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The Influence of Sea Surface Salinity Variability on the Equatorial Pacific Mean State and Extreme ENSO Events

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Takeaway

***Greater SSS variability** is associated with **stronger El Niño** and **stronger mean-state stratification** in the western Equatorial Pacific.*

Introduction

- Theory and observations indicate **strong salinity stratification in the western Equatorial Pacific (WEqP) may enhance El Niño** by trapping heat and momentum in the surface ocean[1]
- Clarifying salinity & ENSO interactions is important as the hydrologic cycle strengthens[2]; increases in **sea surface salinity (SSS) variance** have already been observed[3]
- With limited historical observations of salinity and extreme El Niños[4], conducting artificial perturbation model experiments can help disentangle the simultaneous phenomena that influence salinity

Model experiments (GFDL CM2.5-FLOR)

Control: freely-varying SSS (**CTRL**)	Seasonal SSS only **(fixed-SSS)**
• Initial cond.: Year 1990 radiative forcing & land use • Spin-up: 100 years (discarded)	• **Global SSS nudged to monthly climatology** from CTRL yr 101-200 • Nudged every 5 days • Initial cond.: CTRL yr 101

Same SSS climatology, but CTRL has more SSS variability than fixed-SSS.

Monthly data: 900-year single runs

Daily 3D ocean data: 20-member ensemble

Model: Forecast-oriented Low Ocean Resolution model[5]

- Coupled atmosphere and ocean, fully-interactive salinity
- Atmosphere: 50 km horizontal resolution
- Ocean: 1°, 1/3° meridional near Equator, 31 depth levels

References

[1] Zhang et al. (2021). What Role Does the Barrier Layer Play During Extreme El Niño Events? *JGR: Oceans.*
[2] Held & Soden. (2006). Robust responses of the hydrological cycle to global warming. *J. Clim.*
[3] Durack et al. (2012). Ocean salinities reveal strong global water cycle intensification during 1950 to 2000. *Science.*
[4] Santoso et al. (2017). The Defining Characteristics of ENSO Extremes and the Strong 2015/2016 El Niño. *Reviews of Geophysics.*
[5] Vecchi et al. (2014). On the Seasonal Forecasting of Regional Tropical Cyclone Activity. *J. Clim.*

Funding & Contact

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El Niño strengthening

*CTRL has ~**2x** more frequent extreme El Niños than fixed-SSS*

DEFINITIONS

Extreme El Niño:
Max Niño3.4 SSTA > 2°C

Moderate El Niño:
Max Niño3.4 SSTA > 1°C

Western Equatorial Pacific (**WEqP**):
140-170°E, 2°N-2°S

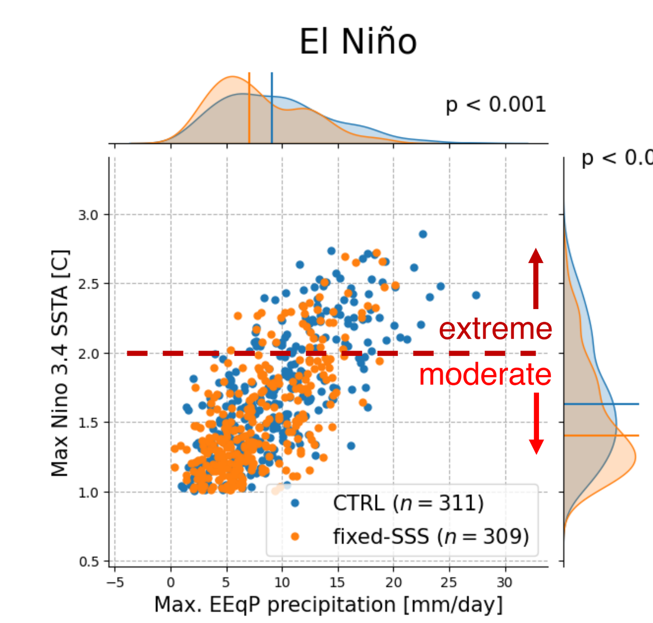


Fig. 1. Stronger El Niño in CTRL than fixed-SSS. El Niño defined as max. Niño3.4 SSTA > 1°C, and all adjacent months > 0.5°C. n is the number of El Niño events in each experiment. Precip is the mean in the eastern equatorial Pacific (120–90°W, 0N). Lines on marginal PDFs indicate median. *p*-values from K-S tests indicate significant differences between PDFs.

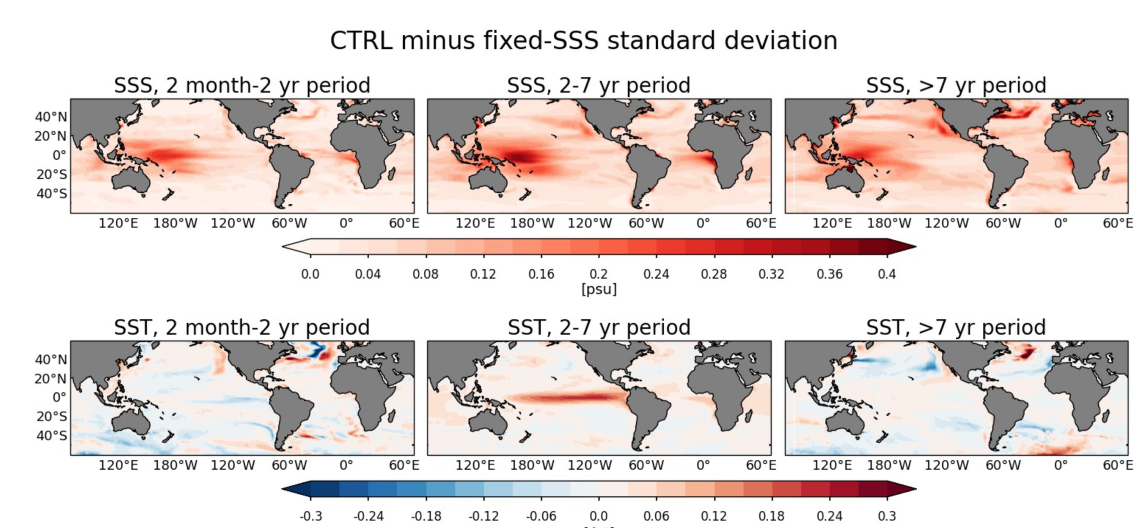
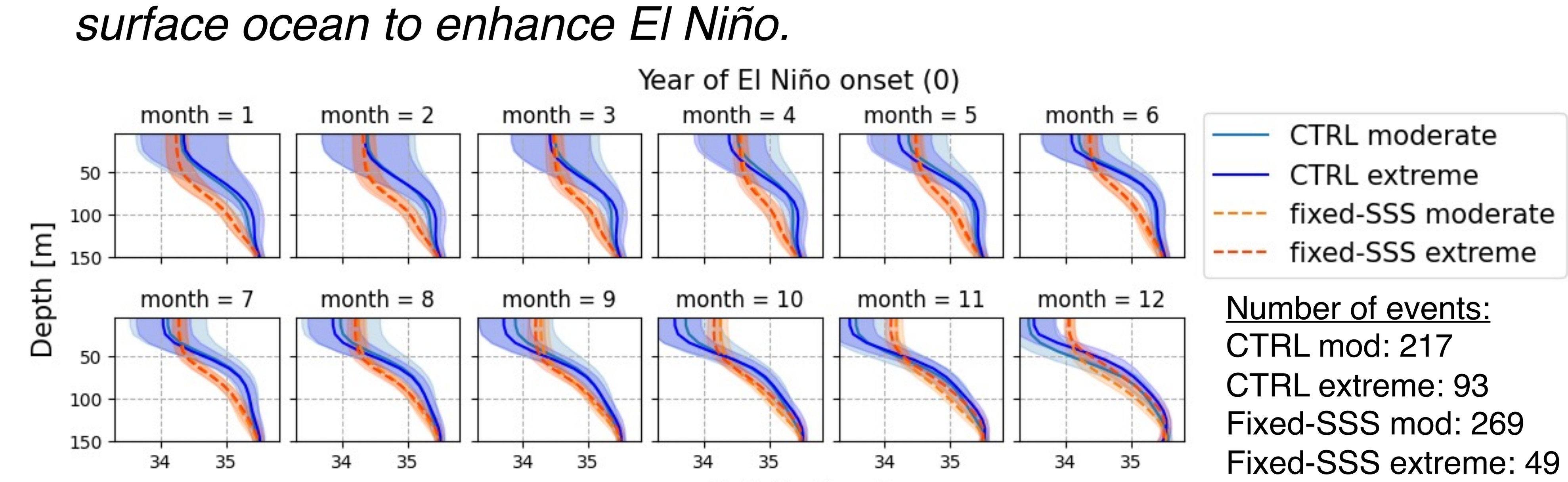


Fig. 2. Impact of non-seasonal SSS variability. SSS and SST standard deviation in CTRL compared to fixed-SSS. Variability filtered for different periods, with a linear trend removed. **CTRL has higher 2-7 year period SST variability in the equatorial Pacific, indicating stronger ENSO compared to fixed-SSS.**

***Hypothesis: El Niño is enhanced by strong mean-state stratification.** Subsurface salinity (& density) stratification is the largest difference in the ocean in CTRL vs. fixed-SSS leading up to El Niño. CTRL's stronger stratification could trap momentum in the surface ocean to enhance El Niño.*



Number of events:
CTRL mod: 217
CTRL extreme: 93
Fixed-SSS mod: 269
Fixed-SSS extreme: 49

Fig. 3. Salinity stratification composites during El Niño onset year for extreme and moderate events in CTRL and fixed-SSS. Shading indicates standard deviation across El Niño events.
The difference between extreme and moderate events within experiments is small compared to the mean-state difference between the experiments.
Temperature stratification (not shown) looks the same for both experiments & event types.

Mean-state salinity stratification

***Although only surface salinity was nudged**, the CTRL vs. fixed-SSS difference in mean-state salinity stratification is in the **subsurface**. The difference forms due to **subseasonal, local processes** (within weeks, Pacific 10N-10S).*

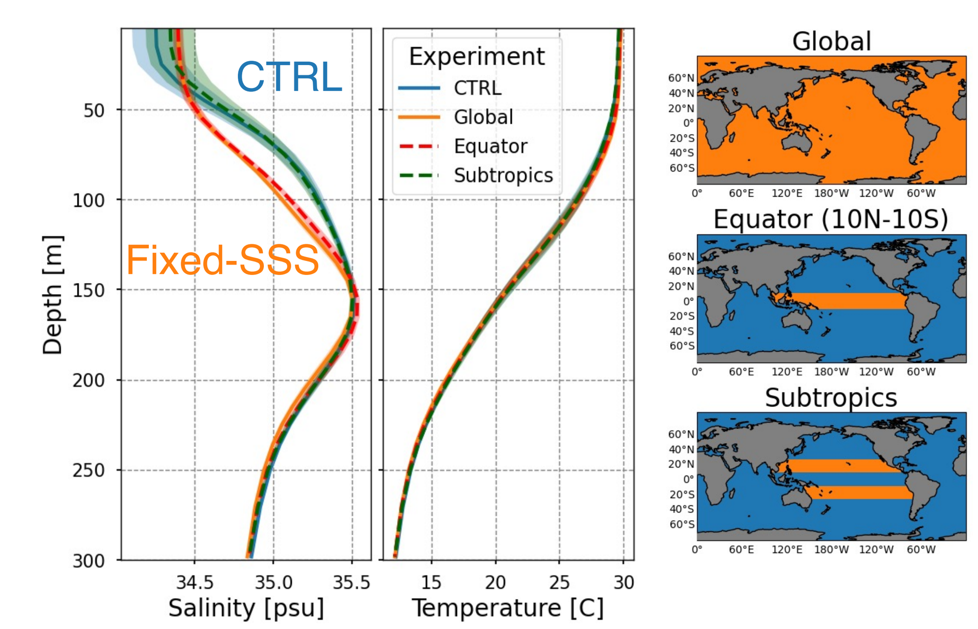


Fig. 4. Geographically-targeted nudging experiments. WEqP salinity and temperature stratification (runs: 40 years). Maps show where the SSS was nudged to climatology.

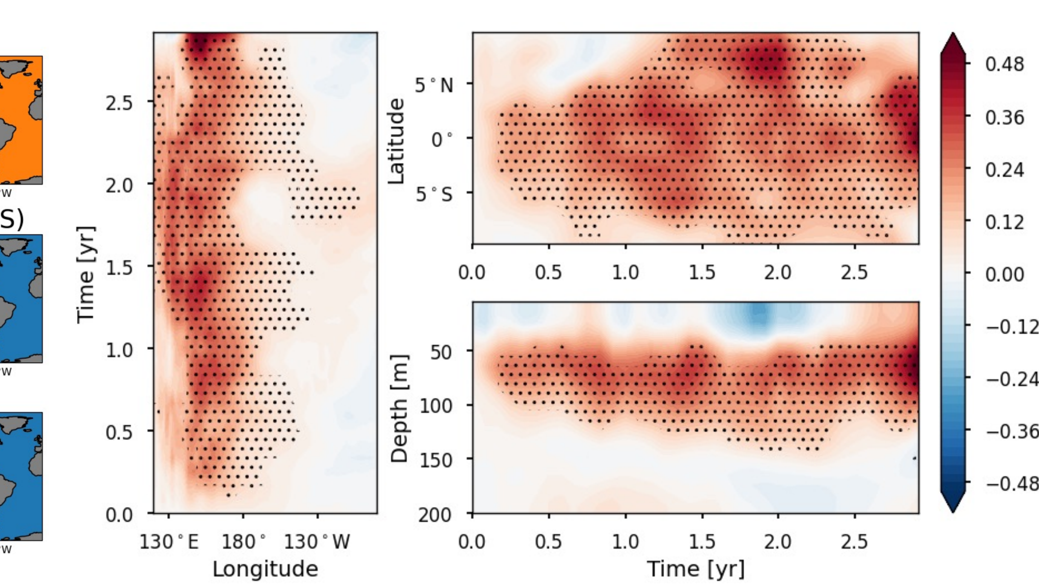


Fig. 5. Salinity difference between CTRL and fixed-SSS ensembles (20 members). Monthly data averaged over the WEqP and 60-100m depth where applicable. Stippling indicates significant difference in CTRL vs. fixed-SSS ensemble means at 95% confidence.

***Hypothesis:** The differences in salinity stratification between CTRL and fixed-SSS may be due to several processes. CTRL has greater SSS variance, the saltier side of which would get mixed into the subsurface. Fixed-SSS cannot salinify as much at the surface, so the surface waters mixing down are fresher, and saltier subsurface waters mixing up are nudged at the surface (also freshened).*

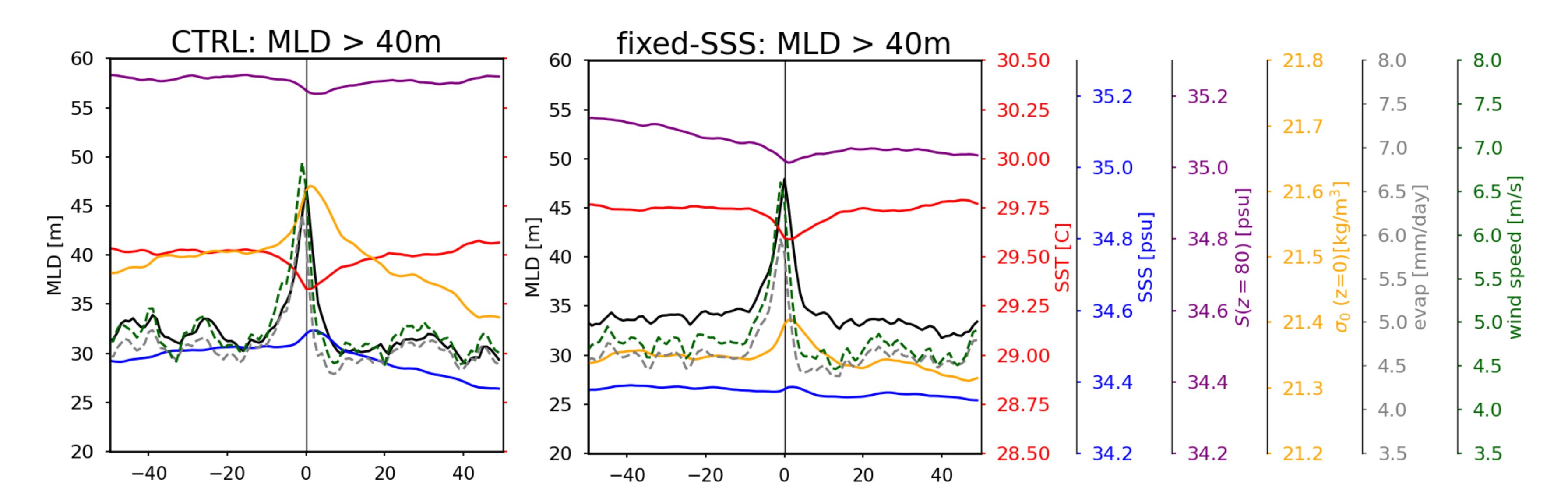


Fig. 6. Composites of MLD anomaly >40 m events in the CTRL (left) and fixed-SSS (right) ensembles during the first year of SSS nudging. Mean over WEqP. Events are spaced at least 20 days apart. Variables shown: Mixed layer depth (MLD), SST, SSS, salinity at 80m depth, surface density, evaporation, and wind speed.