Salinity-Induced Eastward Flow in Boreal Spring Favors Extreme El Niño

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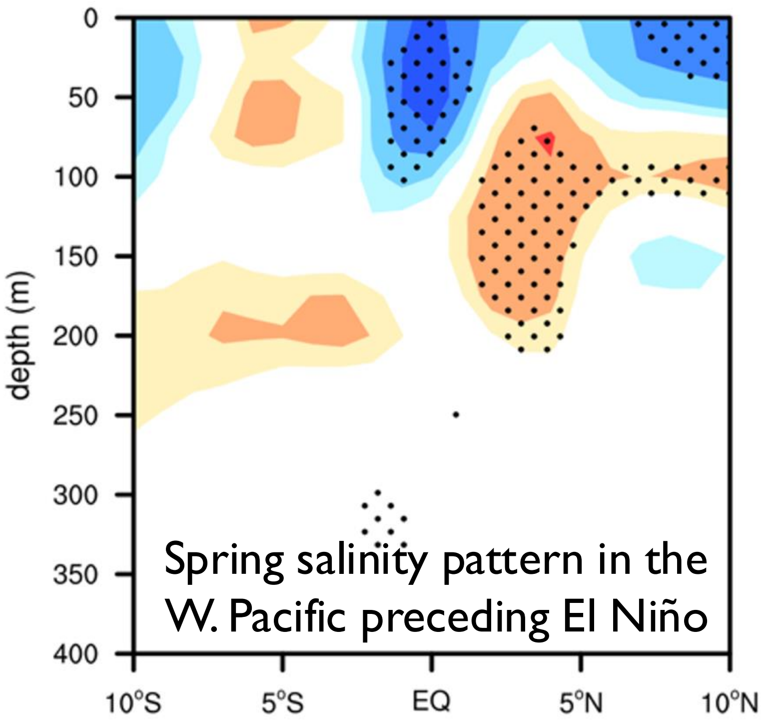
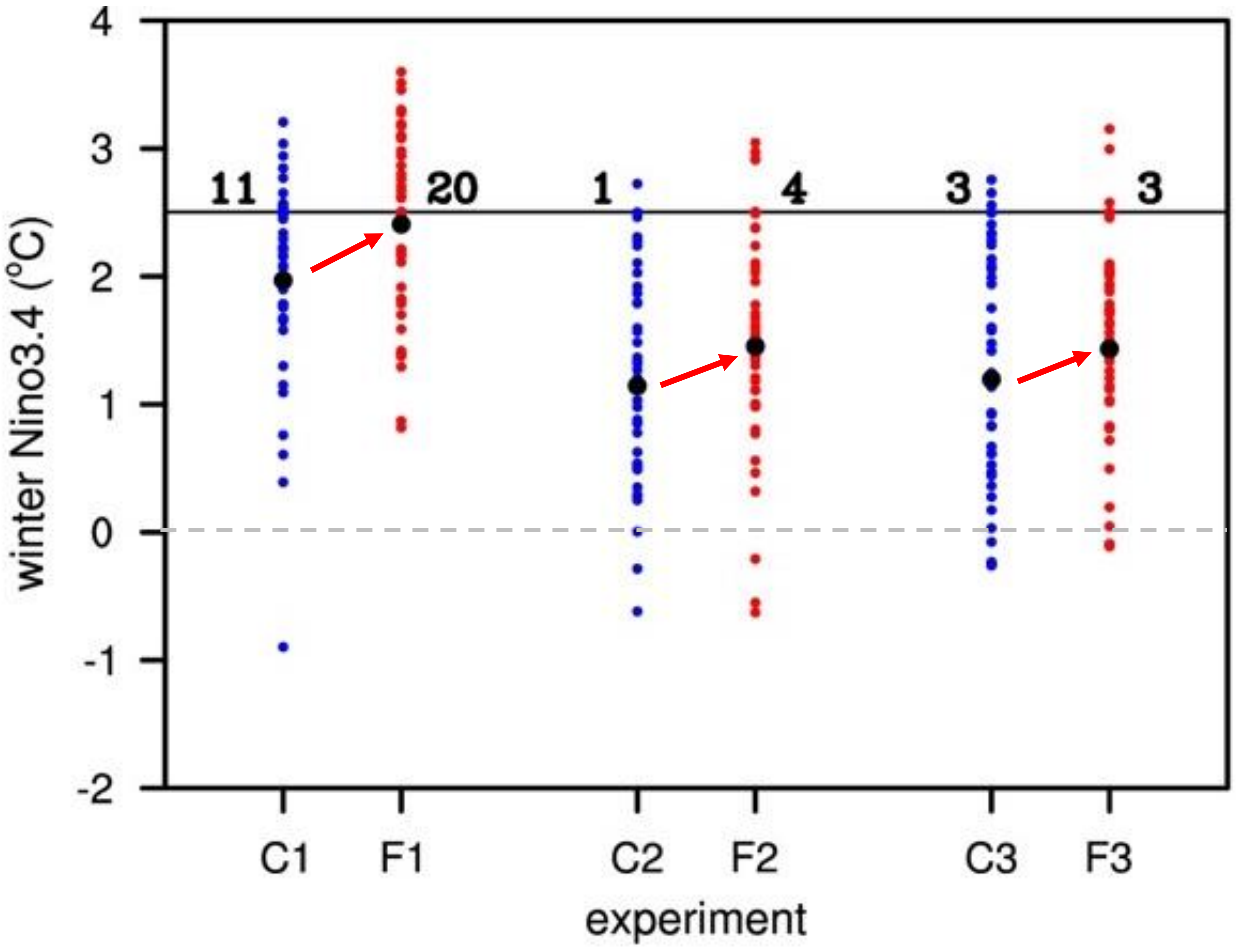


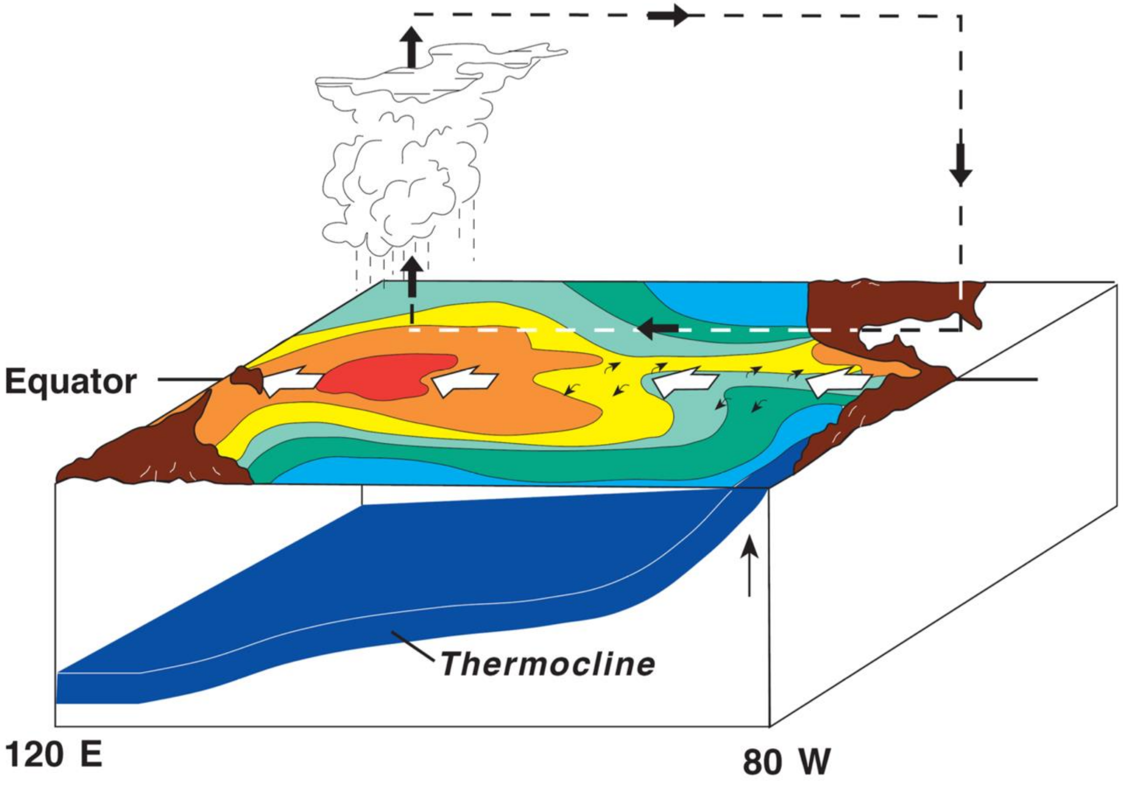


Dr. Shizuo Liu

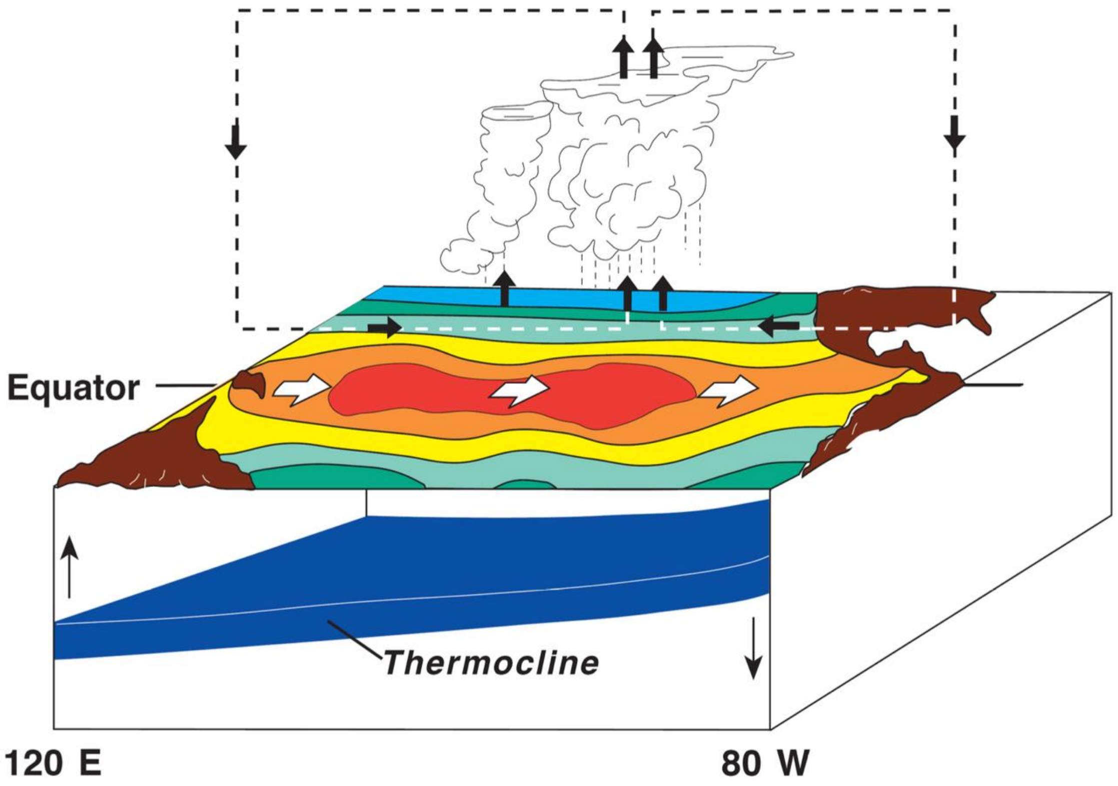
May 20, 2026 @ OSST Meeting

El Niño-Southern Oscillation (ENSO)

Normal condition



El Niño



McPhaden et al. (1998)

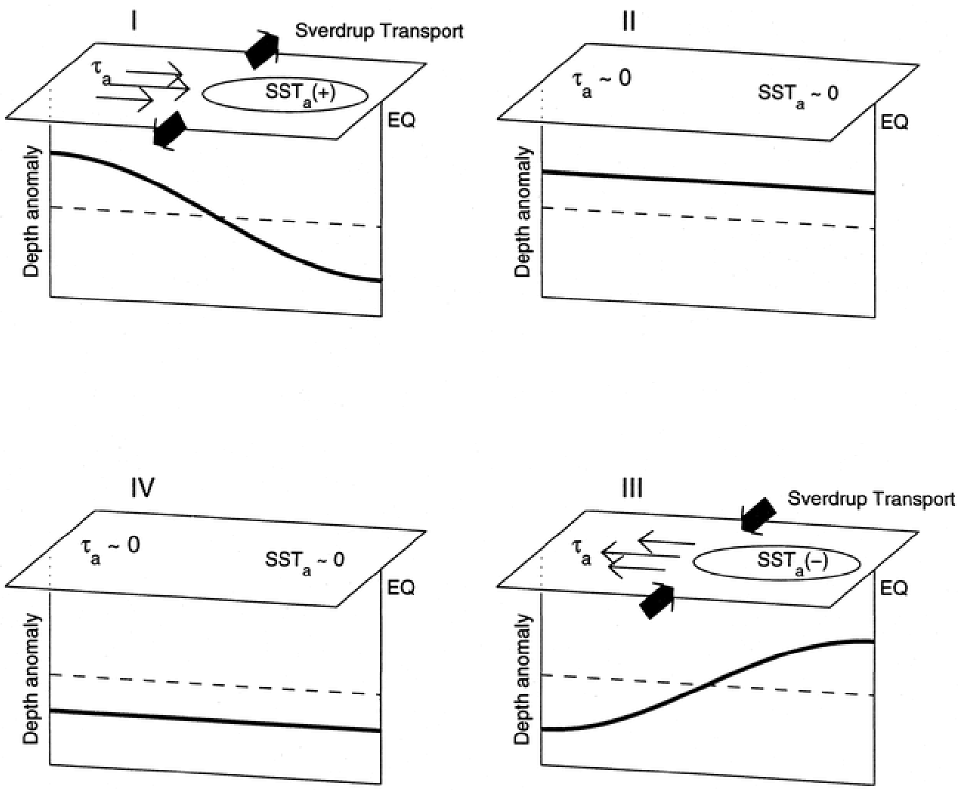
A recipe of ENSO:

1) Bjerknes feedback: a positive feedback involving sea surface temperature, wind, and thermocline
(Bjerknes 1969)
(How does El Niño/La Niña amplify?)

2) "Recharge Oscillator": a delayed, negative feedback involving subsurface ocean heat change
(Jin 1997; Meinen and McPhaden 2000; Vialard et al. 2025)
(How does El Niño/La Niña change phase?)

3) Westerly wind bursts: a trigger of El Niño events & a part of the Bjerknes feedback as a multiplicative noise
(e.g. Kessler et al. 1995, Yu et al. 2003; Lengaigne et al. 2004; Eisenman et al. 2005; Hu et al. 2014; Hu and Fedorov 2019)
(What maintains and energizes the oscillation?)

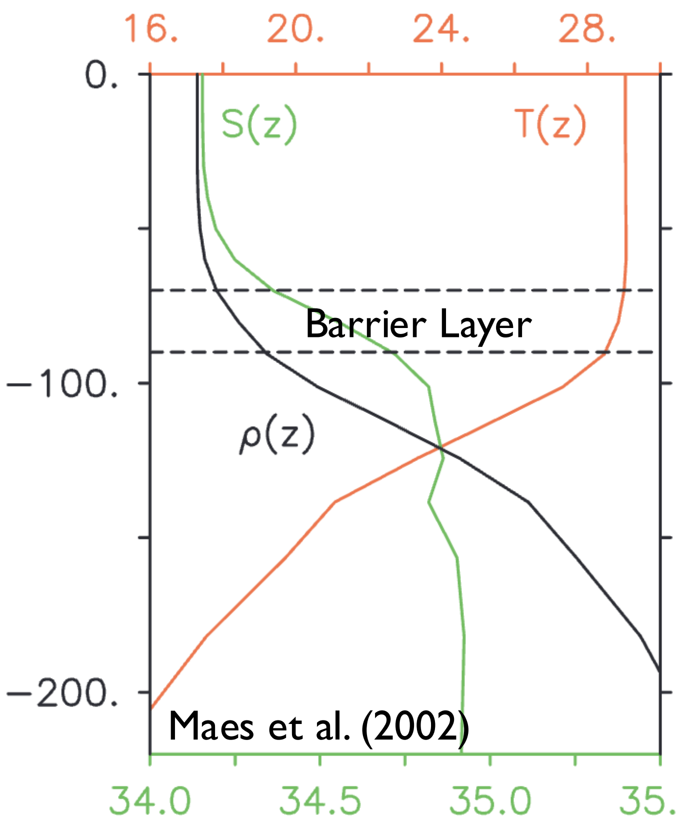
Schematic of "Recharge Oscillator"



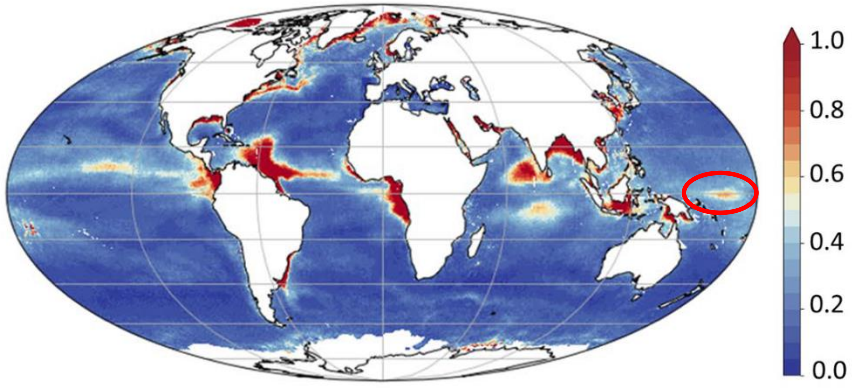
Jin (1997); Meinen and McPhaden (2000)

What is the role of ocean salinity in ENSO dynamics?

A role of ocean salinity in ENSO dynamics?

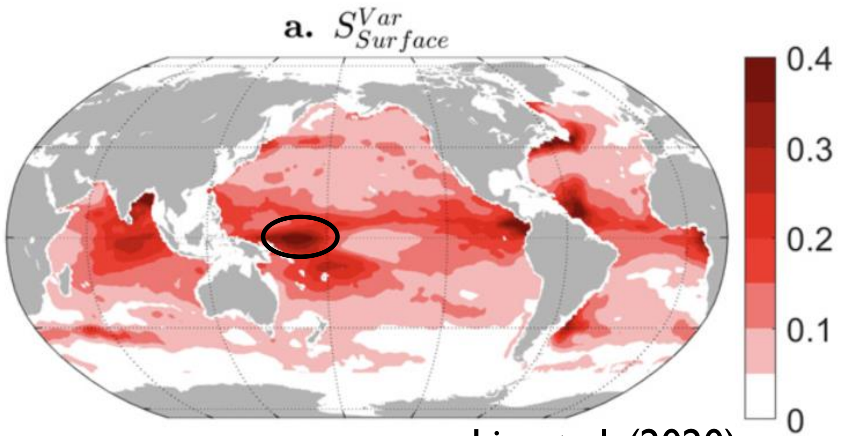


Satellite-based surface salinity variability



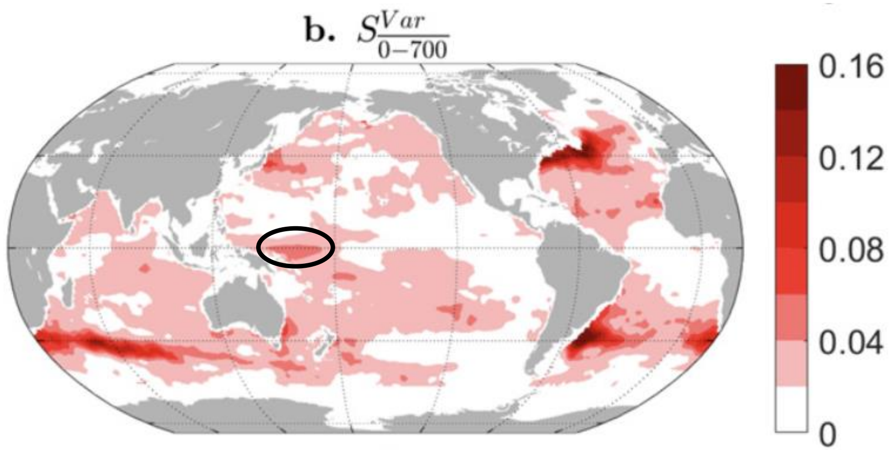
Boutin et al. (2021) psu

Argo-based surface salinity variability



Liu et al. (2020) psu

Argo-based upper ocean salinity variability



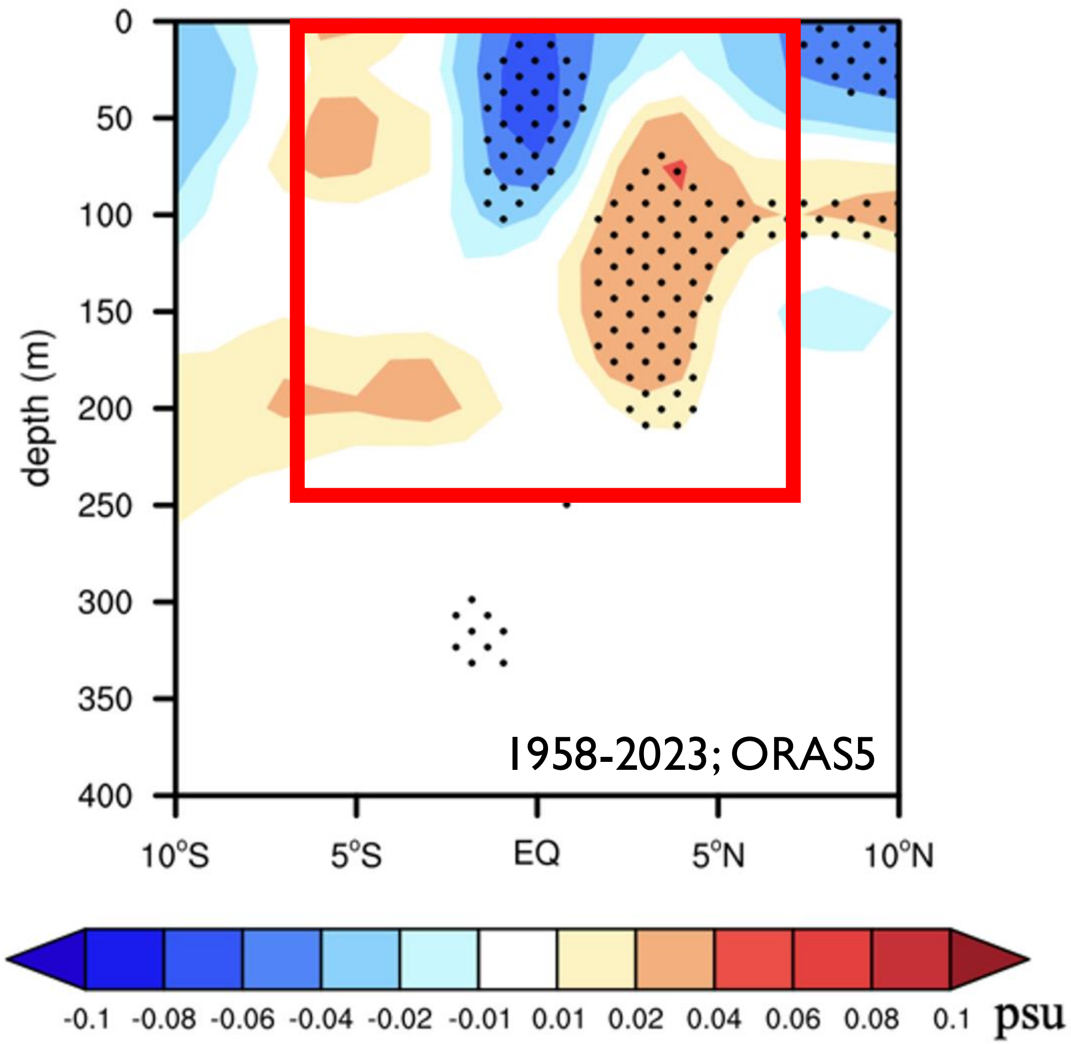
psu

Can ocean salinity *variability* influence ENSO dynamics?

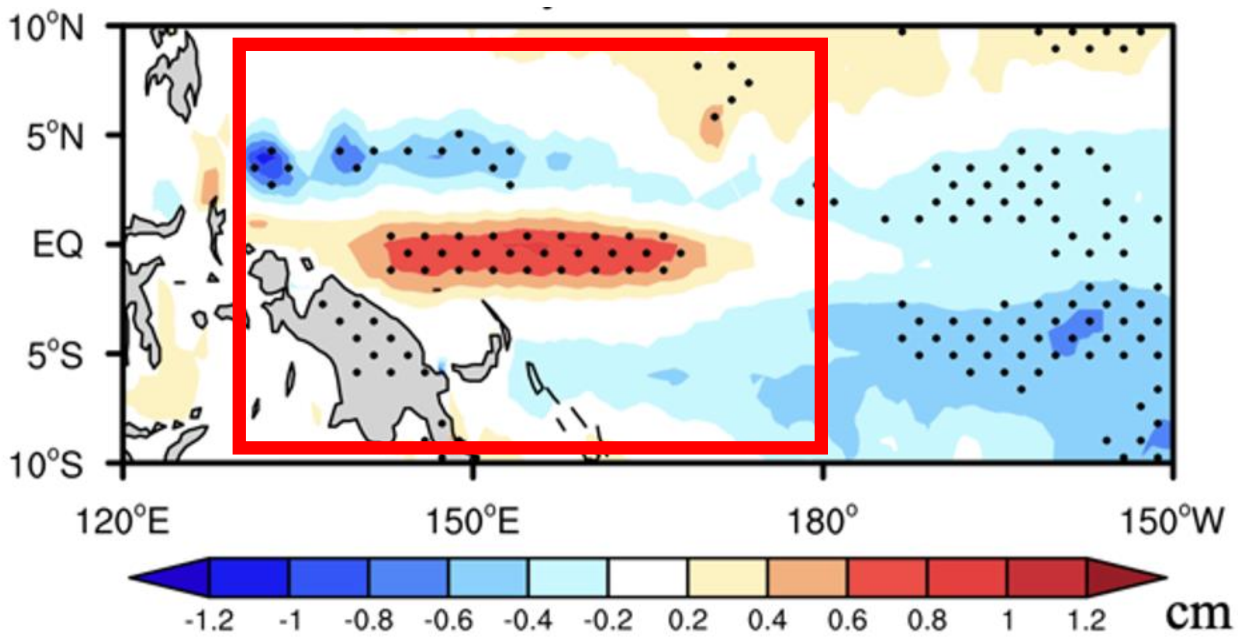
- Ocean barrier layer in the western Pacific hinders entrainment of subsurface cool water and preserves ocean heat content. (e.g., Vialard and Delecluse 1998; Maes et al. 2002;)

March-May salinity pattern preceding El Niño events (Regression onto normalized December-February Niño3.4)

Salinity anomalies in the W. Pacific (130°E-180°)



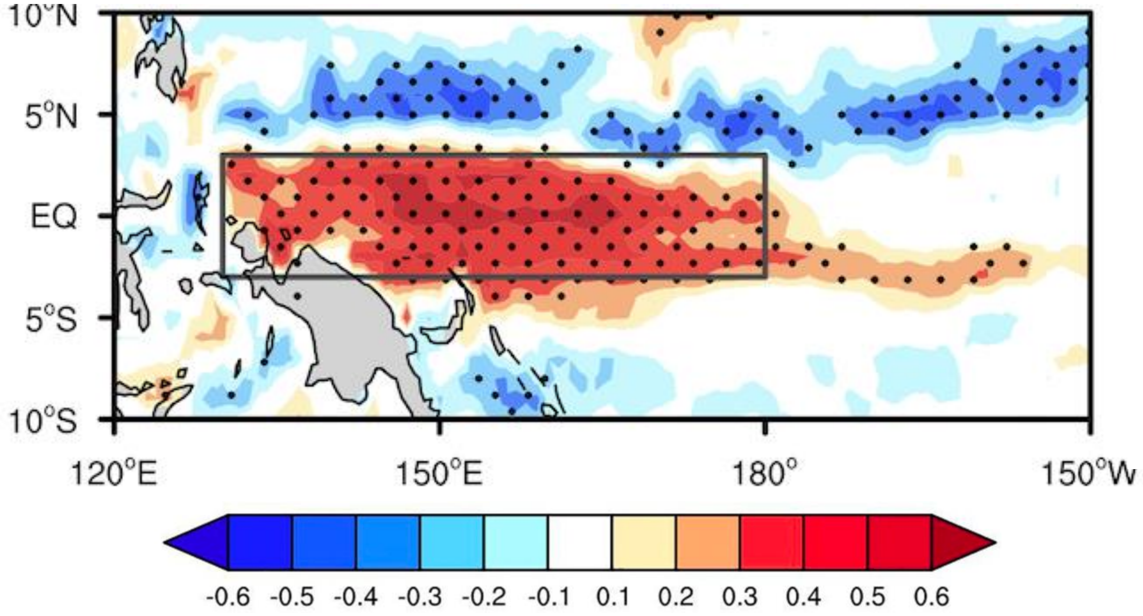
Steric sea level due to subsurface salinity anomalies (0-400m)



$$\xi_S = -\int_{z=0}^{H} \frac{\rho(\bar{T},S,p)-\bar{\rho}(T,S,p)}{\bar{\rho}(T,S,p)}\,dz$$

Surface zonal (semi)geostrophic current associated with the spring salinity pattern

Correlation between spring (MAM) salinity-induced surface zonal geostrophic current and winter (DJF) Niño3.4

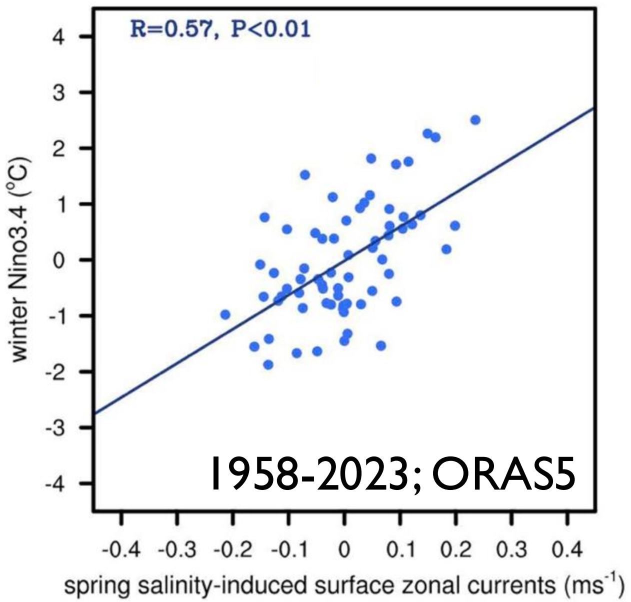


Off the equator:

$$u_g = -\frac{g}{f}\frac{\partial \xi}{\partial y}$$

At the equator:

$$u_{sg} = -\frac{g}{\beta}\frac{\partial^2 \xi}{\partial y^2}$$



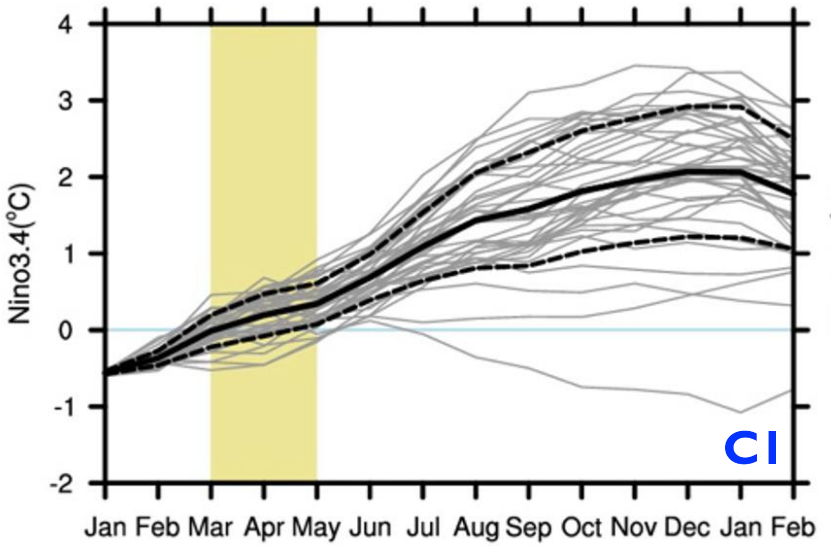
Hypothesis:

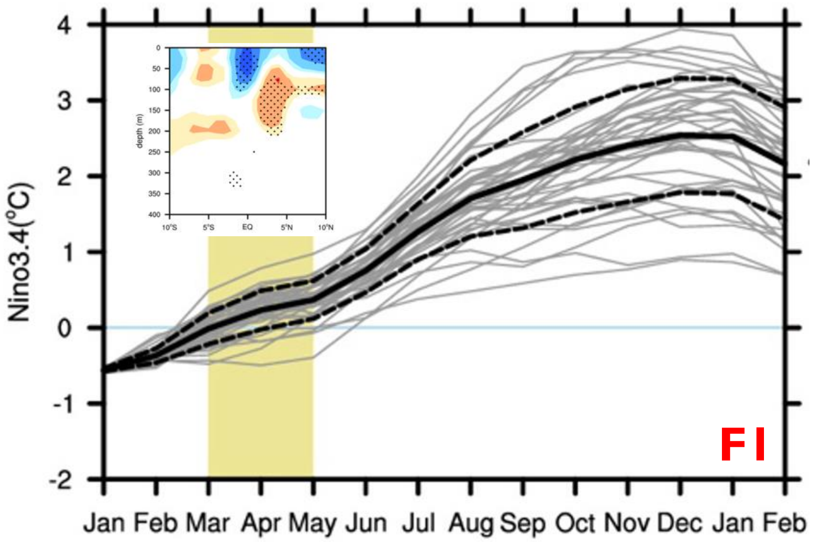
The observed spring salinity pattern can facilitate El Niño development through dynamical processes (geostrophic currents, Kelvin waves, etc.)

See Jauregui and Chen (2024) for short-term adjustment of density currents.

Ocean-atmosphere coupled simulations with imposed salinity anomalies

- The Community Earth System Model version 2.1 (CESM2.1)
- Step 1: From a long pre-industrial run, pick a "recharged" ocean initial condition favorable for El Niño development
- Step 2: Control Ensemble (C1) & Salinity-Forced Ensemble (F1):
  - Same ocean initial condition ("recharged")
  - F1: salinity forcing applied from March to May in the tropical western Pacific (10°S–10°N, 130°E–180°) between 0-400 m with a magnitude equivalent to two times of the regression of the salinity against the subsequent winter Niño3.4
  - C1 & F1: 40 ensemble members each (slight perturbations of atmospheric initial state)
  - Each simulation: 14 months (from Jan 1 to Feb 28 of the following year).





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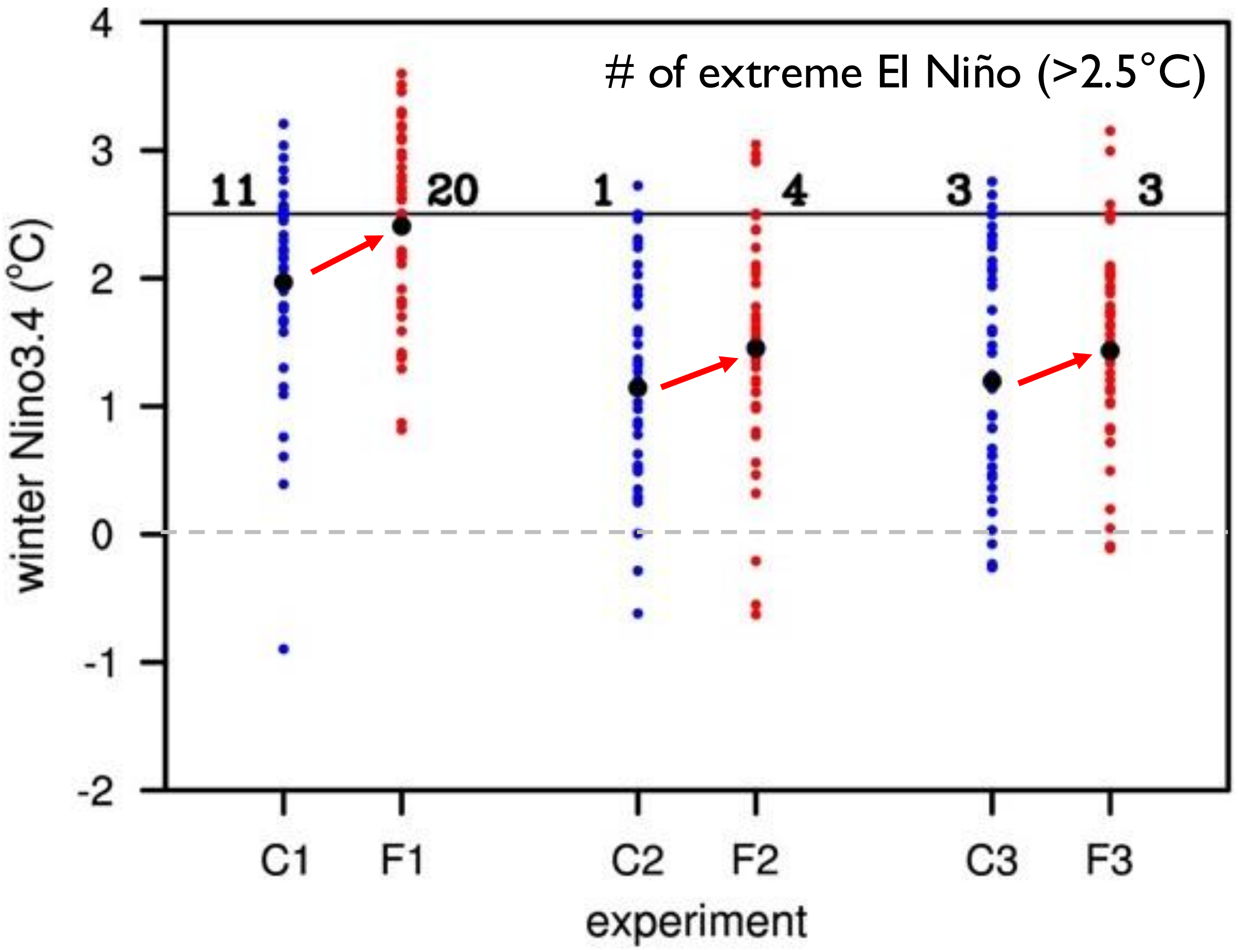
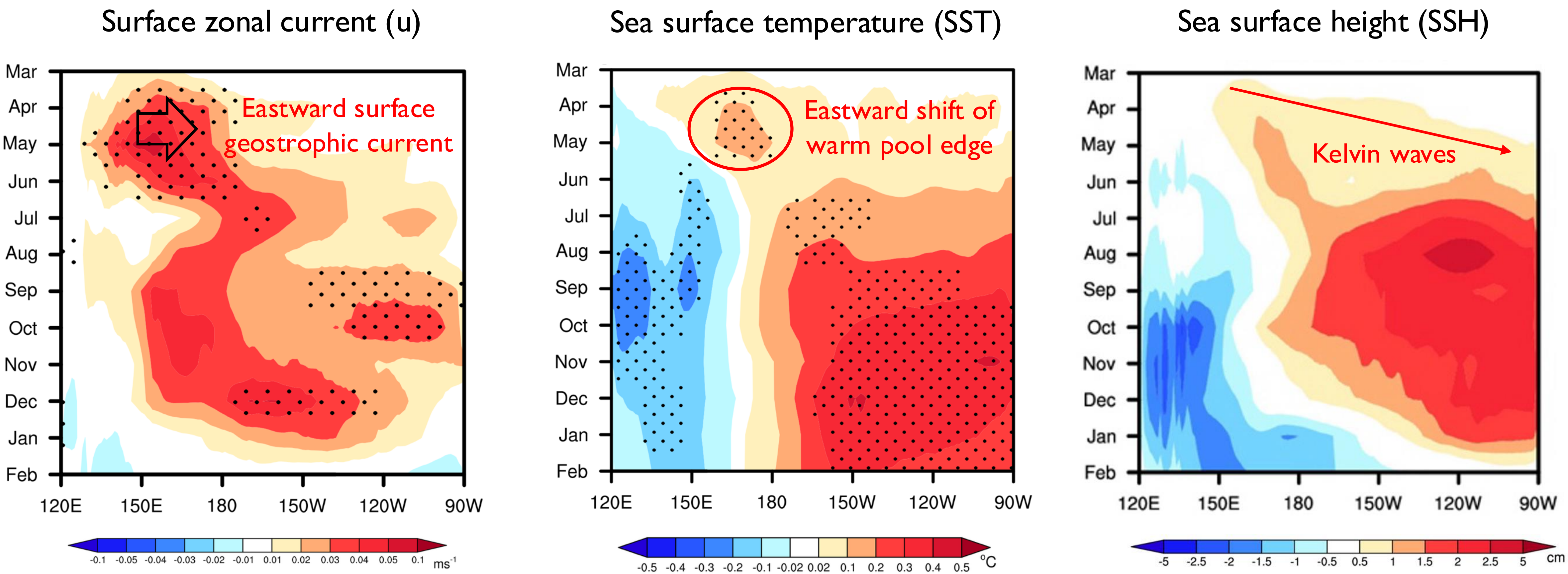
- Step 3: Repeat Steps 1 & 2 to generate (C2, F2), (C3, F3).

Winter (DJF) Niño3.4 response to spring salinity forcing (forcing = salinity pattern for a 2-std El Niño)



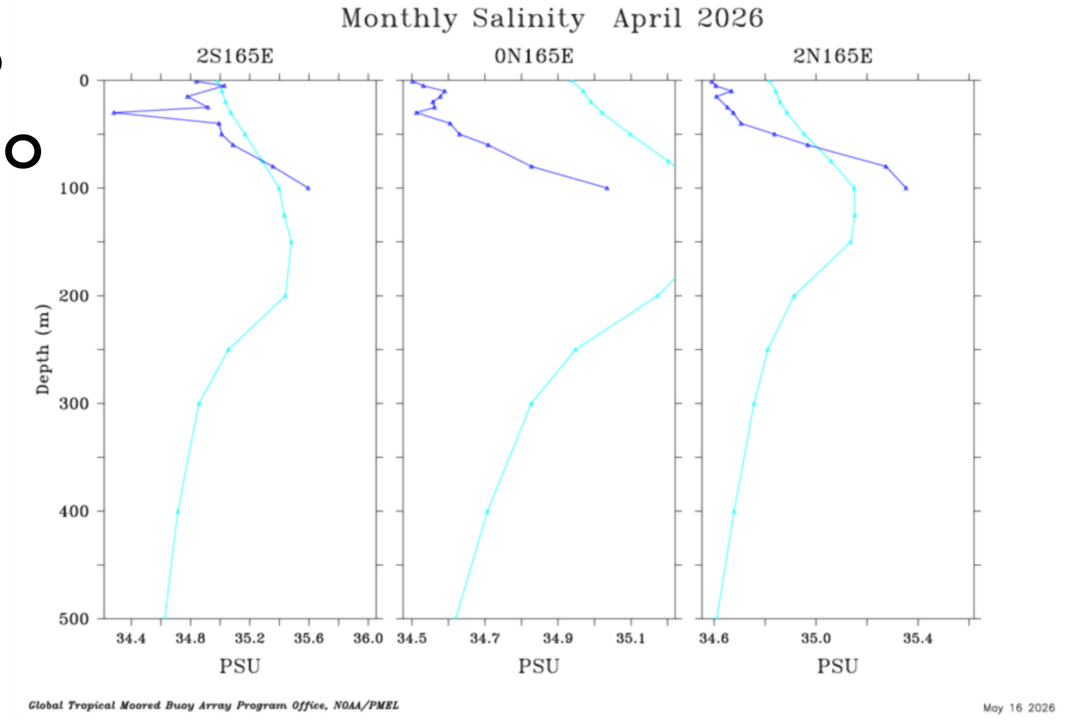
- On average, wintertime Niño3.4 increases by +0.32°C (from +1.44°C to +1.76°C).
- The probability of extreme El Niño (wintertime Nino3.4 > +2.5°C) almost doubles, from 15 to 27 out of 120.

Hovmoller diagrams (ensemble mean)

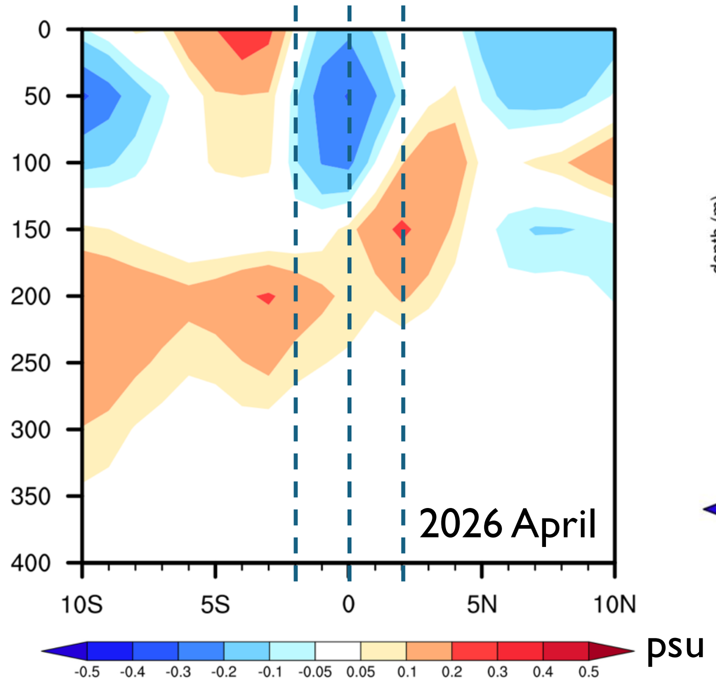


- Imposed salinity anomalies → Eastward surface geostrophic currents & higher SSH in the W. Eq. Pacific.
- Eastward flow → Shifted warm pool edge → Warm SST anomalies near the Dateline
- Higher SSH → Downwelling Kelvin waves → Warm SST anomalies in the E. Eq. Pacific
- Warm SST anomalies trigger positive Bjerknes feedback

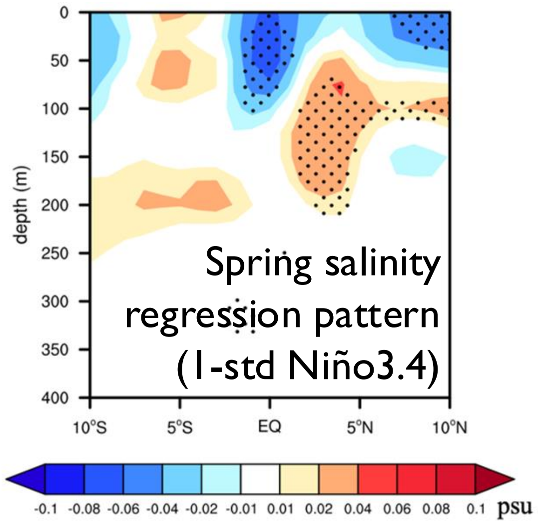
2026 El Niño



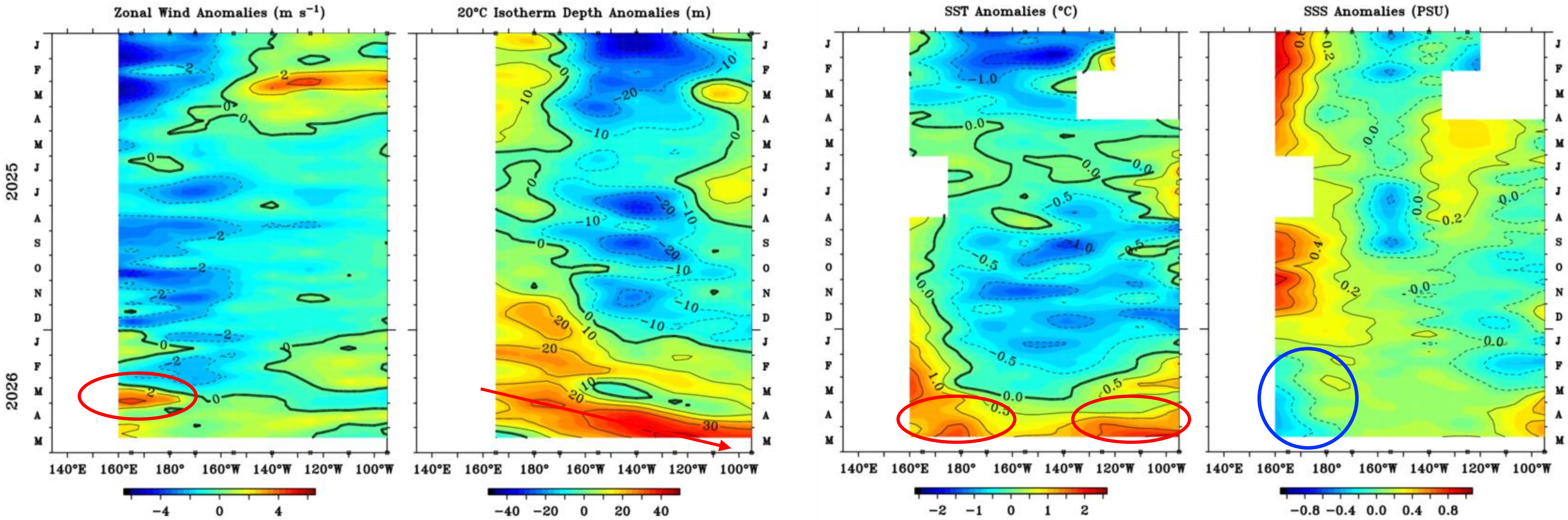
Monthly Salinity April 2026
2S165E
0N165E
2N165E
Depth (m)
PSU
Global Tropical Moored Buoy Array Program Office, NOAA/PMEL
May 16 2026



2026 April
10S
5S
0
5N
10N
psu



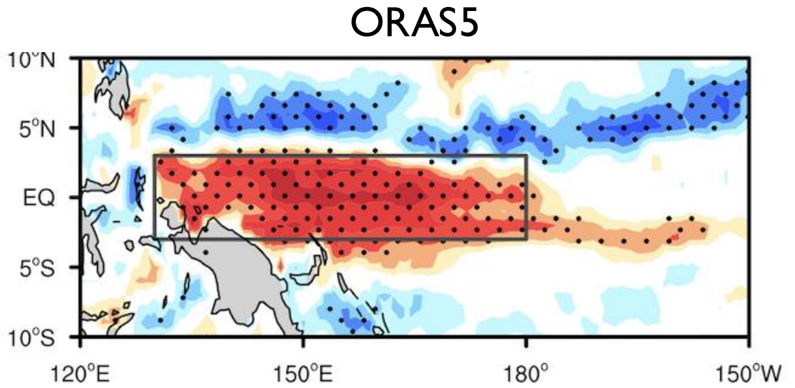
Spring salinity regression pattern (1-std Niño3.4)
depth (m)
10°S
5°S
EQ
5°N
10°N
psu

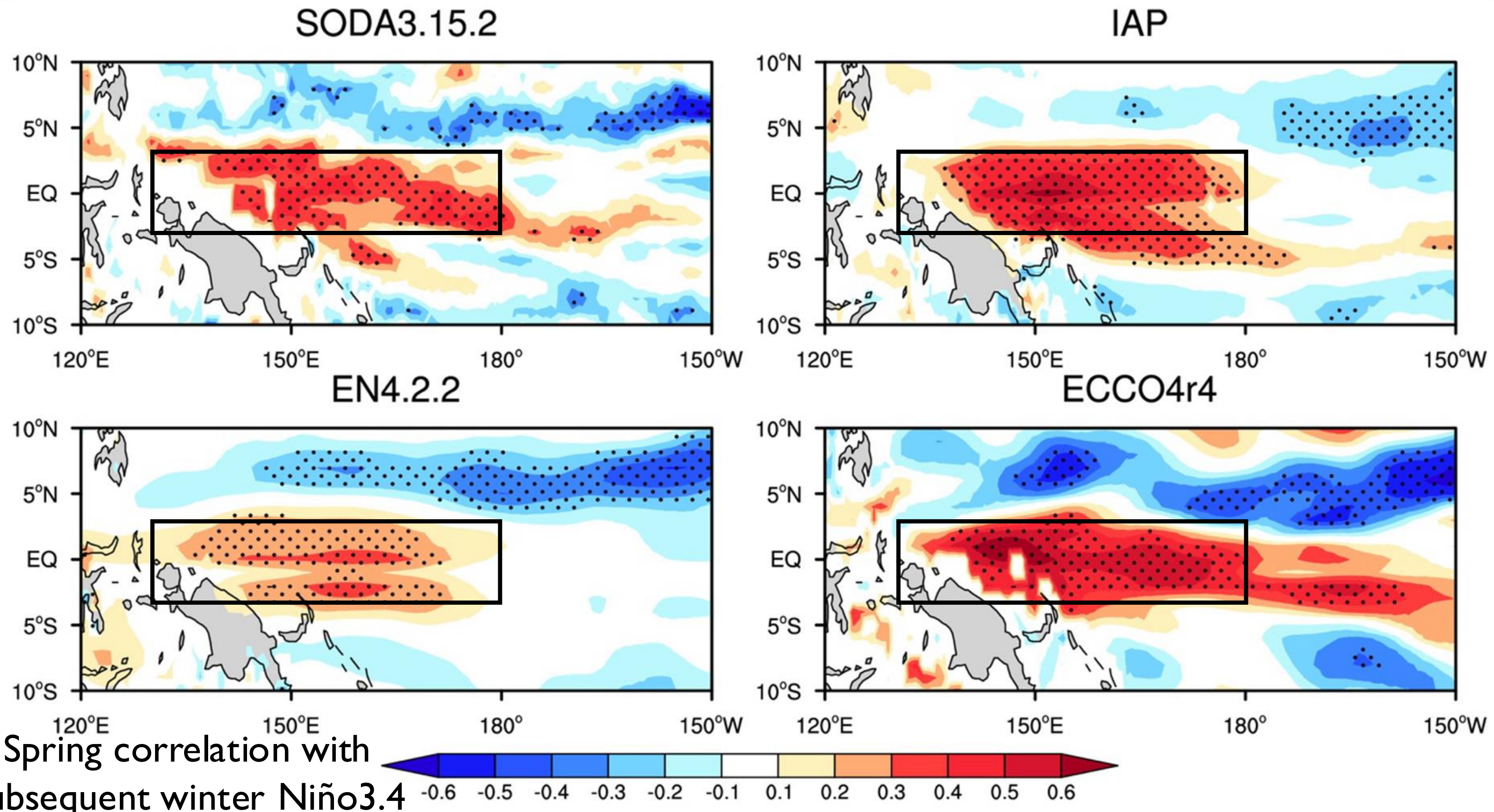


Zonal Wind Anomalies (m s⁻¹)
20°C Isotherm Depth Anomalies (m)
SST Anomalies (°C)
SSS Anomalies (PSU)
2025
2026
140°E 160°E 180° 160°W 140°W 120°W 100°W

Satellite-based subsurface T & S data are needed

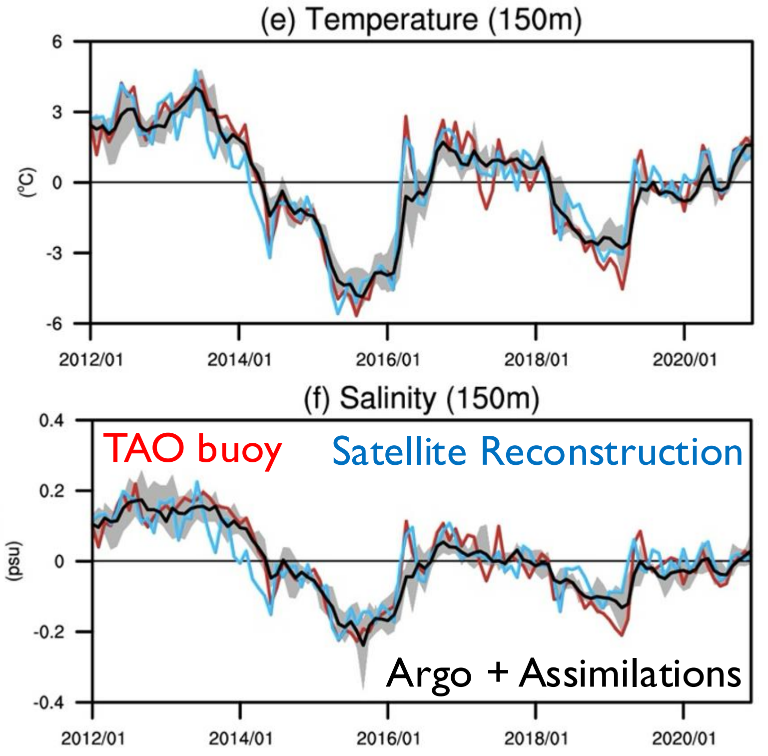
Diverging signals of ENSO-related salinity-induced surface currents among observational products





Spring correlation with subsequent winter Niño3.4

Reconstructed T(z) & S(z) in the upper ocean (0-400 m) based on satellite measurements of SSH, SST, and SSS (Liu and Hu, 202X)



An example in W. Pacific (8°N, 137°E) at 150 m

Summary

- A robust spring salinity pattern with fresher equatorial and saltier off-equatorial anomalies in the western Pacific precedes El Niño events.

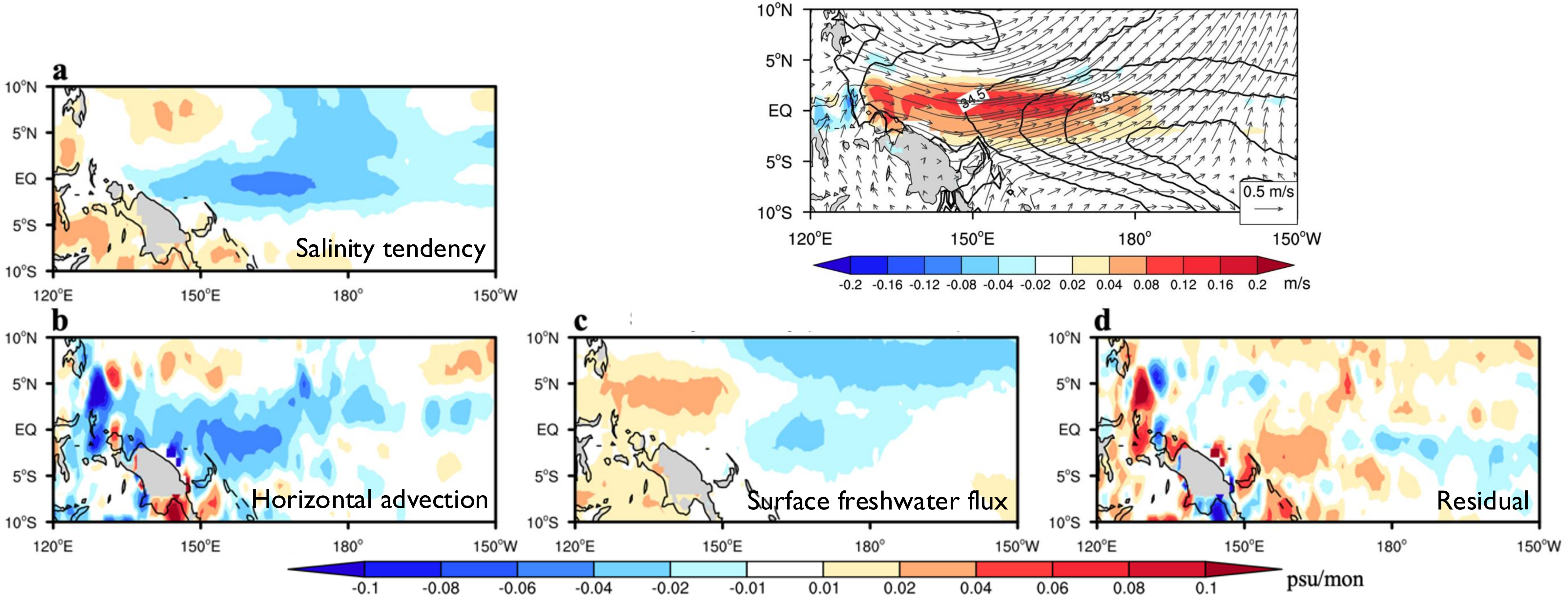
- These boreal spring salinity anomalies can influence El Niño development through salinity-induced surface zonal geostrophic currents.

- Large-ensemble simulations (w/ CESM2) indicate this salinity mechanism can increase El Niño intensity by ~20%.

- This spring salinity pattern has been identified in March-April 2026, which may contribute to the increase of winter Niño3.4 by ~0.8°C (CESM2-based rough estimate).

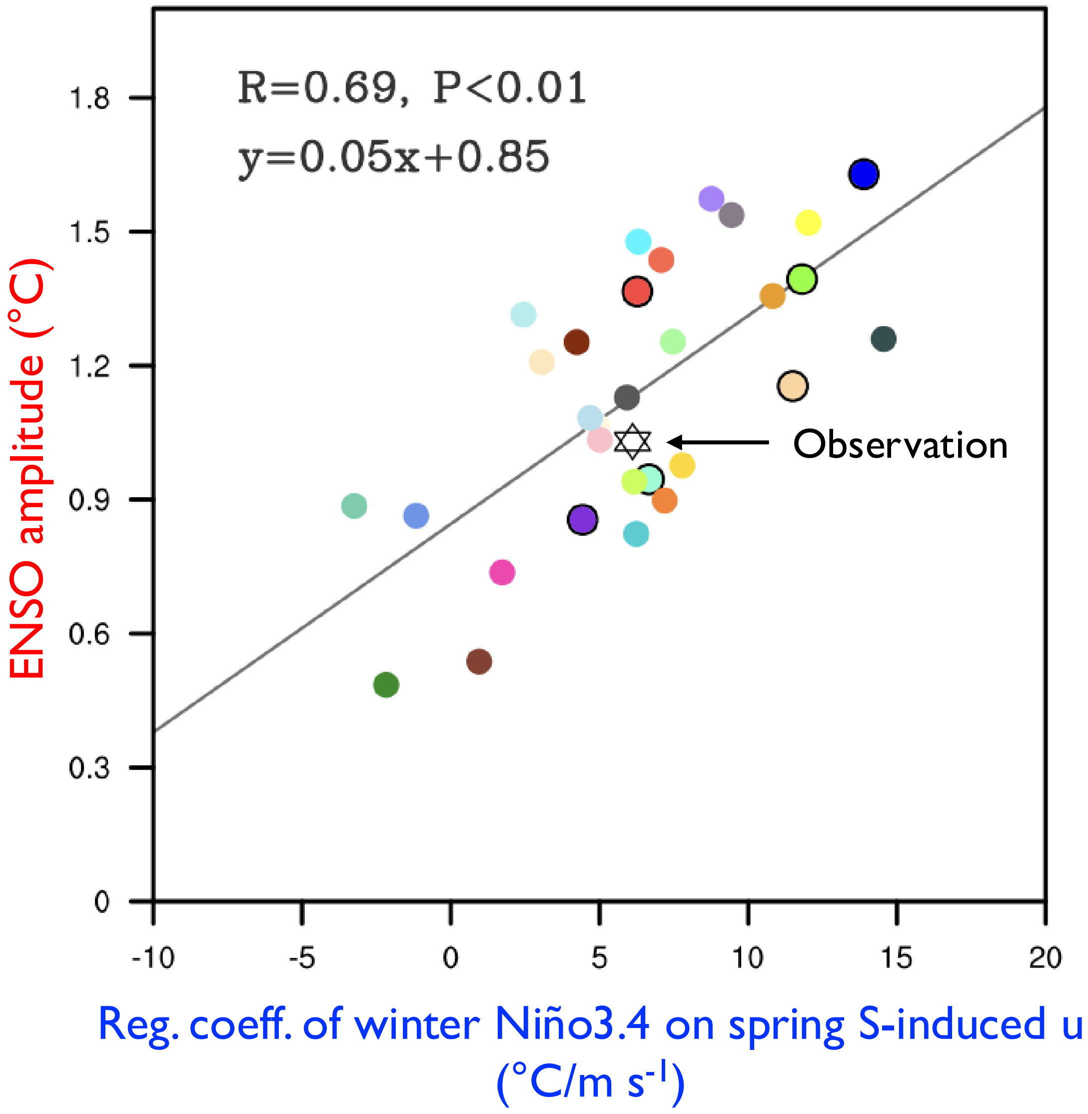
Liu, S., Hu, S., & McPhaden, M. J. (2025). **Salinity-induced eastward flow in boreal spring favors extreme El Niño.** *Geophysical Research Letters*, 52(24), e2025GL118731.

Spring mixed layer salinity budget
(Regression onto normalized December-February Niño3.4)



- The spring salinity pattern preceding an El Niño results mainly from horizontal advection driven by westerly wind bursts and associated surface freshwater flux. (Therefore, probably a booster rather than an independent precursor.)

CMIP6 model spread in salinity-ENSO connection



- A model that has a higher sensitivity of the winter Niño3.4 index to the preceding spring western tropical Pacific salinity-induced surface zonal currents tends to produce a stronger ENSO.