A systematic bias in the relationship between equatorial zonal wind stress and equatorial undercurrent strength with implications for SST trends

Sloan Coats[1, 2, 3], Kristopher Karnauskas[3, 4]

(1) Woods Hole Oceanographic Institution; (2) Climate and Global Dynamics Laboratory, National Center for Atmospheric Research;

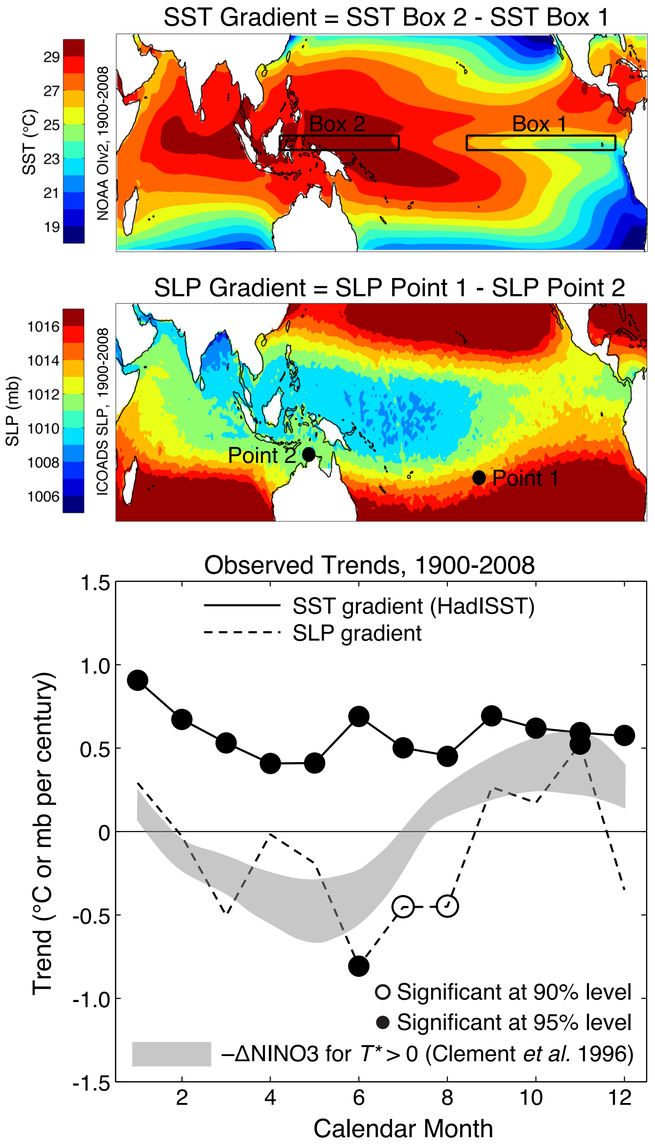
(3) Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder; (4) Department of Atmospheric and Oceanic Sciences, University of Colorado, Boulder

Intro:

Here we demonstrate that equatorial ocean dynamics related to the equatorial undercurrent (EUC) can help to explain seemingly contradictory 20th century trends in the tropical Pacific atmosphere and ocean. Moreover, it is shown that coupled general circulation models (CGCMs) do not correctly simulate these dynamics; we identify a systematic bias in the relationship between changes in equatorial zonal wind stress and EUC strength. The identification of this bias is critical because observations and CGCMs appear to have opposing trends in the zonal SST gradient of the tropical Pacific over the 20th century (Coats and Karnauskas, GRL, 2017).

I. 20th century trends in the tropical Pacific atmosphere and ocean

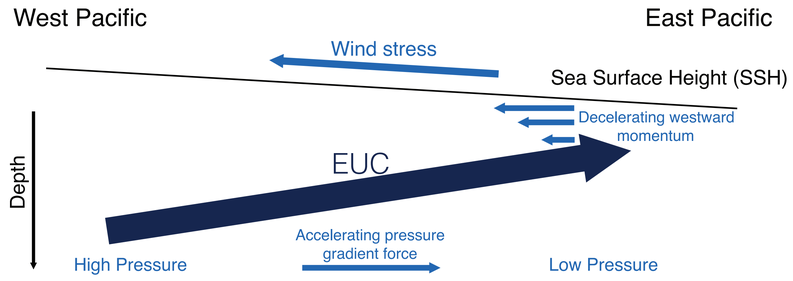
Observational uncertainties are large (e.g. Deser et al., GRL, 2010) but 20th century trends in the atmosphere and ocean are counter to our canonical understanding of the tropical Pacific, where the atmosphere and ocean typically vary in phase (e.g. El Niño-Southern Oscillation; ENSO).



Boreal fall through winter trends are consistent with ocean dynamical thermostat mechanism (Clement et al., J. Clim., 1996). Spring and summer trends suggest a weakening of the SLP gradient (potentially the Walker circulation) and strengthening of the SST gradient. Can this be explained?

II. A role for the EUC

Dominant equatorial mechanisms determining EUC strength and characteristics:



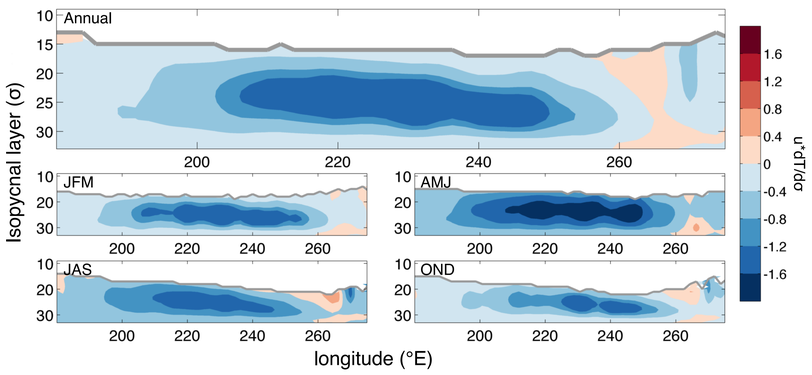
In the presence of weakening wind stress (i.e., that associated with a weakening Walker circulation)

1) SSH gradient and pressure gradient force decrease - Deceleration

2) Westward momentum decrease - Acceleration

For small in wind stress changes: Acceleration via 2) > Deceleration via 1)

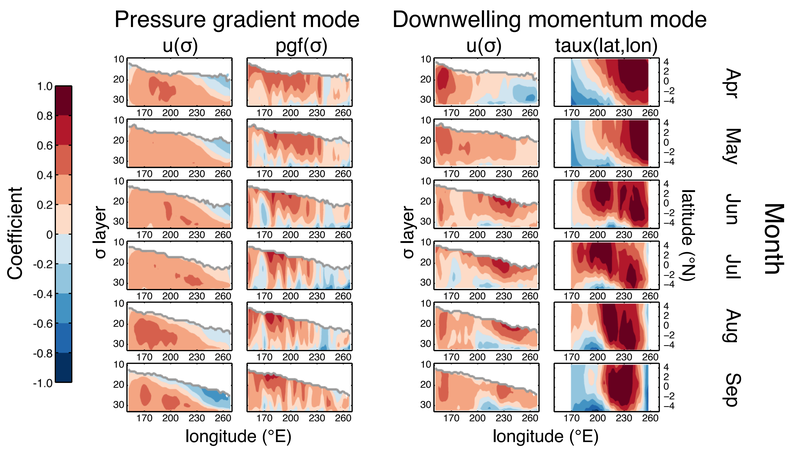
This is akin to the springtime surge (Yu et al., JPO, 1997) and it can drive EUC strengthening on centennial timescales (Drenkard and Karnauskas, J. Clim., 2014). Can these dynamics help to explain the contradictory boreal spring and summer trends in Section 1?



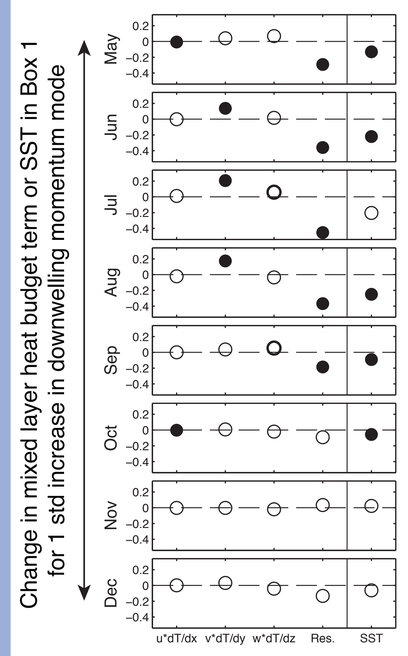
Along isopycnal heat budget on Simple Ocean Data Assimilation (SODA) reanalysis suggests that the EUC is associated with cold advection, if the EUC strengthens SSTs should cool where those waters outcrop...

III. Quantifying SST change related to EUC variability

Isolating EUC variability related to changes in the decelerating westward momentum by using coupled SVD and the along isopycnal momentum budget on SODA.



SVD of u(σ) and pressure gradient force (σ) on left. Remove first mode from u(σ) and take SVD with tau_x to get "downwelling momentum mode" on right.



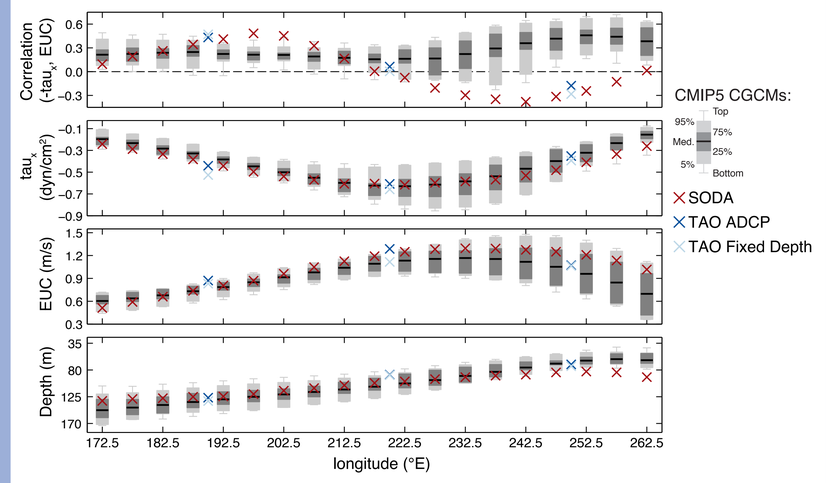
Impact of downwelling momentum mode on Box 1 SSTs, quantification through regression analysis suggests:

- **Large and significant cooling of Box 1 SSTs in May, June, and August.**
- **Residual (unresolved mixing) dominates this cooling.**
- **Weakening equatorial zonal wind stress can cool Box 1 SSTs, particularily May-Aug.**

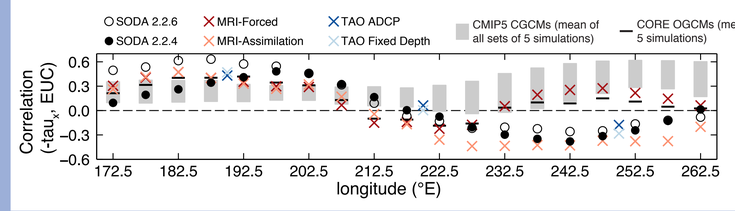
○ Significant at 90% level
● Significant at 95% level

IV. CGCM fidelity in simulating these dynamics

Do CGCMs simulate the downwelling momentum mode and do we see evidence for it in observations?



CGCMs do not have a downwelling momentum mode like the observations and reanalysis despite having a realistic EUC. Can we determine why there is this bias?



Conclusions:

- **Weakening equatorial zonal wind stress can increase the SST gradient by cooling Box 1 via a strengthened EUC.**
- **The magnitude of this cooling is large in boreal spring and summer when there is the largest discrepancy in observed 20th century Walker circulation and SST gradient trends.**
- **CGCMs cannot represent these dynamics, does that bias the simulation of 20th century trends in the tropical Pacific?**