Predictability of tropical Pacific decadal variability is dominated by oceanic Rossby waves

Xian Wu[1], Stephen Yeager[2], Clara Deser[2], Antonietta Capotondi[3], Andrew Wittenberg[4], Michael McPhaden[5]

[1]UT Dallas [2]NCAR [3]CIRES & NOAA PSL [4]NOAA GFDL [5]NOAA PMEL

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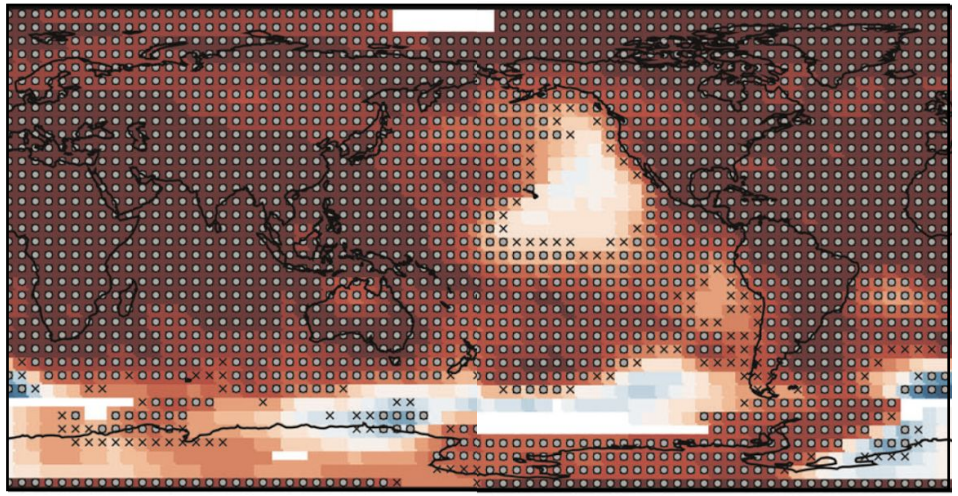
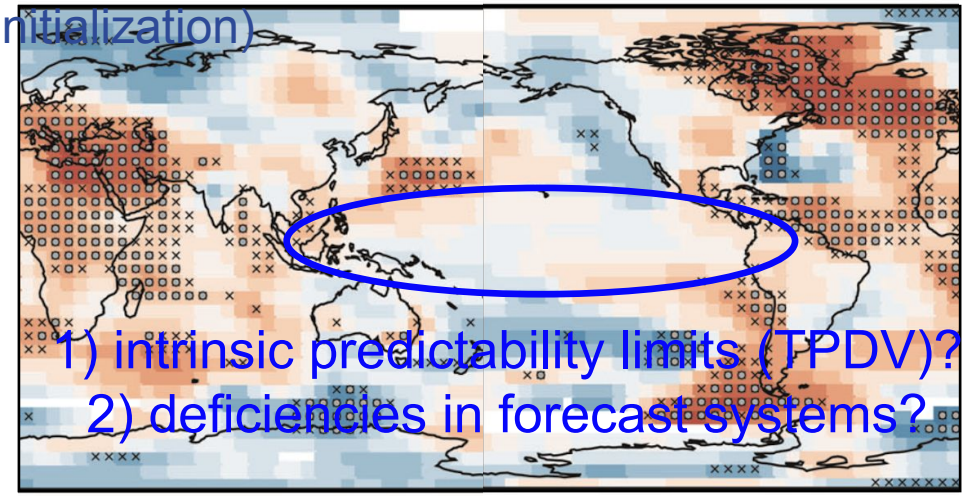
Low internal decadal prediction skill in the tropical Pacific

1960–2015, Lead Year 2–9 average, 8 CMIP models, 71 ensemble members

Total correlation skill



Residual correlation skill (Impact of initialization)



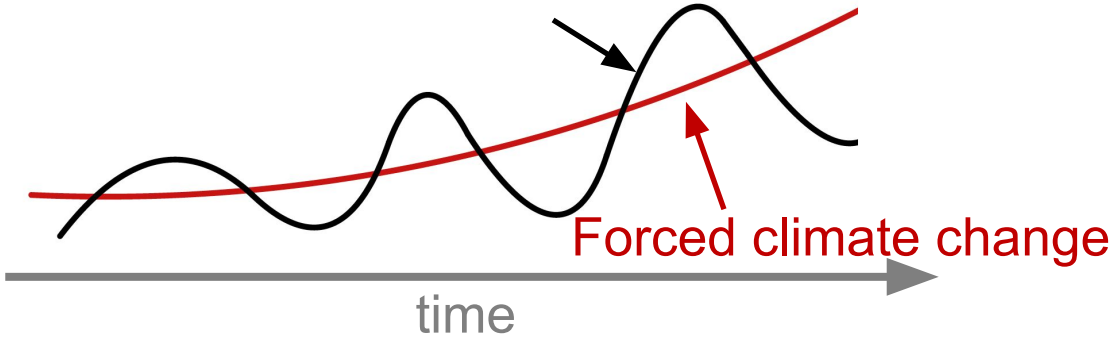
1) intrinsic predictability limits (TPDV)?
2) deficiencies in forecast systems?

anomaly correlation coefficient (ACC)

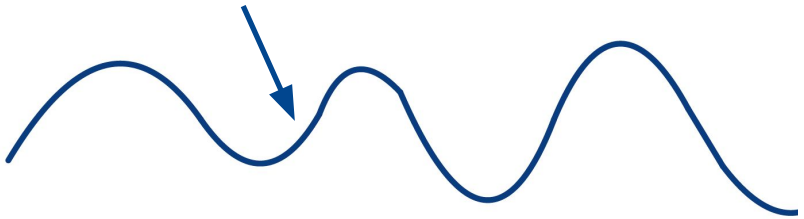
−0.9 −0.6 −0.3 0.0 0.3 0.6 0.9

Smith et al. 2019

Total decadal variations



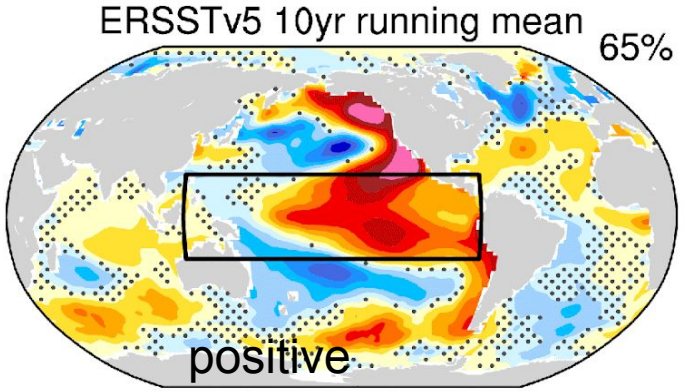
Internal decadal variability

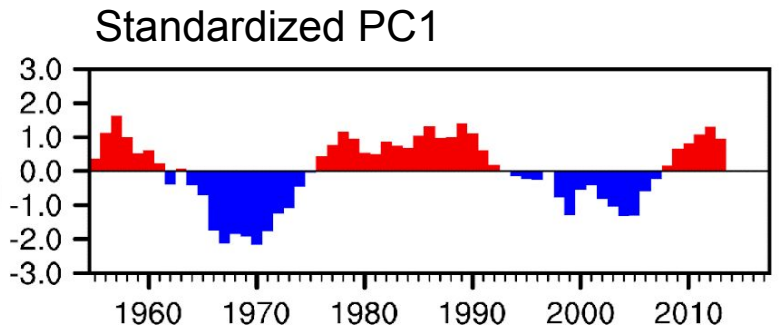


Tropical Pacific decadal variability (TPDV) during 1955–2022

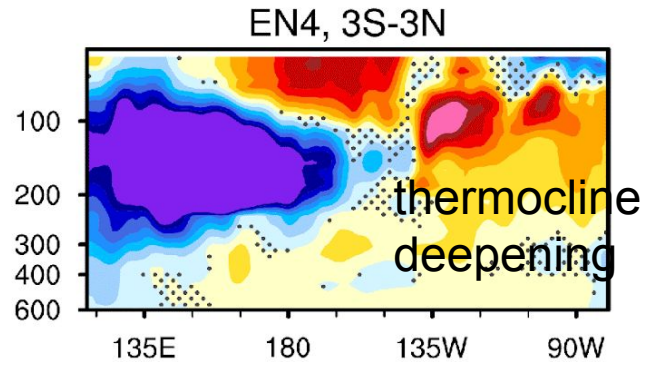
Leading EOF mode of *10-yr running mean* and *quadratically detrended* SST anomalies in the tropical Pacific

Observation



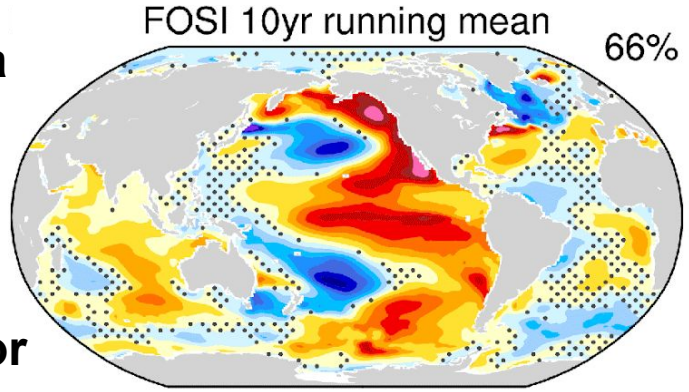


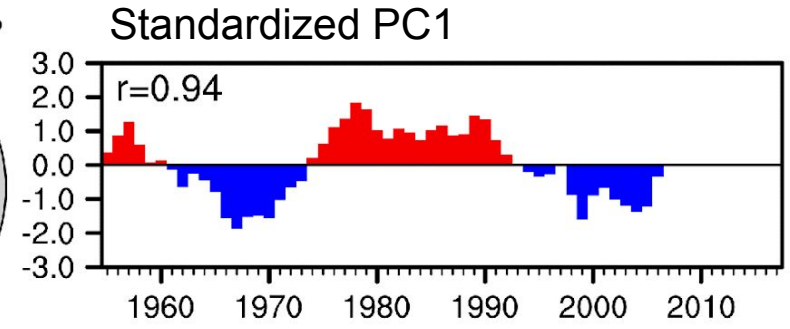
The abscissa denotes the **start year** of any **10-yr averaging** window.

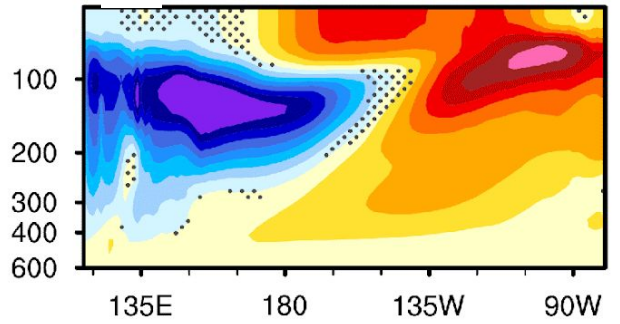


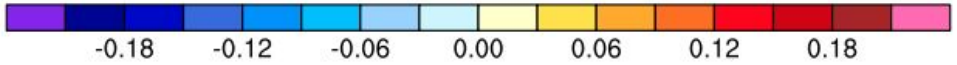
Forced Ocean Sea Ice Simulation (FOSI)

used as **initial conditions for decadal forecasts**









Decadal prediction systems with CESM1 (1°)

1) CESM1 Decadal Prediction Large Ensemble (DPLE), *Yeager et al. (2018)*

- **Initialized with** 'observed' oceanic and sea ice states on Nov 1st of each year during 1954–2015
- 40 members x 10 years
- **CMIP5 radiative forcing** (Historical & RCP8.5)

2) CESM1 DPLE without historical volcanic forcing (DPLE_NoVolc), *Wu et al. (2023)*

- 10 members

1) vs 2) Role of volcanic forcing

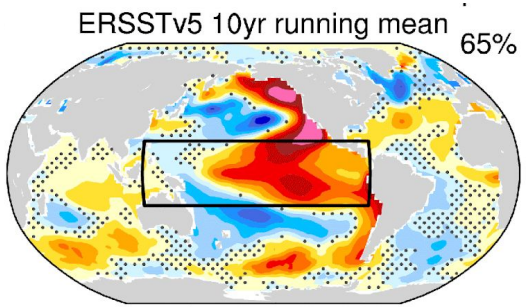
3) CESM1 Large Ensemble (LE), *Kay et al. (2015)*

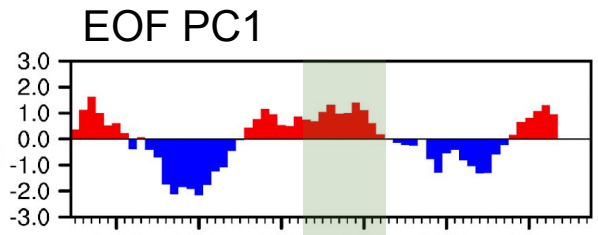
- 1920-2100, 40 members
- CMIP5 external forcing (including historical volcanic forcing)

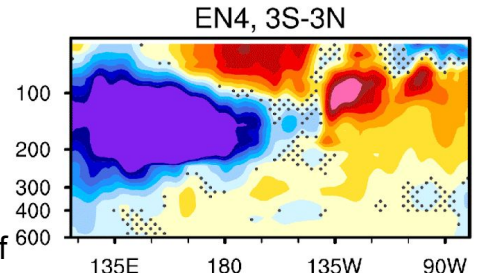
1) vs 3) Role of ocean initialization

TPDV in initialized forecasts and un-initialized simulations

Observation

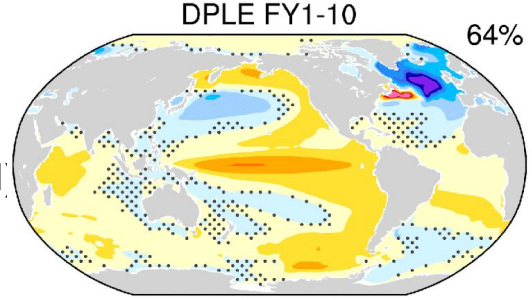


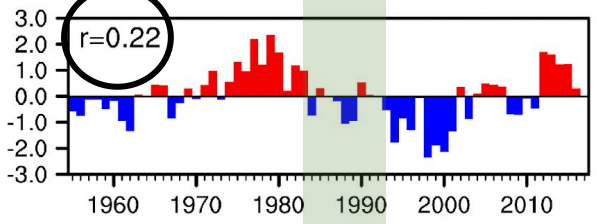


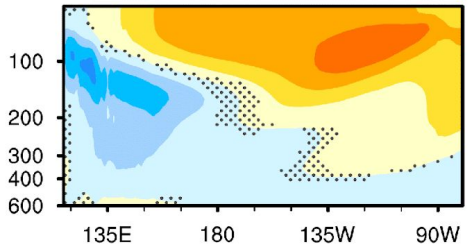


The abscissa denotes the **start year** of any **10-yr averaging** window.

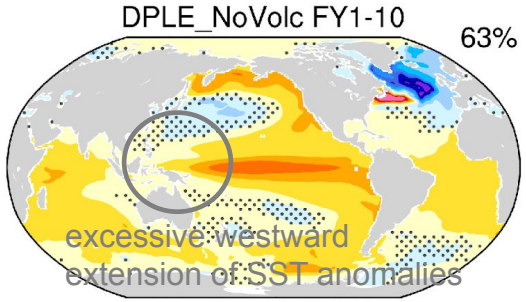
DPLE
(Forecast Year 1-10 averaged)

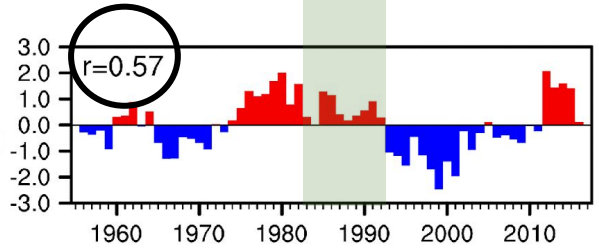


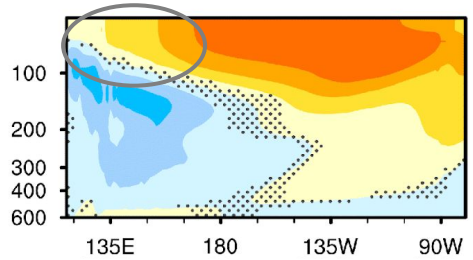




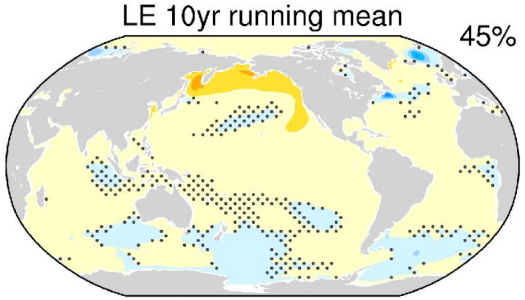
DPLE_NoVolc
(Forecast Year 1-10 averaged)

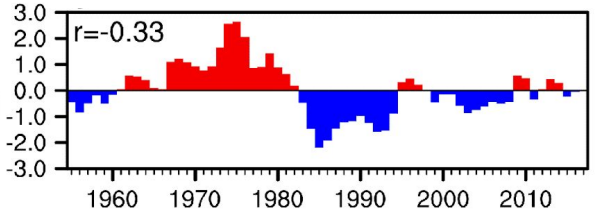


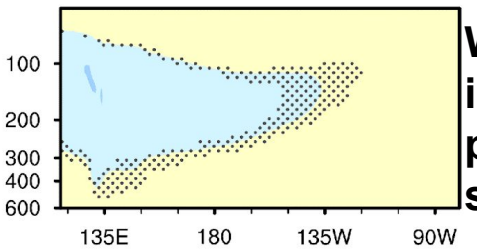




Large Ensemble
(10-yr running mean)







Volcanic forcing degrades prediction skill of TPDV
(Wu et al. 2023)

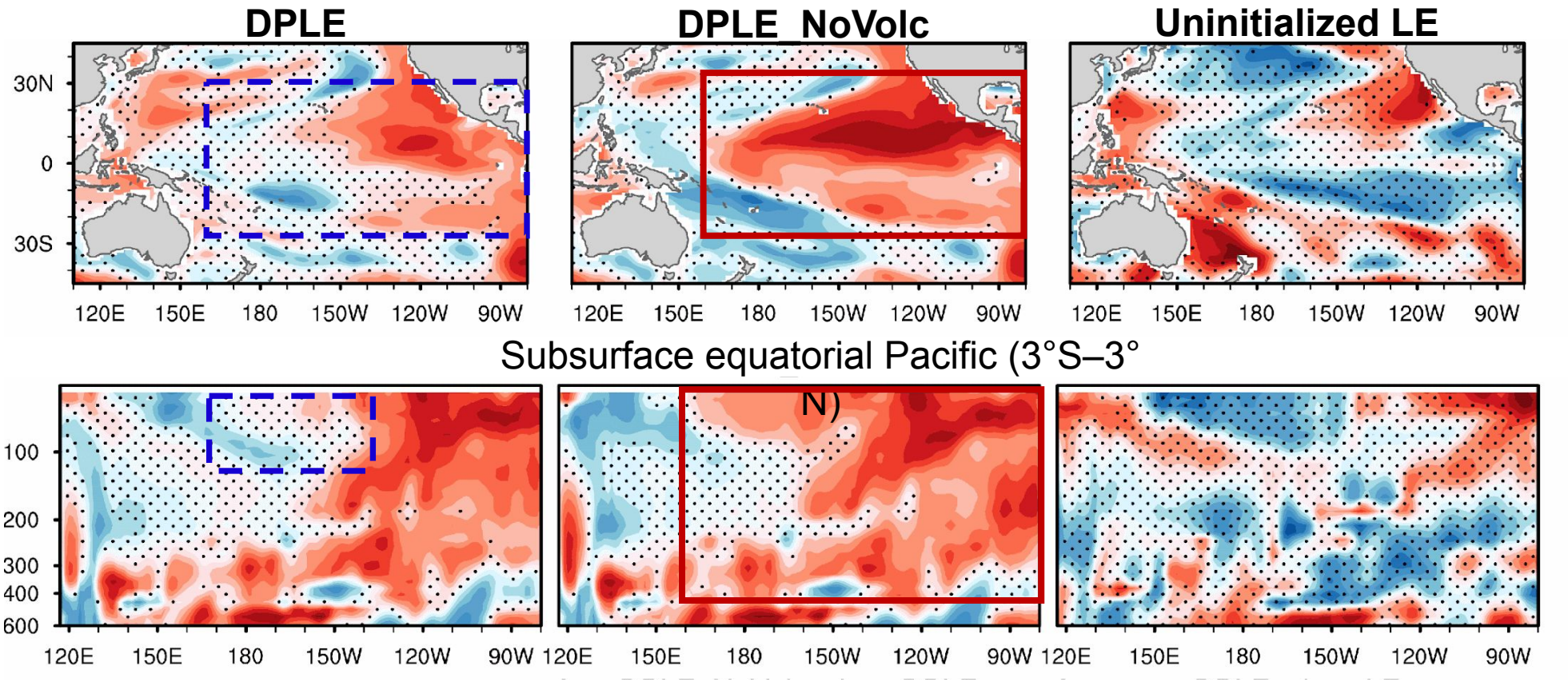
Without ocean initialization, TPDV prediction shows no skill!

ACC skill of decadal SST and subsurface ocean temperature

1955–2016, Forecast Year 1–10 average

SST
verified against ERSSTv5

Subsurface ocean temperature
verified against EN4



Volcanic forcing decreases ACC within the thermocline depth via shortwave radiation and ENSO dynamical processes

High ACC in DPLE_NoVolc, in contrast to CMIP decadal hindcasts.

No ACC skill without ocean Initialization

Complex origins and mechanisms of TPDV

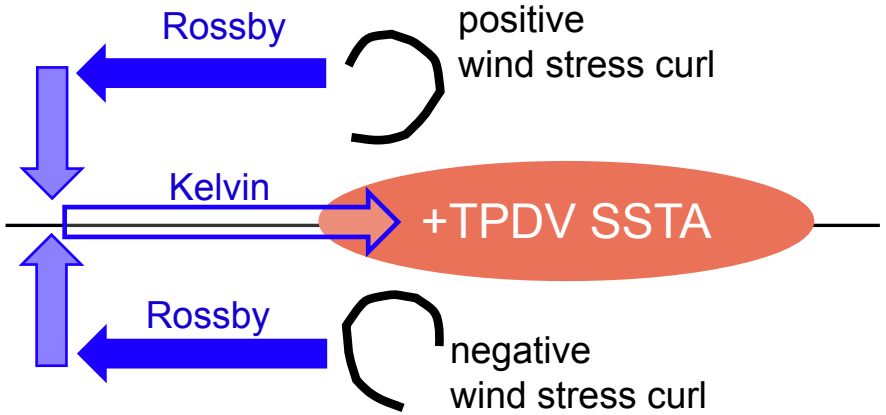
Origin of TPDV remains uncertain

1) Tropical Origin: residual of ENSO variability *(e.g., Rodgers et al. 2004; Vimont 2005; Power et al. 2021)*
2) Extratropical Origin: Low frequency SST variability in the extratropical Pacific driven by stochastic atmospheric variability *(e.g., Hasselmann 1976)* propagate into tropics via thermodynamic processes *(Sun and Okumura et al. 2019; Zhao and DiLorenzo 2020)*

Oceanic mechanisms that may provide a source of predictability for TPDV *(Capontondi et al. 2023. Liu and DiLorenzo 2018)*

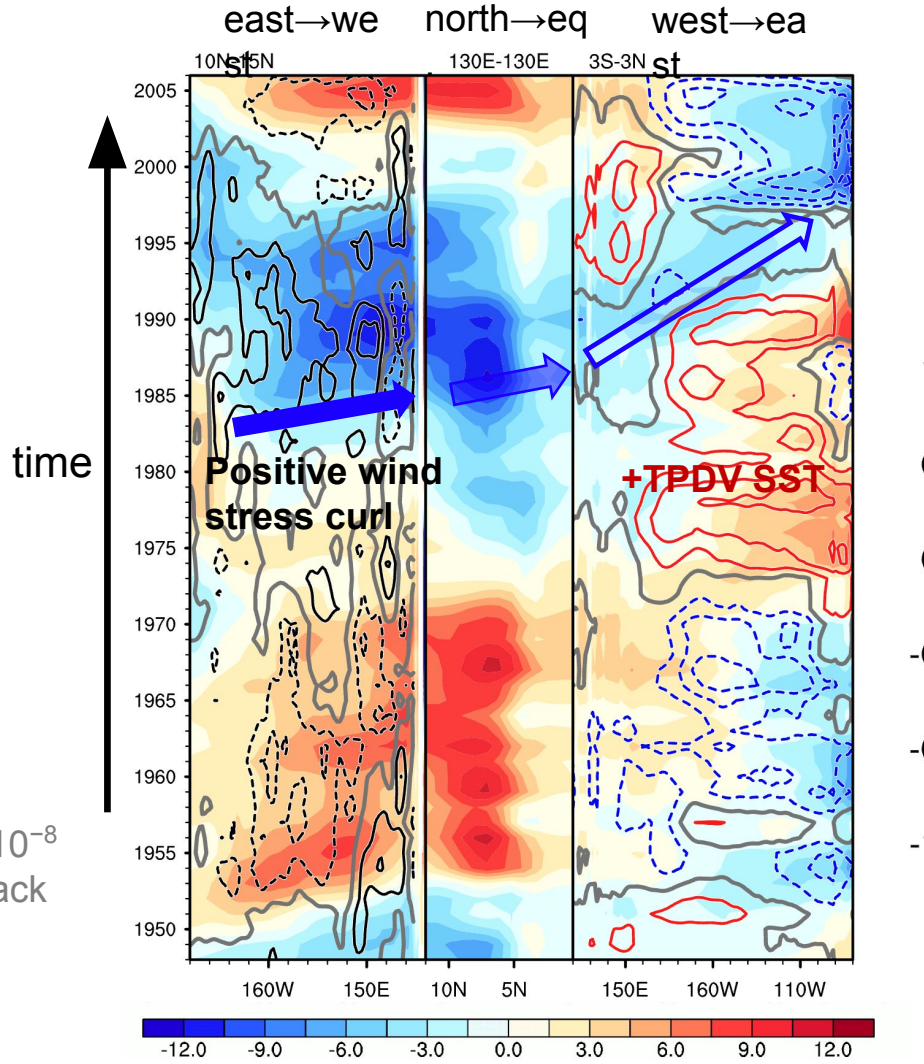
1) Off-equatorial oceanic Rossby wave *(e.g., Knutson and Manabe 1998; Capotondi and Alexander 2001; Jin 2001)*
2) Speed of Pacific subtropical cells *(Schneider et al. 1999; Kleeman et al. 1999; McPhaden and Zhang 2006)*
3) Spiciness advection along isopycnal surfaces *(Yeager and Large 2004; Zeller et al. 2021)*
4) Influence from other ocean basins *(reviews by Cai et al. 2019; Power et al. 2021)*

Relation of oceanic Rossby wave reflection to TPDV in FOSI



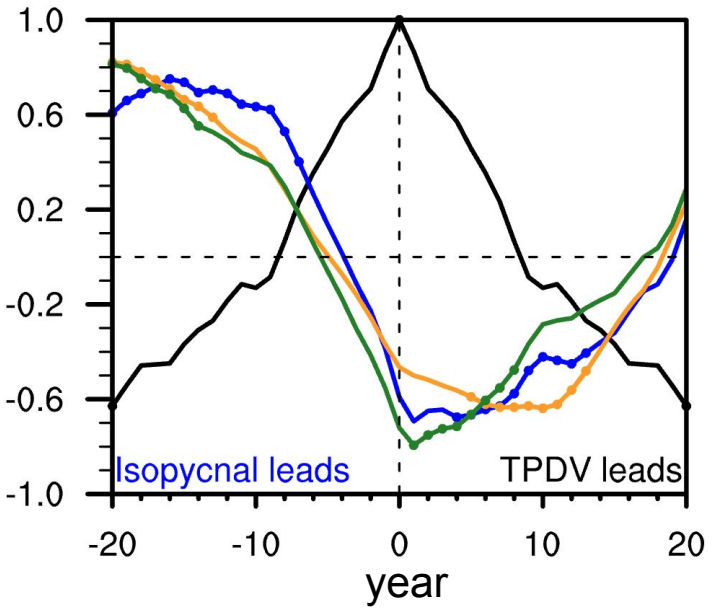
+TPDV
→ off-equatorial wind stress curl
→ upwelling Off-equatorial Rossby wave
→ upwelling equatorial Kelvin wave
→ -TPDV

FOSI, 1950–2015
Depth of isopycnal σ_θ = 25.5 kg m^{-3} /SST/wind stress curl
10-yr running mean



SST: CI = 0.1°C; positive red solid, negative blue dashed, zero thick gray
Surface wind stress curl: CI = 0.5 × 10^{-8} N m^{-3}; positive black solid, negative black dashed, zero thick gray
isopycnal depth: m; color shading)

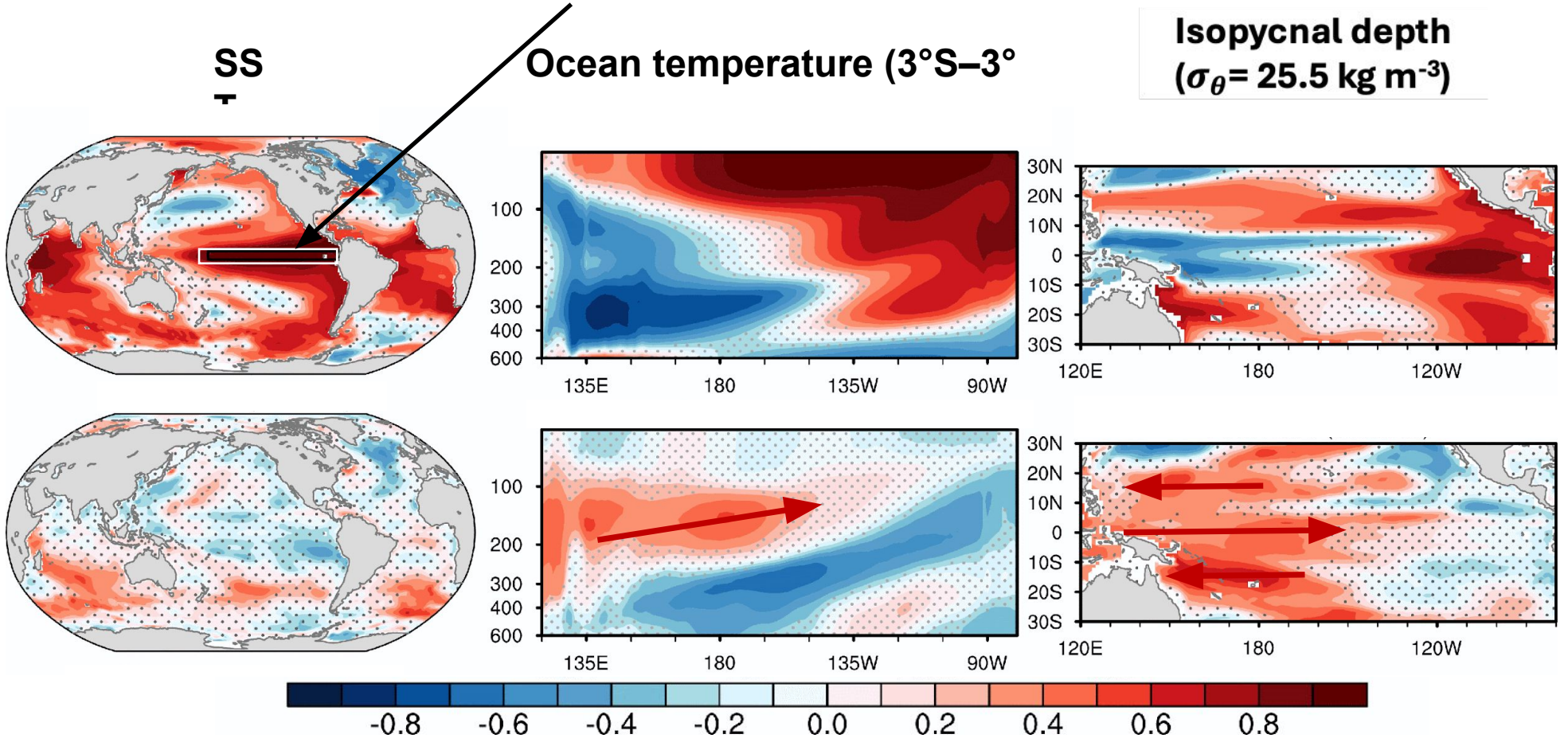
Lead-lag correlation of the **Eq. Pac. SST** in year 0 with
Eq. Pac. SST
W. Eq. Pac. Isopycnal
W. N. Pac. Isopycnal
W. S. Pac. Isopycnfal



Isopycnal precedes Eq. Pac. SST by > 7 years

Rossby waves provide the source of TPDV predictability

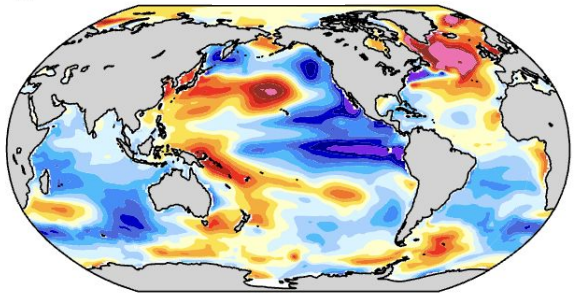
DPLE_NoVolc, Correlation maps with Eq. Pacific SST index in Forecast Year 1-10, 1955–2016



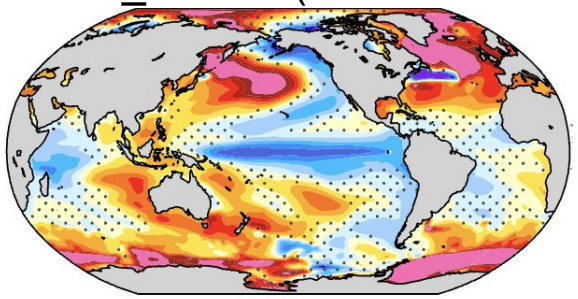
TPDV warming in Forecast Year 1–10 is correlated with isopycnal depth deepening in the equatorial and off-equatorial western Pacific, indicative of the Rossby wave reflection mechanism.

Regional initialization experiments: a case study for 1999-2008

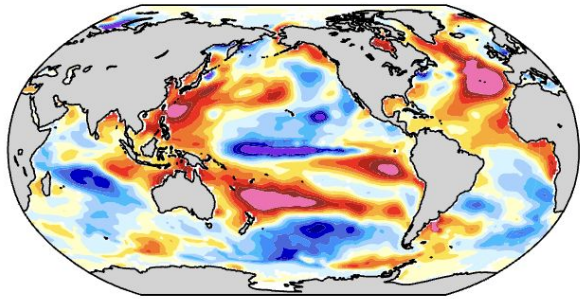
Decadal SST anomalies
1999 – 2008
FOSI



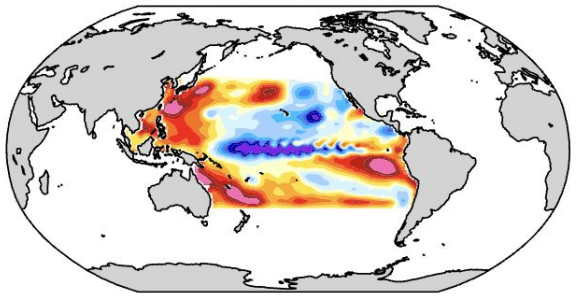
DPLE_NoVolc (Global Initialization)



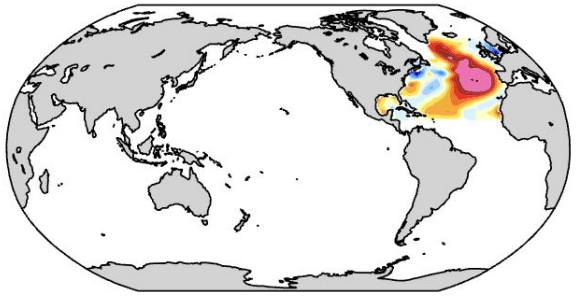
Initial SST anomalies
Nov 1998 in FOSI



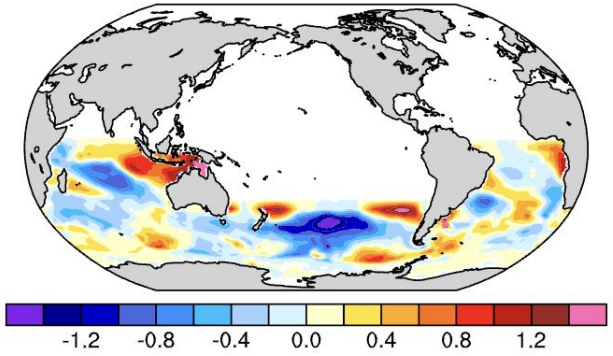
TPAC Initialization



NATL Initialization



SH Initialization



1) Climatology Initialization (Control)

2) Climatology everywhere
+ **Tropical Pacific Initialization**
(30°S-30°N)
full-depth ocean temperature & salinity anomalies

3) Climatology everywhere
+ **North Atlantic Initialization**
(20°N-60°N)

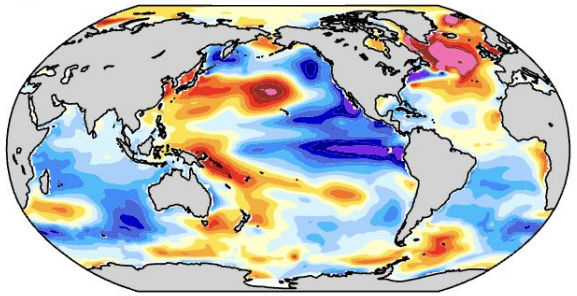
4) Climatology everywhere
+ **Southern Hemisphere Ocean Initialization**

+ external forcing during 1998 Nov–2008 Dec, 10 forecast members

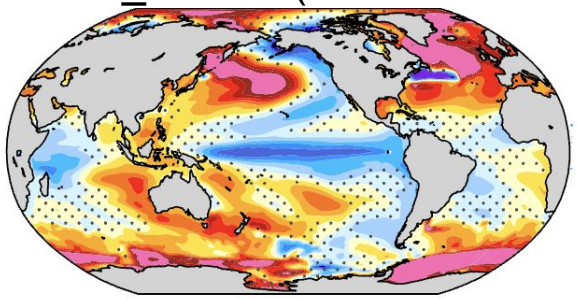
Remove 1) from 2), 3), 4) and DPLE_NoVolc to calculate forecast anomalies.

Regional initialization experiments: a case study for 1999-2008

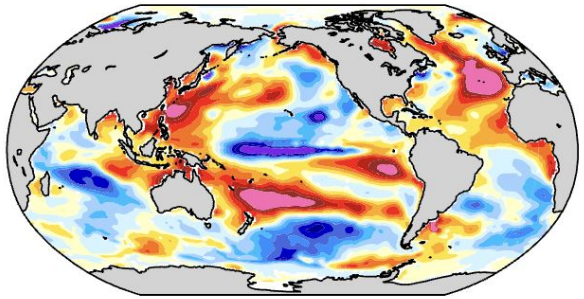
Decadal SST anomalies
1999 – 2008
FOSI



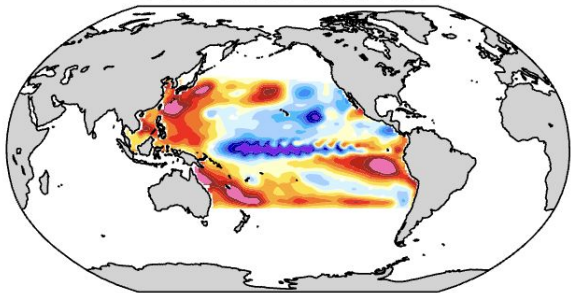
DPLE_NoVolc (Global Initialization)



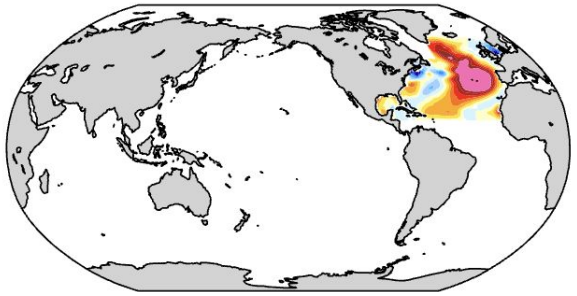
Initial SST anomalies
Nov 1998 in FOSI



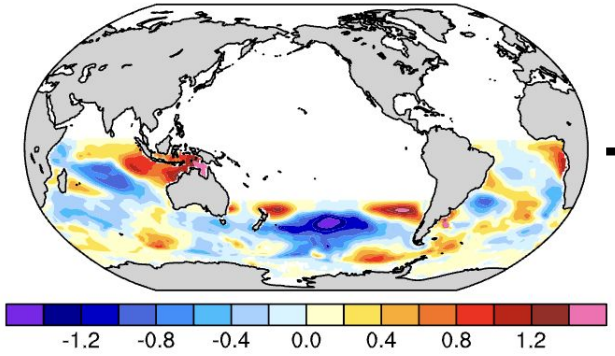
TPAC Initialization



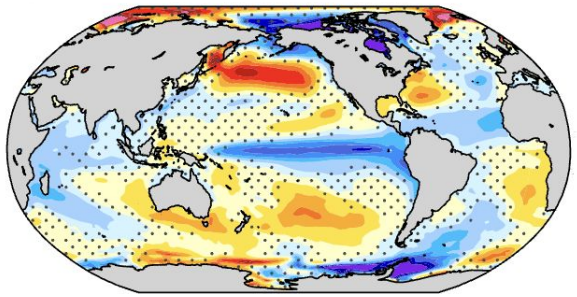
NATL Initialization



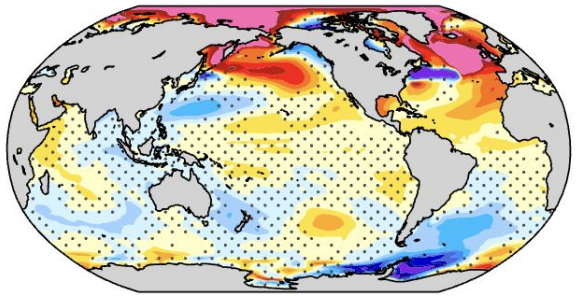
SH Initialization



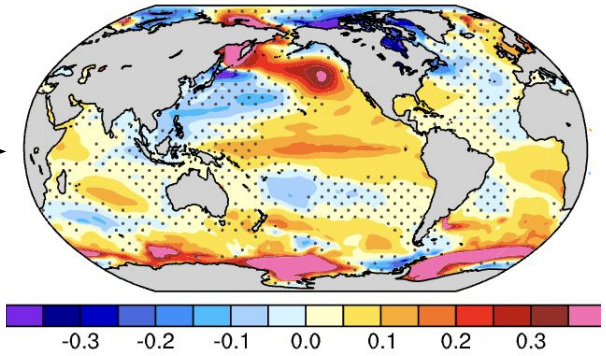
Predicted decadal SST anomalies
1999 – 2008



TPAC Initialization is important to the prediction of tropical Pacific decadal cooling.



NATL initialization does not generate significant tropical Pacific SST anomalies.



Southern Hemisphere Ocean initialization generates tropical Pacific warming, which is an error!

Summary

- Decadal isopycnal depth variability driven by oceanic Rossby waves in the tropical Pacific provides the most important source of predictability for TPDV.
- The predictability arising from initial isopycnal depth conditions is further amplified by tropical ocean-atmosphere coupling and variations in the strength of subtropical cells in the Pacific throughout the decadal forecasts.
- Regional initialization experiments can effectively isolate the impact of different ocean basins on TPDV predictability and highlight the essential role of tropical Pacific initialization.

References

Oceanic mechanisms of TPDV prediction : Wu, X et al. (2024). Predictability of tropical Pacific decadal variability is dominated by oceanic Rossby waves. *Npj Clim. and Atmos. Sci.*, *7*(1), 292. https://doi.org/10.1038/s41612-024-00851-7

Volcanic impact on TPDV prediction: Wu, X et al. (2023). Volcanic forcing degrades multiyear-to-decadal prediction skill in the tropical Pacific. *Sci. Adv.,* 9(15), eadd9364. https://doi.org/10.1126/sciadv.add9364

Thank you!

Email: xian.wu@utdallas.edu

Research website: https://www.xianwuclimate.com