Investigating the role of wind and precipitation biases on the equatorial Pacific cold tongue bias in CESM through a hindcast approach

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The equatorial Pacific cold tongue bias

- SST biases persist in coupled climate models. Over the equatorial Pacific, models exhibit too cold SSTs.
- The mean cold tongue bias can impact how well a model captures interannual variability such as ENSO.
- Diagnosing the cause of the cold tongue bias is challenging due to the complex and coupled processes involved.
  → hindcast approach
A hindcast approach

I. Bias Correspondence

CESM Large Ensemble Simulations (CESM LENS)

CESM Ensemble Seasonal Hindcasts (Coupled CAPT framework)

II. Bias Attribution

CAM5 hindcasts

POP2 hindcasts

CESM sensitivity experiments
The Coupled CAPT Framework

- 6-month long, 24-ensemble member hindcasts covering the years 2000-2005
- Atmospheric and land initial conditions from Cloud Associated Parameterizations Testbed (CAPT) procedure (Ma et al. 2015)
- Ocean initial conditions from POP-DART (Karspeck et al. 2013)
- A reconstructed timeseries based on lead-time is used to study the annual cycle
The correspondence of the mean state bias in hindcasts and climatology

- Annual mean cold bias shows up in the eastern equatorial Pacific after 3 months lead-time
- In succeeding lead-times, the cold bias extends westwards comparable to the climatological bias
The seasonal cycle of the equatorial cold tongue bias

- The climatological bias is present year-round, with a minimum during boreal summer
- In the hindcasts, the cooling first appears during June-December
Start-date dependence of the cold tongue bias

- The start date has an influence on the SST drift and ensemble spread
- For all years, strong drift occurs with August and May start dates
  → model biases develop quickly during peak upwelling period
  → heat budget analysis confirms that anomalous cooling comes from too strong vertical advection
Possible mechanism: A wind-driven upwelling bias at the central-eastern equatorial Pacific

- The zonal windstress bias is present since the first month of leadtime, whereas the cold SST bias develop gradually with lead time
- Simple test: ocean-only run with enhanced wind stress
# Test: enhanced surface zonal wind over the eastern equatorial Pacific

<table>
<thead>
<tr>
<th>Name</th>
<th>Ocean IC</th>
<th>Surface zonal wind forcing</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTRL.OCN</td>
<td>DART 2005</td>
<td>COREv2 2005</td>
</tr>
<tr>
<td>EXP.OCN.UMOD</td>
<td>DART 2005</td>
<td>Modified COREv2 2005 input file: surface zonal wind increased by 25% over the eastern equatorial Pacific (210-270E,15S-15N) during MJJAS</td>
</tr>
</tbody>
</table>

![Graph showing surface zonal wind stress over time](image1)

![Graph showing SST over time](image2)
What causes the surface zonal wind bias?

• Hypothesis #1: The surface zonal wind bias is linked with precipitation biases which originate from the atmospheric component

• Hypothesis #2: The surface zonal wind bias is sensitive to horizontal resolution
Role of precipitation bias?

JJA mean bias (2001-2005)
The development of precipitation and zonal wind stress bias in atmosphere-only hindcasts

- Atmosphere-only 40-day hindcasts are performed with CAM5.1 covering the JJA period for the year 2005

![Graph showing precipitation bias leads zonal wind stress bias](graph1.png)

![Graph showing precipitation bias lags zonal wind stress bias](graph2.png)

*mean over 10°S-10°N, 210°-270°E*
What causes the surface zonal wind bias?

- Hypothesis #1: The surface zonal wind bias is linked with precipitation biases which originate from the atmospheric component.
  - It is plausible that the northern ITCZ bias in boreal summer drives anomalous easterlies.

- Hypothesis #2: The surface zonal wind bias is sensitive to horizontal resolution.
Role of horizontal resolution

Zudeima et al. 2016

a) CCSM4 1° ocean/atmosphere
b) CESM1

c) CCSM4 0.1° ocean/0.5° atm
d) CESM1 0.1° ocean/0.25° atm
Role of horizontal resolution

- The equatorial cold tongue bias in CESM-H improves slightly compared to CESM-S
- CESM-H and CESM-S have smaller bias compared to LENS
Role of horizontal resolution

**CESM_H still has the wind stress bias**

**CESM_H has warmer ocean than LENS**
What causes the surface zonal wind bias?

• Hypothesis #1: The surface zonal wind bias is linked with precipitation biases which originate from the atmospheric component
  ➔ It is plausible that the northern ITCZ bias in boreal summer drives anomalous easterlies

• Hypothesis #2: The surface zonal wind bias is sensitive to horizontal resolution
  ➔ Surface zonal wind bias is still too strong in high resolution (whether cold bias manifests depends on temperature profile of ocean)
Summary

- The cold bias emerges within 3 months of lead time, and first develops during boreal summer-fall.
- The cooling comes mostly from vertical advection, associated with a too strong surface zonal wind stress that precedes the cold SST bias.
- The surface zonal wind stress is possibly linked to the overestimated precipitation over the northern Pacific ITCZ.
Future work

- Test the sensitivity of the wind stress bias to the excessive precipitation over the northern ITCZ (artificially suppress deep convection)

- Explore other possible reasons for the wind stress bias, such as shallow convective parameterization (Woelfle et al. 2018) and PBL static stability and momentum mixing (Wallace 1989, Bond 1992)