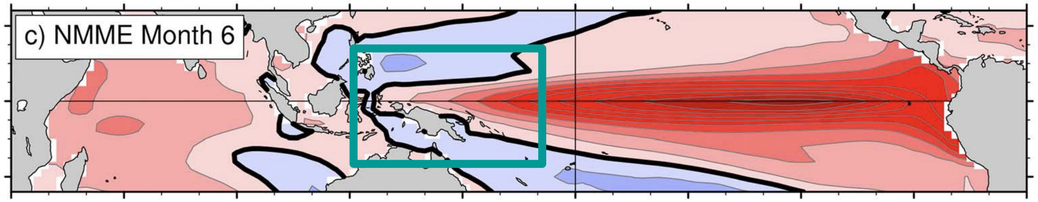


A weak SW feedback helps explain the ENSO forecast bias in the western Pacific (region R2)

Dominant EOF of monthly SSTs in observations



Dominant EOF of Month-6 SST predictions in the National Multi-Model Ensemble

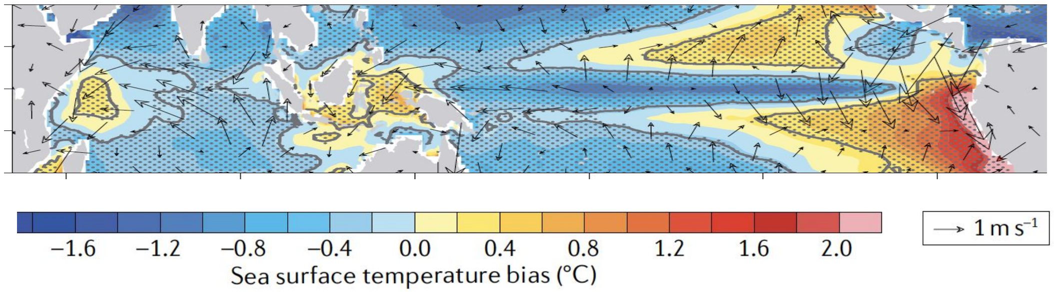


Newman and Sardeshmukh 2017

A weak SW feedback also helps explain the Indo-Pacific climate bias in climate models:

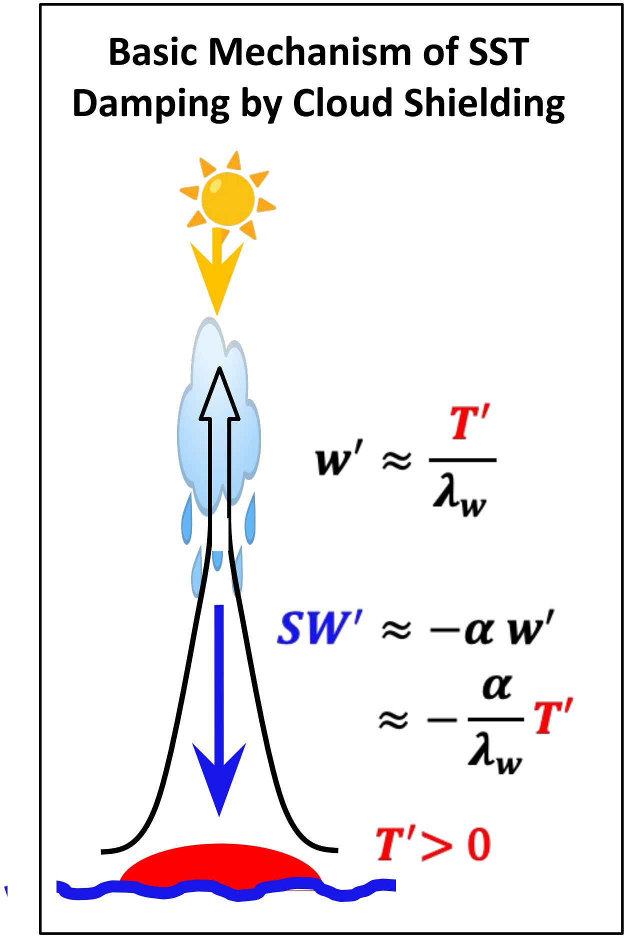
It likely contributes to the warm SST bias over the maritime continent, which forces the easterly wind bias and then the cold tongue bias through stronger upwelling

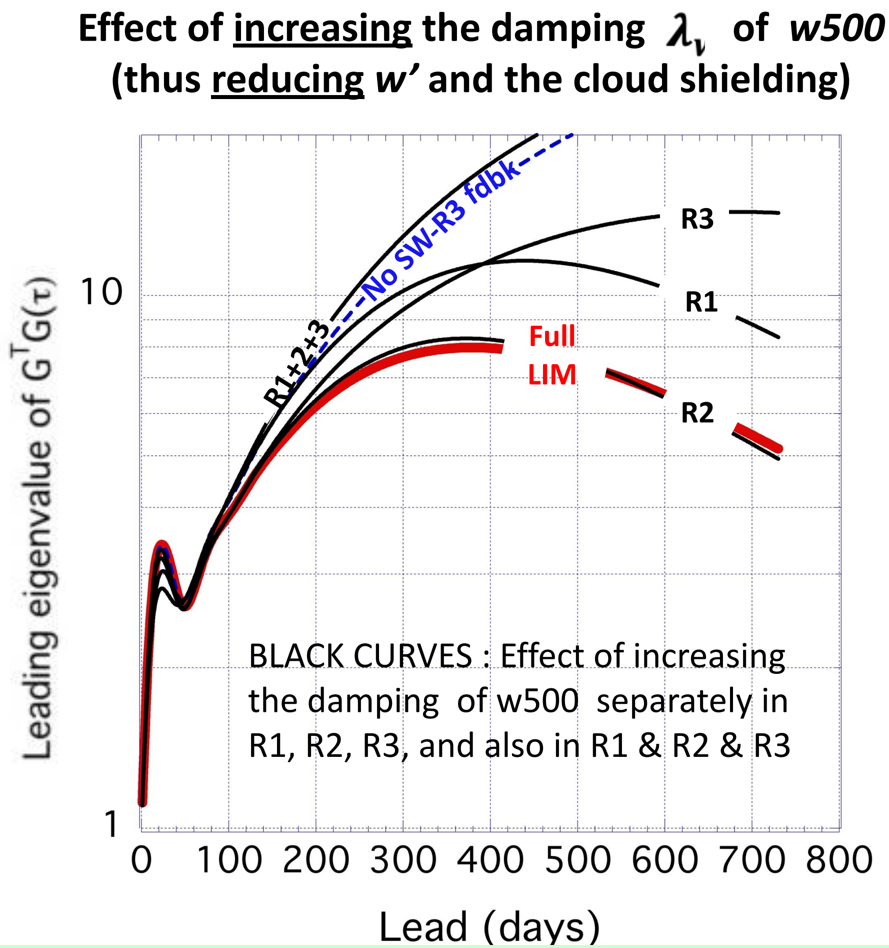
CMIP5 and CMIP6 mean climate biases



Cai et al 2021

These figures suggest that the negative SW feedback on SST in our LIM is largely controlled by the damping parameter λ_w of *w*500, representing the damping of boundary-layer convergence. **Importantly, this λ_w <u>inferred from data</u> also includes the mean effect of stochastic boundary-layer damping associated with mesoscale atmospheric and oceanic processes.**





The influence of stochastic mesoscale processes on the cloud shielding suggested here is also consistent with the recent work of Williams et al 2024, who find that increasing the resolution of their GCM alleviates its westward ENSO extension bias.

Summary and Conclusions

1) Using atmospheric and oceanic reanalysis data for 1979-2018, we have developed a 15-variable coupled Linear Inverse Model (LIM) of the tropical Indo-Pacific climate system to determine the dominant feedbacks on predictable ENSO evolution.

2) This approach yields a clear picture of the competition between **the destabilization of ENSO by air-sea coupled wind and subsurface oceanic feedbacks** and its **stabilization by a surface shortwave (SW) flux feedback associated with cloud shielding.**

3) **A weak SW feedback** is likely behind the tendency of current climate models to extend the warming during El Nino (and cooling during La Nina) too far west into the western Pacific.

4) **A weak SW feedback over the maritime continent** is likely also a major contributor to the mean easterly wind and cold tongue biases of climate models.