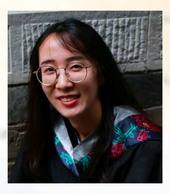
Decadal Variability of ENSO and its North American Teleconnections over the Last Millennium: new insights from paleoclimate data assimilation

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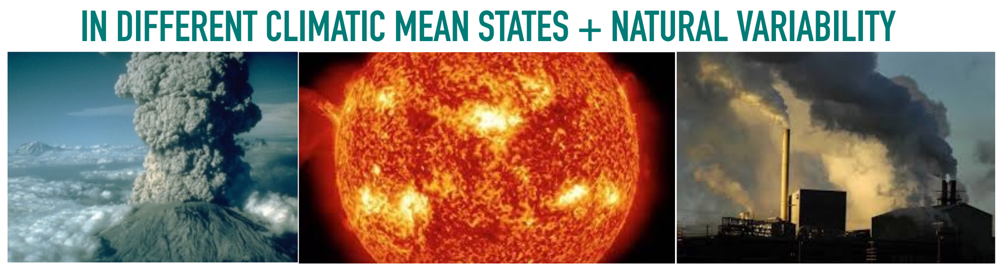
INTRODUCTION: ENSO TELECONNECTIONS AND CLIMATE CHANGE

- Pronounced seasonal changes in U.S. rainfall occur in association with the El Niño-Southern Oscillation (ENSO) via atmospheric teleconnections. However, ENSO's extratropical teleconnections are not always consistent due to stochastic atmospheric variability and the diversity of SST anomalies, making it difficult to quantify teleconnections using 20th century data alone.
- Furthermore, recent climate modeling studies show that teleconnection rainfall over North America may be systematically altered by mean state temperature changes in the tropical Pacific [Stevenson, 2012].
- Thus, characterizing teleconnection rainfall and improving prediction requires a large number of realizations of El Niño/La Niña events, and 20th century instrumental data are temporally limited.
- Given the immense bearing of these model projections on future U.S. hydroclimate risk, this study uses high-resolution paleoclimate reconstructions to expand the statistics of how mean state changes in climate may affect teleconnection rainfall, providing validation from independent data provenance. ENSO variations spanning the Common Era are evaluated in two paleoclimate data assimilation products, LMR and PHYDA.
- Using multiple definitions for Central Pacific (CP) and Eastern Pacific (EP) El Niño, we assess changes in El Niño SST patterns, the frequency of CP and EP events, and midlatitude hydroclimate impacts over the past 1000 years.

MOTIVATION: CHANGES IN ENSO TELECONNECTIONS IN DIFFERENT CLIMATIC MEAN STATES + NATURAL VARIABILITY



KEY QUESTION: How does external forcing impact ENSO? Intergovernmental Panel on Climate Change (IPCC):

- HIGH confidence that ENSO itself will continue
- LOW confidence in exactly what will happen to ENSO in the future

PALEOCLIMATE DATA ASSIMILATION TO RECONSTRUCT THE LAST MILLENNIUM

HOW CAN WE IMPROVE PREDICTION FOR ENSO-DRIVEN RAINFALL ANOMALIES?

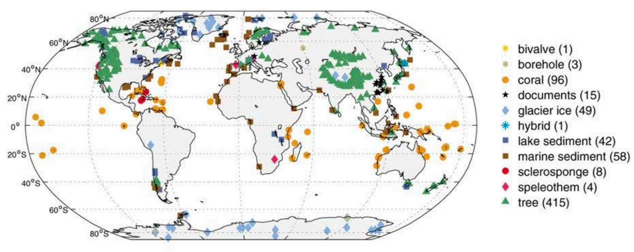
Q_1: HOW DO MEAN STATE CHANGES (E.G. WARMING VS. COOLING) IN THE TROPICAL PACIFIC AFFECT U.S. RAINFALL? (Dee et al., 2020, GRL)

Q_2: HOW DO CENTRAL PACIFIC VS. EASTERN PACIFIC EL NIÑO EVENTS VARY OVER THE COMMON ERA? (Luo et al., 2022, Paleo2)

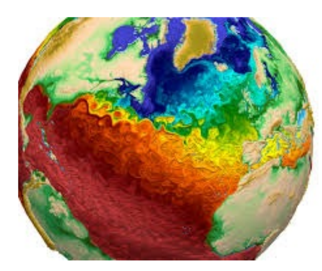
APPROACH: FEW ENSO EVENTS IN 20TH CENTURY (~50). TO REDUCE UNCERTAINTIES, USE A LARGER SAMPLE SIZE (LAST 1000 YRS).

- DATA: PALEOCLIMATE DATA ASSIMILATION RECONSTRUCTIONS (LMR, PHYDA)

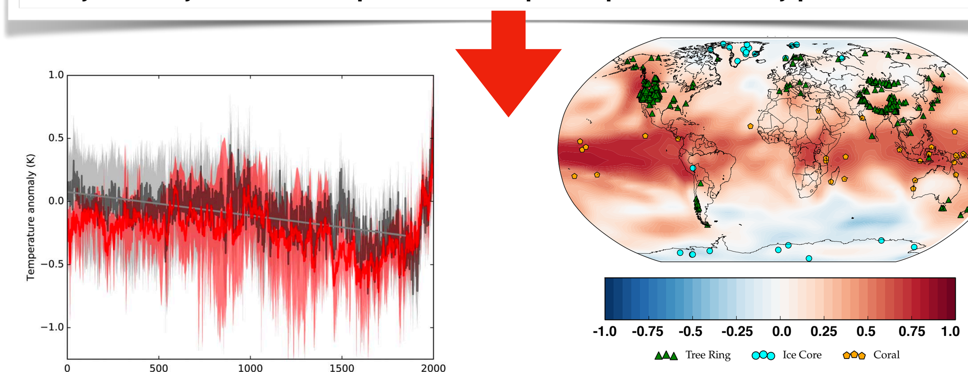
PALEOCLIMATE ARCHIVES (CLIMATE VARIABILITY)

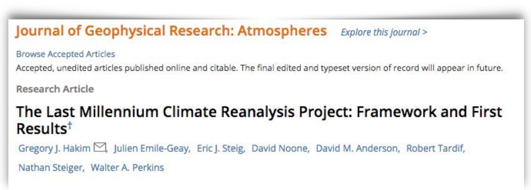


CLIMATE MODEL (DYNAMICS)



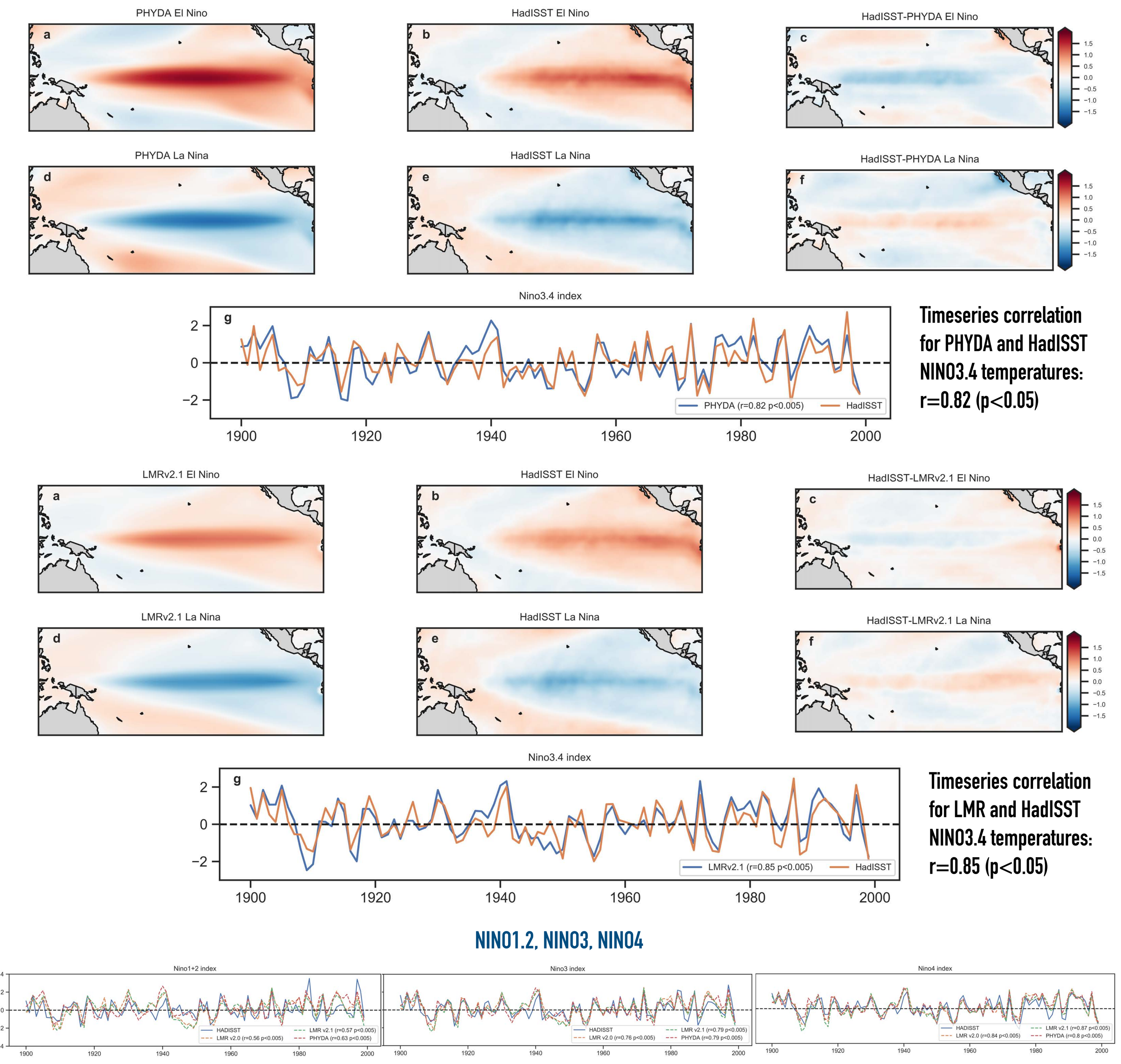
= dynamically consistent snapshots of atmospheres past, informed by paleoclimate data!





We use paleoclimate data assimilation reconstructions to extend the instrumental record & improve prediction.

LMR VALIDATION: 20TH CENTURY ENSO EVENTS



Timeseries correlation for PHYDA and HadISST NINO3.4 temperatures: r=0.82 (p<0.05)

Timeseries correlation for LMR and HadISST NINO3.4 temperatures: r=0.85 (p<0.05)

NINO1.2, NINO3, NINO4

Figure 1: validation of LMR & PHYDA ENSO patterns and amplitudes for the instrumental period. *Luo & Dee et al., 2022, Paleo2*

RESULTS 1: HOW DO CENTRAL PACIFIC VS. EASTERN PACIFIC EL NIÑO EVENTS VARY?

EXPERIMENTAL DESIGN:
Not all El Niño events are created equal ~ "ENSO flavors" - CENTRAL PACIFIC, EASTERN PACIFIC

- Niño 3-4 index (Yeh et al., 2009; Kug et al., 2009): CP: Niño 4 > 1σ and Niño 4 > Niño 3; EP: Niño 3 > 1σ and Niño 3 > Niño 4
- C and E index (Takahashi et al., 2011): a linear combination of the first two principal components (PCs) of tropical Pacific SSTA

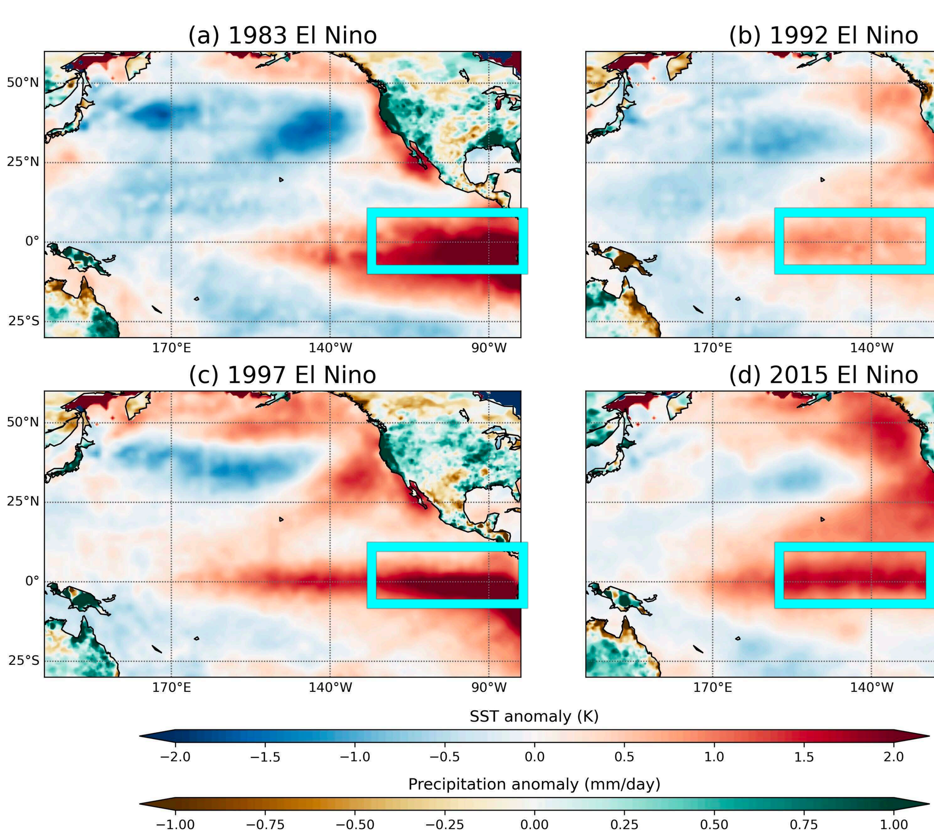


Figure 2: CP and EP ENSO events over the 20th century and SST warming centers

HOW DO THE FREQUENCIES OF EP/CP EVENTS CHANGE OVER THE PAST 1000 YEARS?

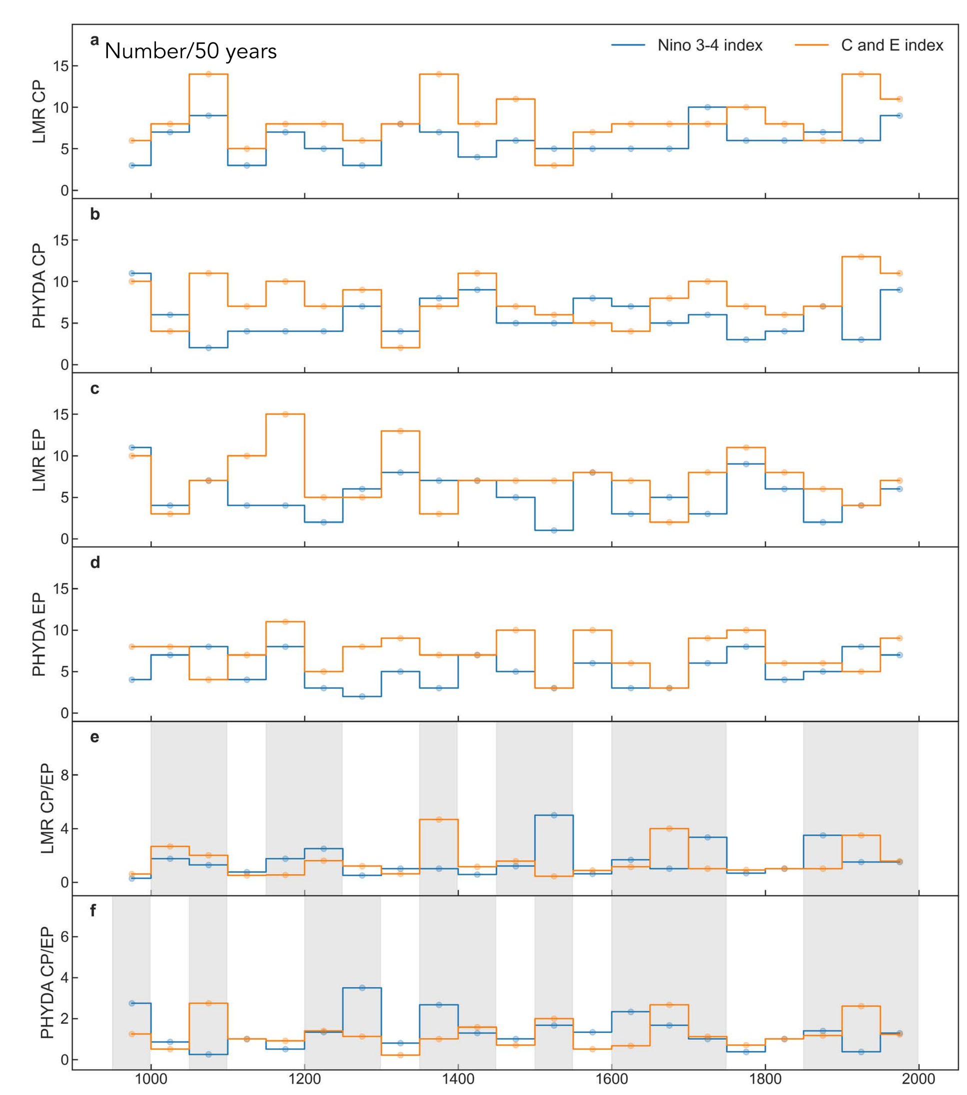


Figure 3: CP and EP frequencies show large natural variability over the Last Millennium

HOW DOES THE AMPLITUDE OF EP/CP EVENTS CHANGE OVER THE PAST 1000 YEARS?

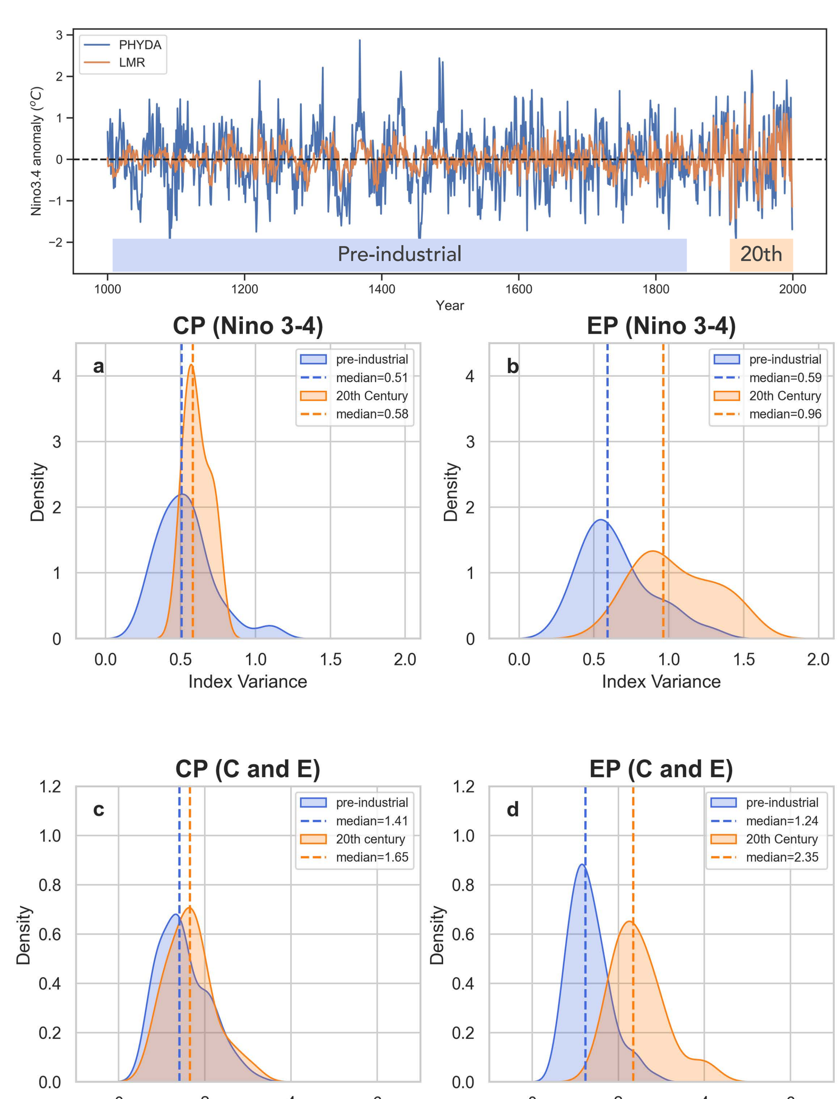


Figure 4 (left): (top) reconstructed NINO34 SST anomalies for LMR (orange) and PHYDA (blue). Note that PHYDA is bias corrected to avoid variance loss as proxy availability declines back in time. (bottom) PDFs for CP and EP events in PHYDA using two different definition methods (a, b) Nino 3-4 index method; (c, d) C & E index method.

KEY FINDINGS: (CONSISTENT BETWEEN LMR AND PHYDA)

- Large variability in CP and EP event frequencies; no increase in CP frequency in context of LM
- Intensified EP events in the 20th century
- High sensitivity to CP/EP index definition choices!

Luo & Dee et al., 2022, Paleo2

RESULTS 2: ENSO TELECONNECTION RAINFALL & PDSI OVER THE COMMON ERA

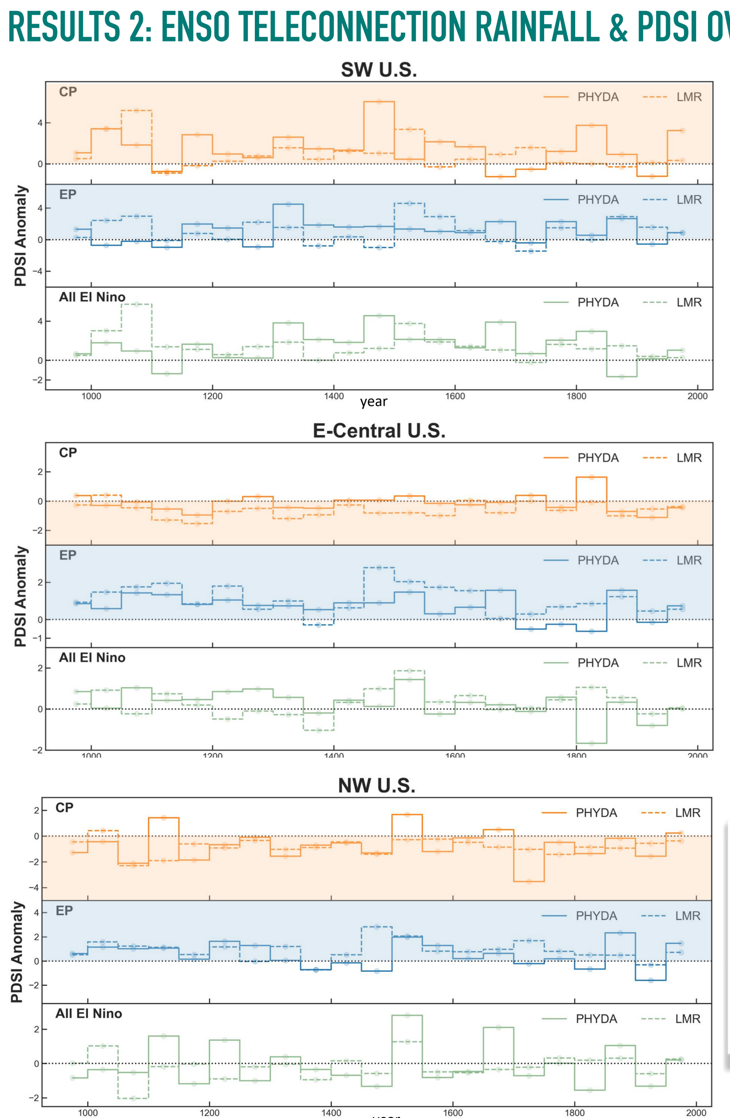
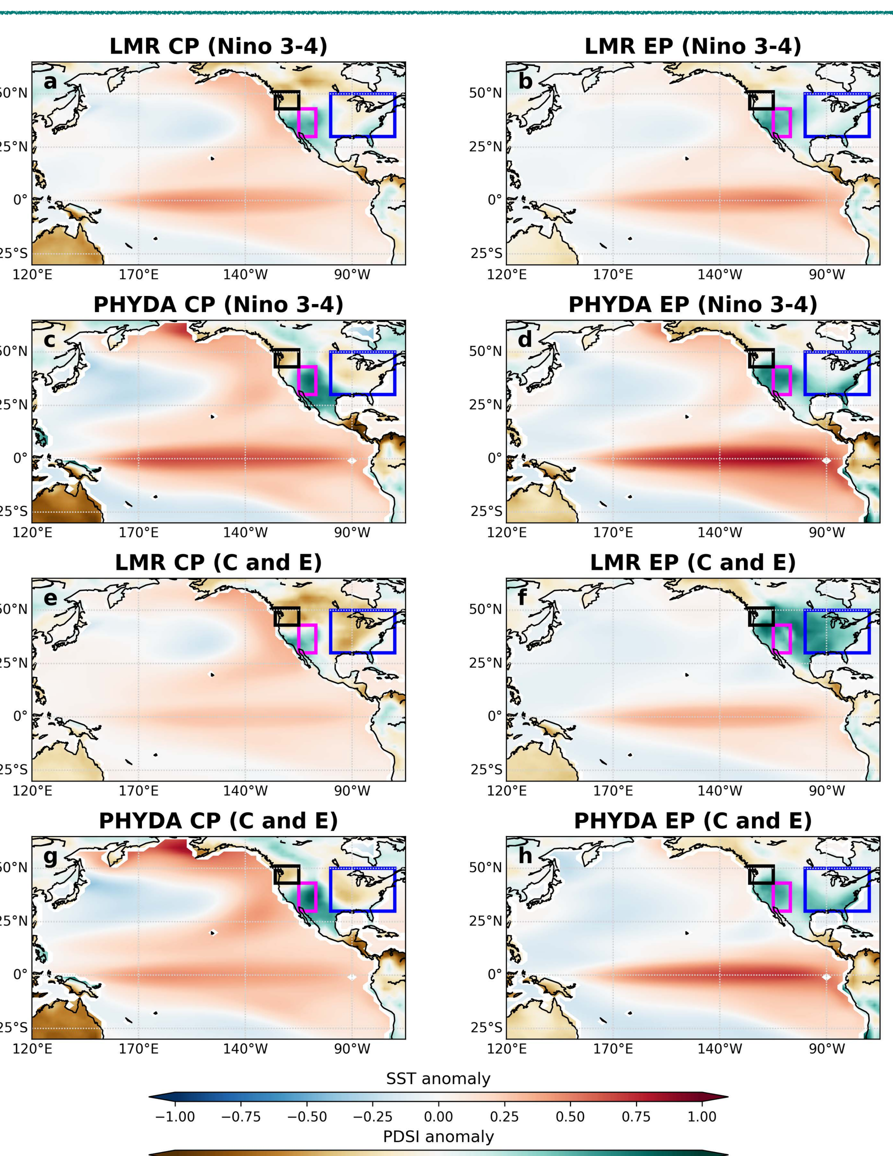


Figure 5 (left): Stationarity of ENSO teleconnections over North America. Large variability and non-stationarity is evident in reconstructed PDSI; wet and dry conditions occur during CP and EP events in different regions.

Figure 6 (right): SSTA (°C) and PDSI anomaly (unitless) map composites of LMR and PHYDA over LM. (a), (b) LMR's and (c), (d) PHYDA's SSTA and PDSI anomaly composites patterns of CP and EP El Niño for the Niño 3-4 method. (e), (f) LMR's and (g), (h) PHYDA's same composites for C and E method. Red boxes represent the region used for the southwestern (SW) U.S.; black boxes encapsulate the northwestern (NW) U.S.; blue boxes encapsulate the eastern-central (E-central) U.S.

CP and EP El Niño hydroclimate teleconnections show substantial variability on decadal-centennial timescales.



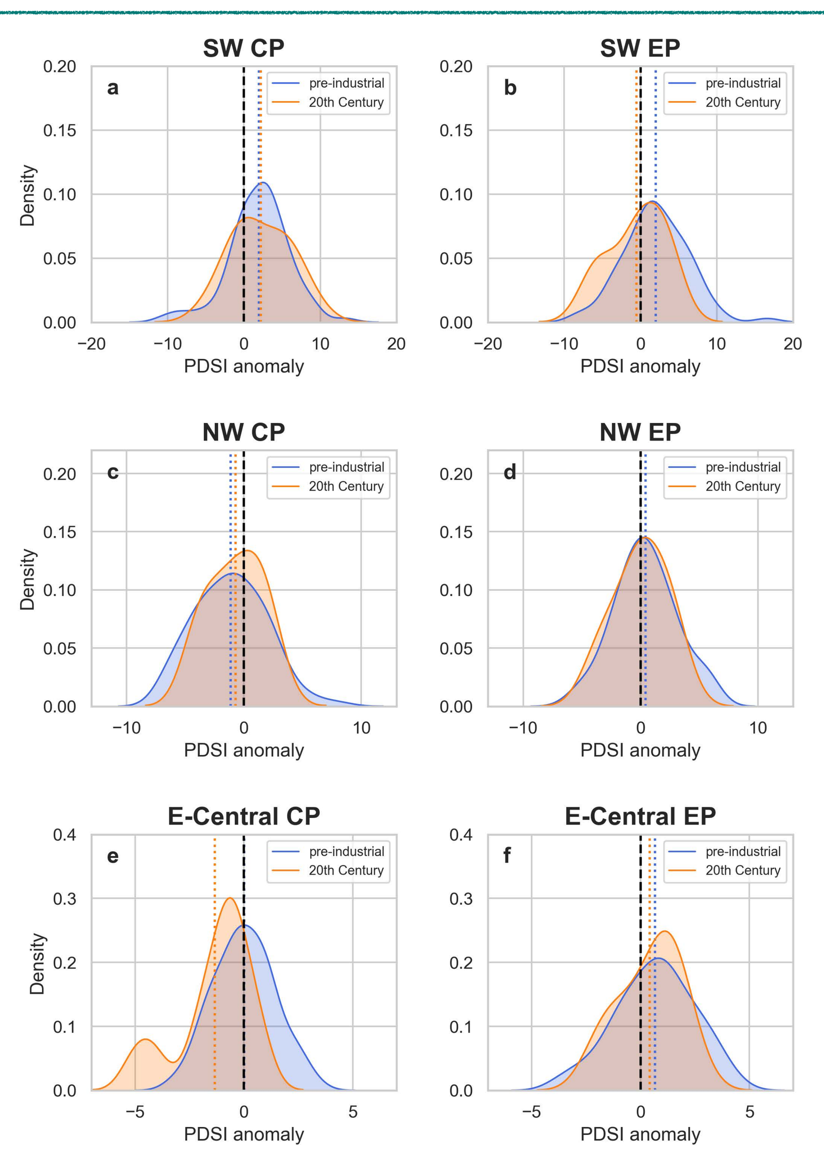


Figure 7 (left): PDFs of PHYDA's PDSI anomaly (unitless) during the pre-industrial (blue lines) and the 20th century (orange lines) for (a) SW CP, (b) SW EP, (c) NW CP, (d) NW EP, (e) E-Central CP and (f) E-Central EP, based on the C and E method. All black dashed lines represent a 0 PDSI anomaly. Dotted lines represent the average of the distribution.

Teleconnections are non-stationary over the LM, but CP/EP shifts in North American hydroclimate teleconnections are relatively consistent:

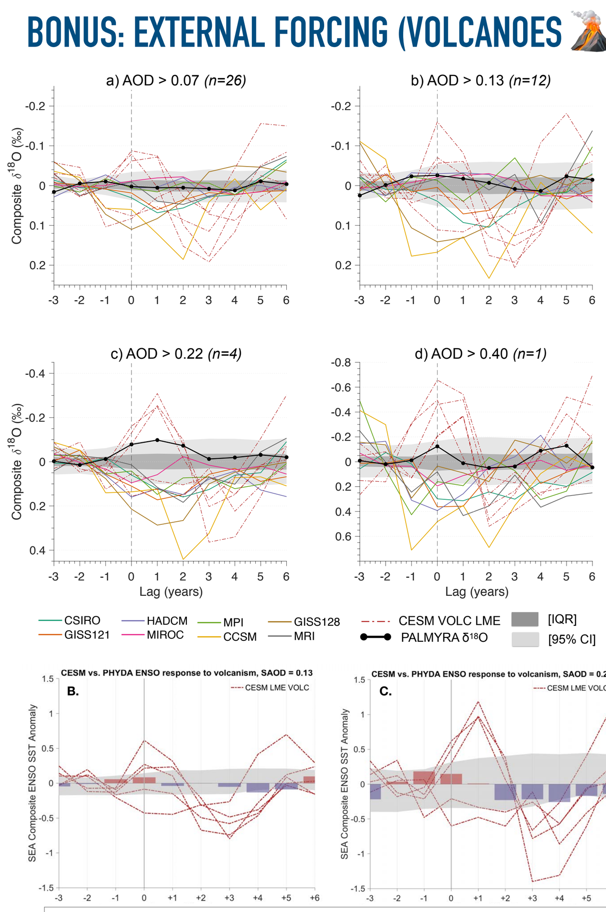
- NW and E-Central U.S.: dry conditions (CP), wet conditions (EP)
- SW U.S.: wet (CP, EP)

TAKE HOME MESSAGES:

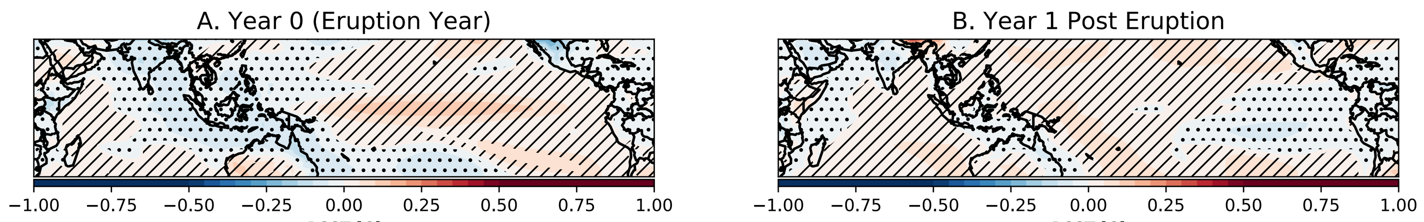
- CP frequency projected to increase in 21st century *(Yeh et al.,2009; Lee & McPhaden, 2010)*
- ENSO teleconnections projected to intensify in the 21st century *(Fasullo et al. 2018)*
- AVERAGE LAST MILLENNIUM RAINFALL PATTERNS YIELD INSIGHT INTO FUTURE CHANGES (E.G. ENHANCED DRYING IN NORTHEAST DURING CP)

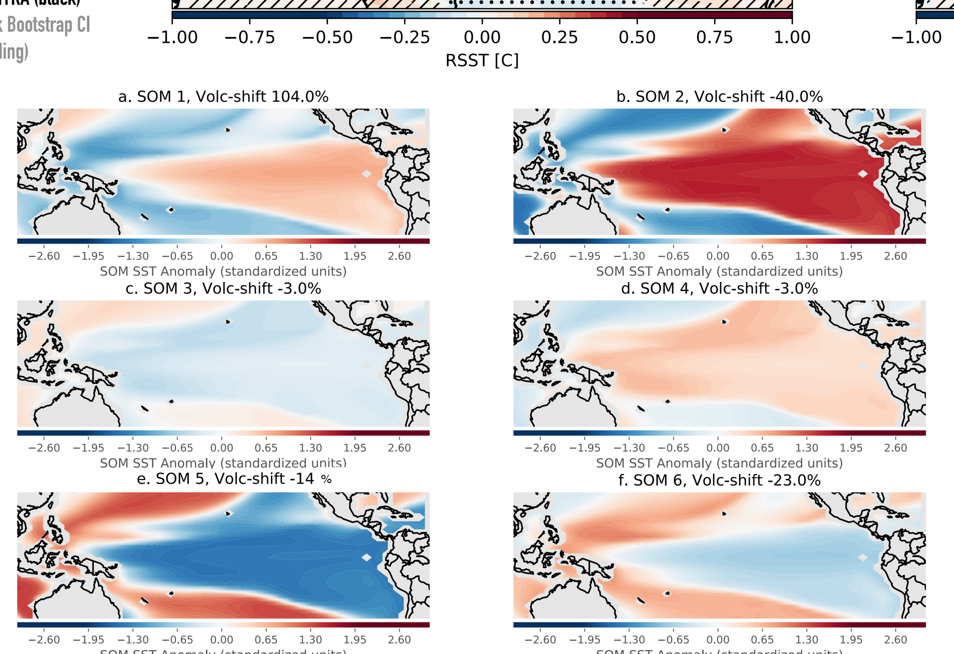
Luo & Dee et al., 2022, Paleo2

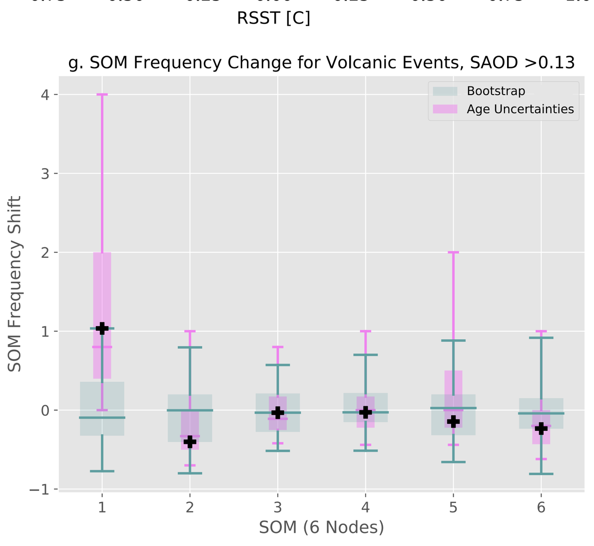
BONUS: EXTERNAL FORCING (VOLCANOES) & ENSO



POST ERUPTION SEA: RSST, SAOD > 0.22







MODEL RESPONSE TO VOLCANISM IS TOO STRONG

Dee et al., 2020, Science; ENSO's response to volcanism in Paleoclimate Data Assimilation reconstructions of the past 2k, Dee & Steiger, 2022, PALEO2

CONCLUSIONS:

- Expanded constraints on average hydroclimate patterns provide insight into past amplitudes and frequencies of diverse El Niño events and the stationarity of hydroclimate impacts over the last 1000 years.
- The recently-observed increased frequency of CP El Niño is not anomalous, but a marked increase in the intensity of EP El Niño occurred in the 20th century.
- Teleconnections strengthen independently of ENSO amplitude, and we suggest caution in the use of paleoclimate reconstructions of ENSO amplitude based on teleconnection strength.
- RIGHT: predicted 2080-2100 change in ENSO rainfall for the U.S. in the Community Earth System Model Large Ensemble (RCP8.5)

Our results underscore the importance of reducing uncertainties in the global warming pattern and mean temperature changes in the tropical Pacific, and harbor implications for the predictability of teleconnection rainfall in the U.S. *DEE ET AL., 2020, GRL*