Extreme El Niño Events and 21st Century Climate Change: Attributing inter-model differences in future projections

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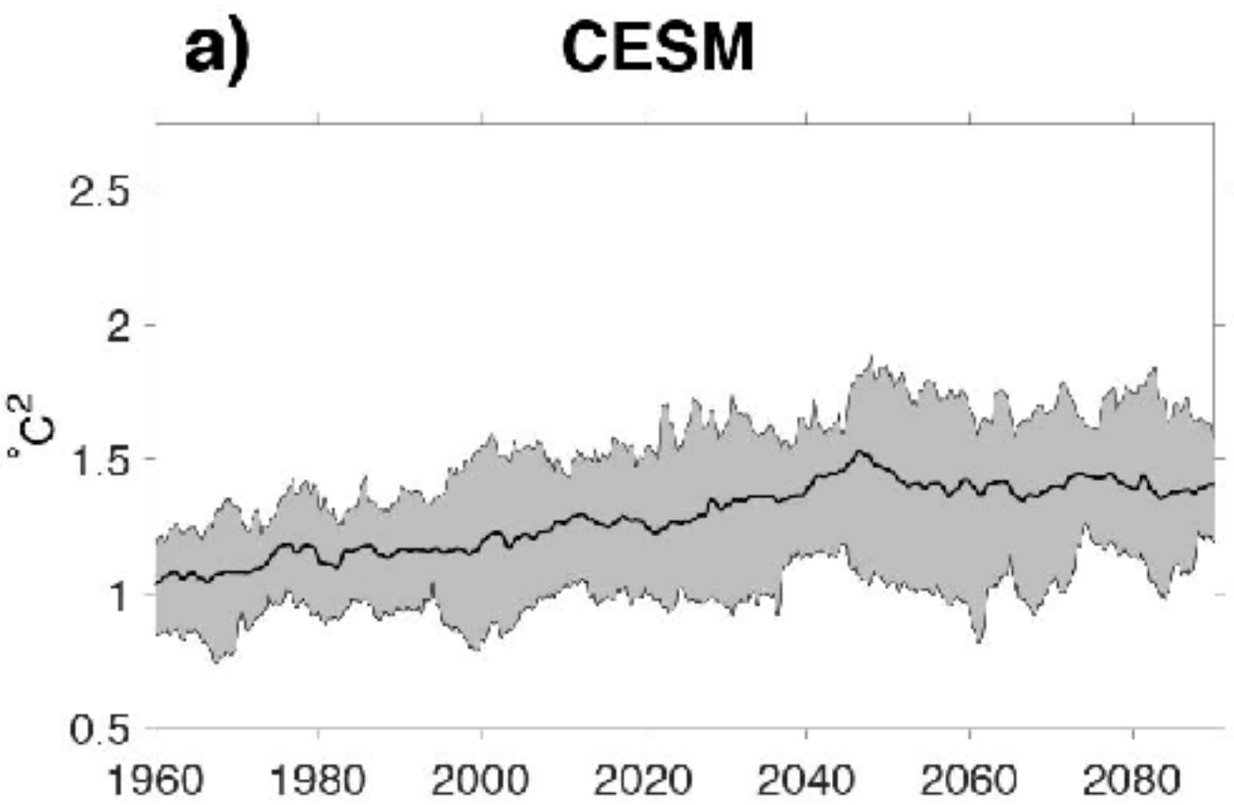
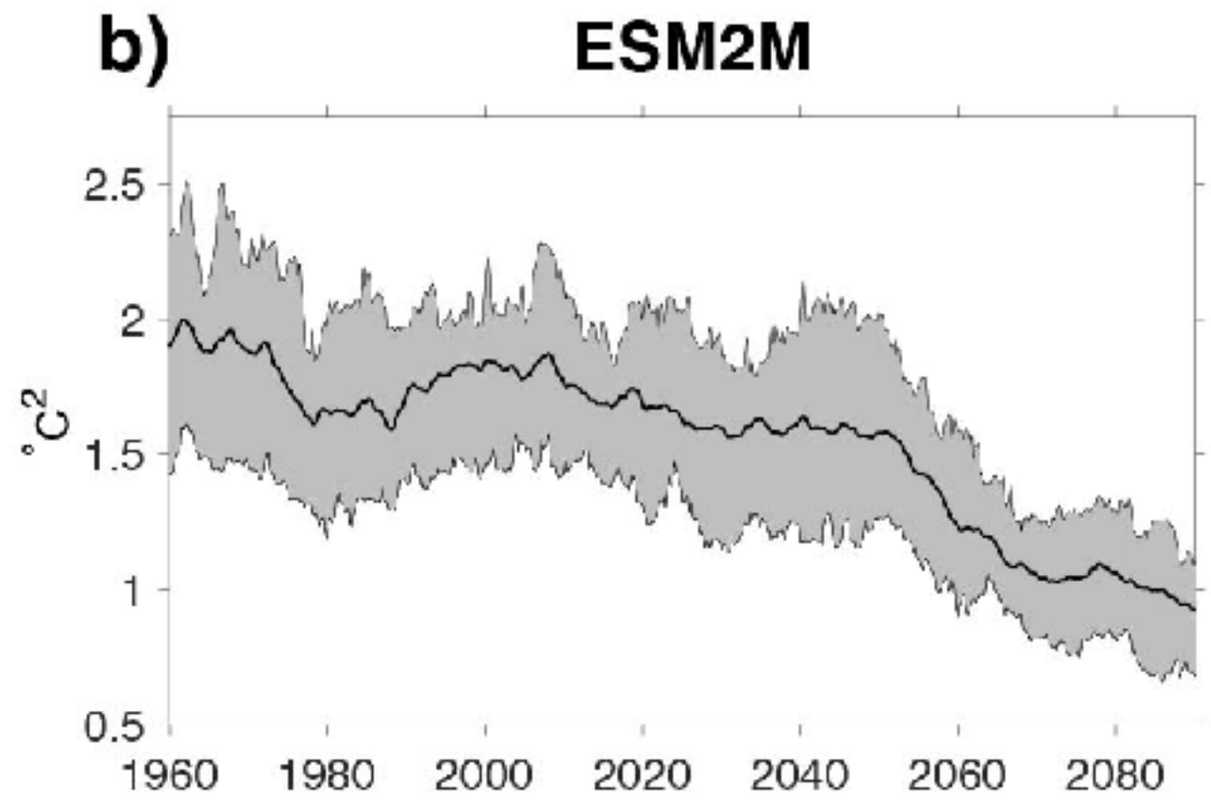
Current-generation models disagree on 21st century ENSO projections

NINO3.4 30-year running variance: large ensembles (LENS) with CESM (Kay et al. 2015),
GFDL ESM2M (Rodgers et al. 2015)
RCP8.5 forcing for both ensembles

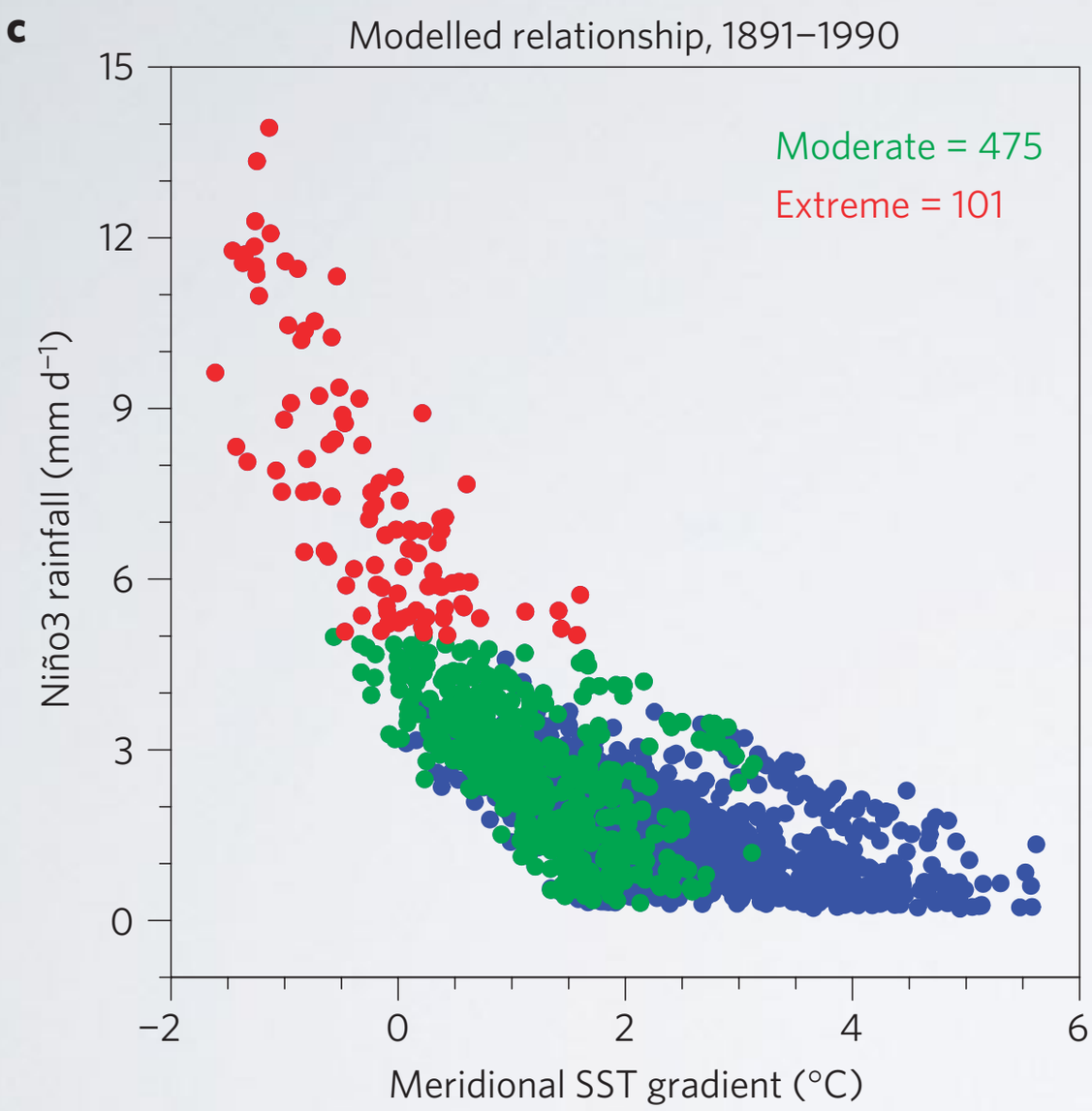


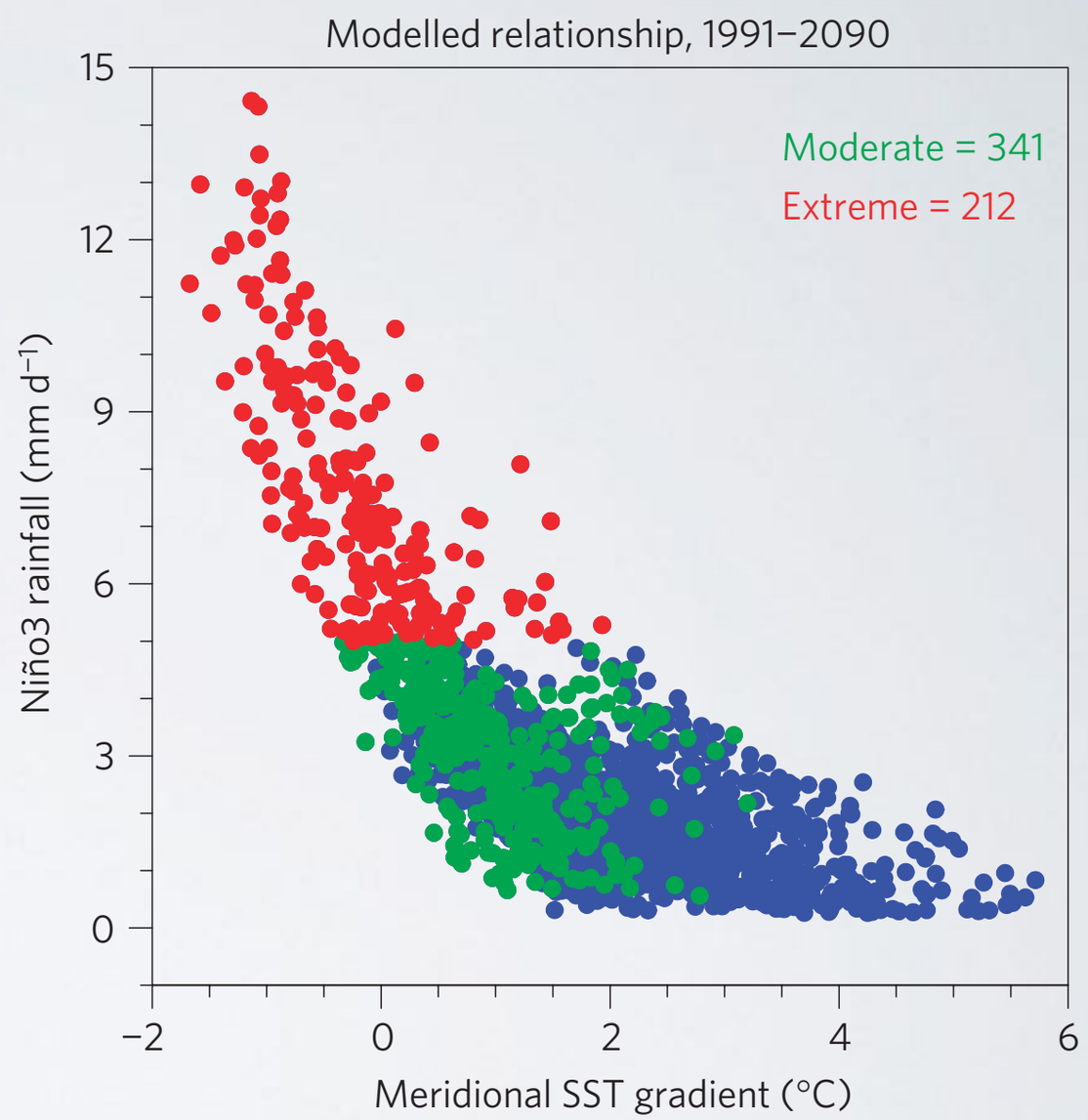


Stevenson et al. (2018), submitted

Previous work suggests changes to precip extremes more robust

Extreme El Nino: event where DJF precip exceeds 5 mm/day





Cai et al. (2014)

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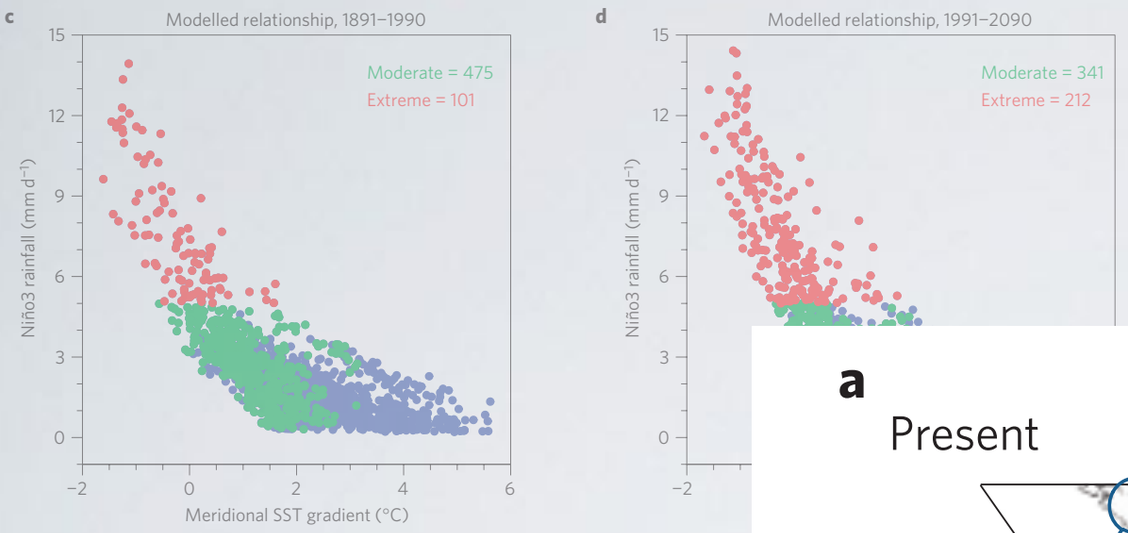
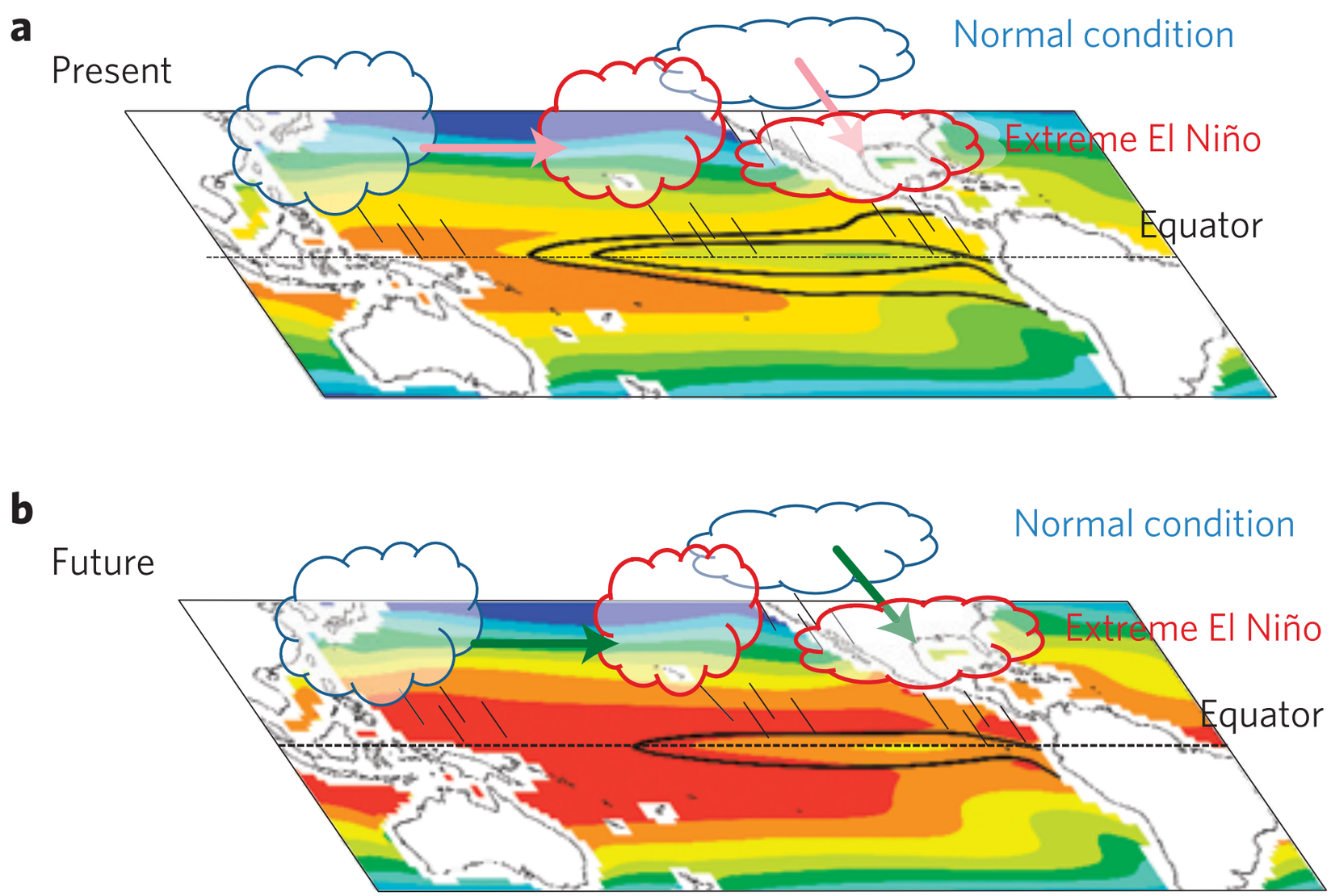


Hypothesis:
Reduced meridional SST gradient favors equatorward ITCZ migration during El Nino



Cai et al. (2014)

What is the 'true' range of projected El Nino extremes?

Are the mechanisms for changing extremes consistent across models?

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Are the mechanisms for changing extremes consistent across models?

For our purposes, "extreme" El Nino = *local* precip anomaly:

above 90th percentile (extreme wet)

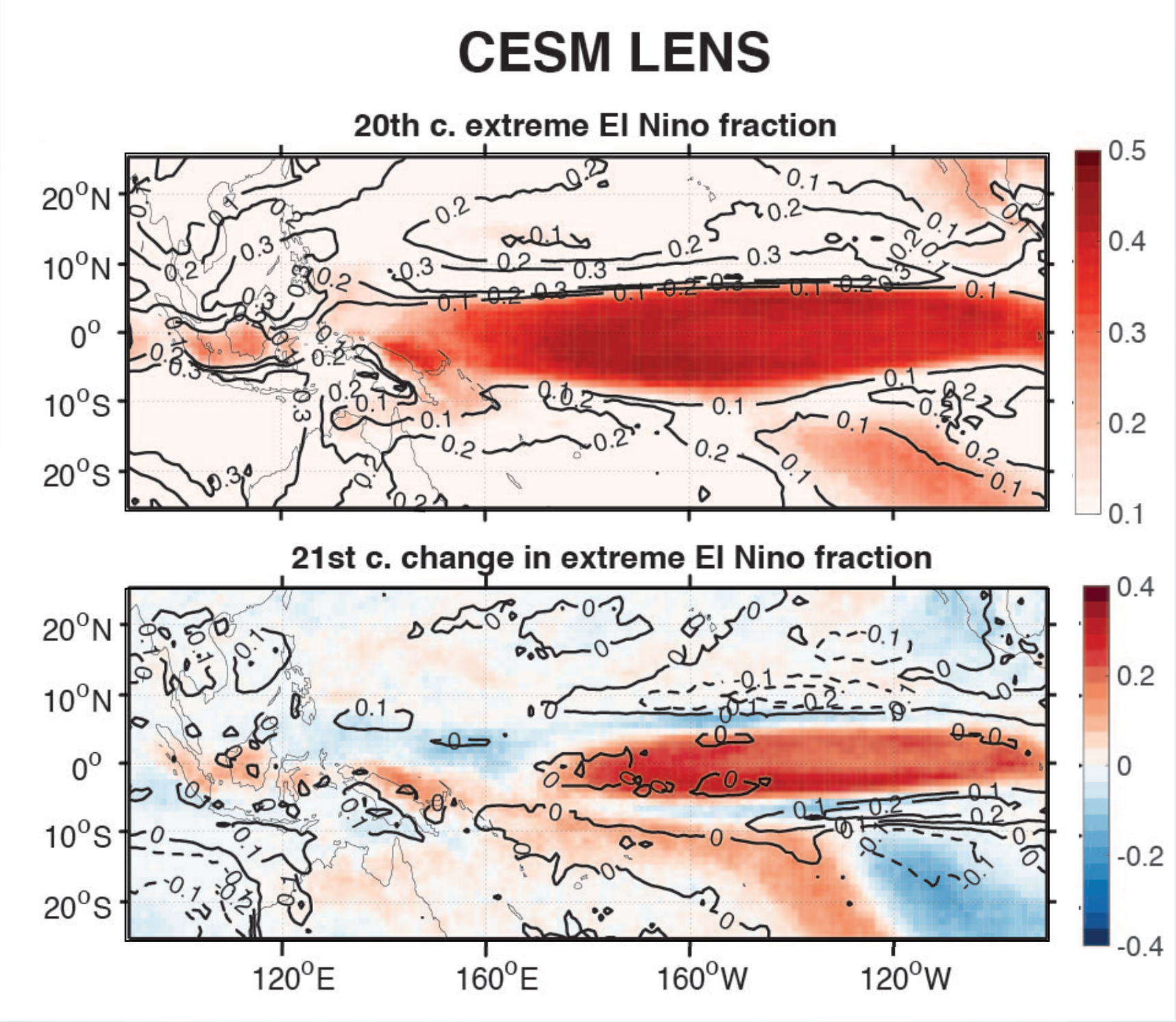
-or-

below 10th percentile of 20th c. distribution (extreme dry)

CESM LENS: (precip-based) extreme El Ninos increase

Colors: extreme wet El Nino

Contours: extreme dry El Nino (dashed = negative change in event frequency)

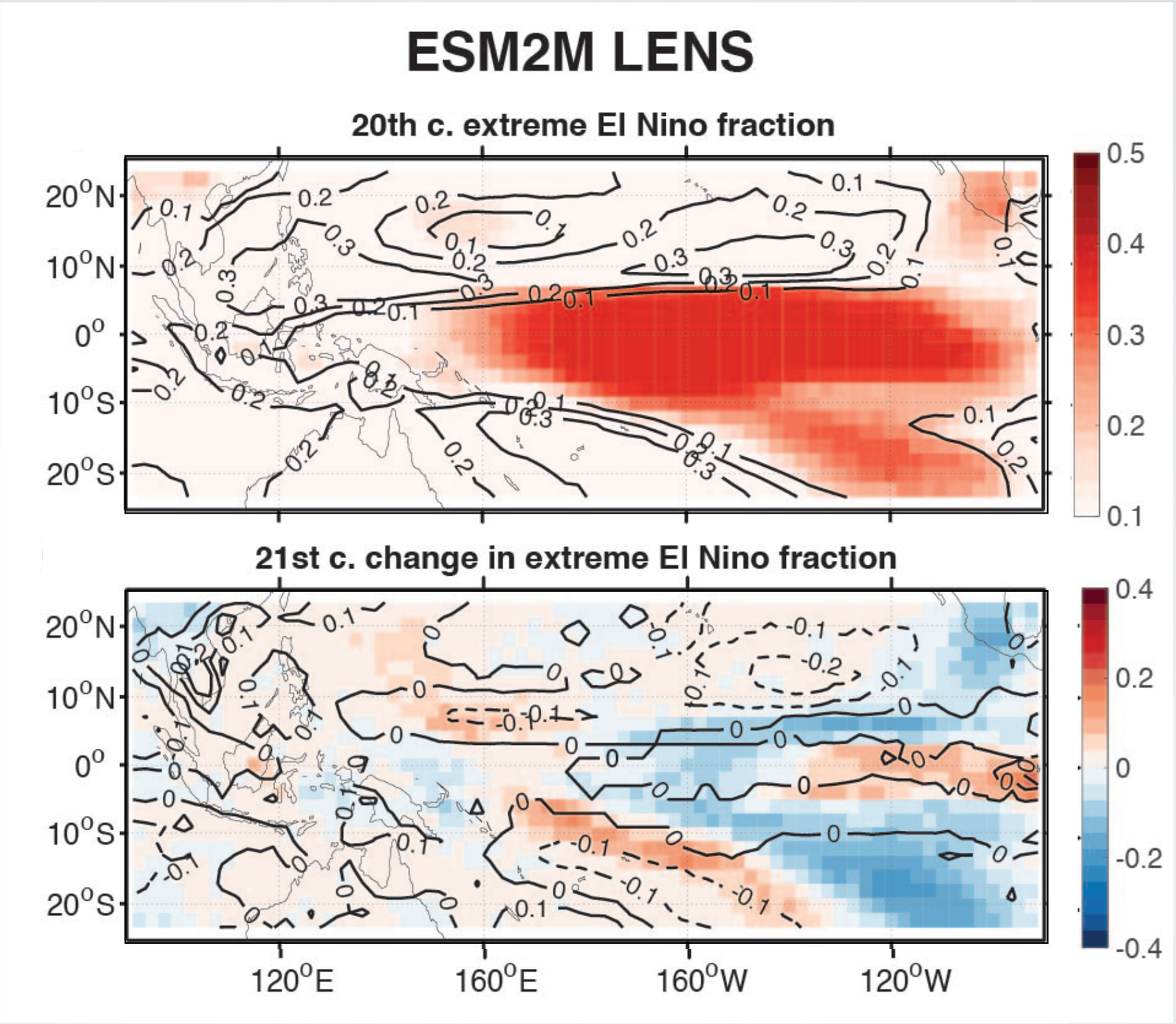


Stevenson et al. (2018), submitted

ESM2M LENS: (precip-based) extreme El Ninos decrease

Colors: extreme wet El Nino

Contours: extreme dry El Nino (dashed = negative change in event frequency)



Stevenson et al. (2018), submitted

Diagnose mechanisms for changes: "PDF method"

Change in SSTA | **Change in precip sensitivity to SSTA** | **Nonlinear interactions between precip/ SSTA**

$$\Delta P'_{nino} = \int \Delta f C_0(T')dT' + \int f_0 \Delta C(T')dT' + \int \Delta f \Delta C(T')dT'$$

$C_0(T')$ = "composite" precipitation anomaly for a given SSTA (20th c.)

f_0 = reference PDF of SSTA (20th c.)

Primes indicate anomalies; deltas indicate differences between 21st., 20th c.

(Stevenson et al. 2018, submitted; adaptation of method from Watanabe & Wittenberg 2012)

CESM LENS: sensitivity of precip to SSTA dominates

$$\int \Delta f C_0(T')dT' \cdot$$

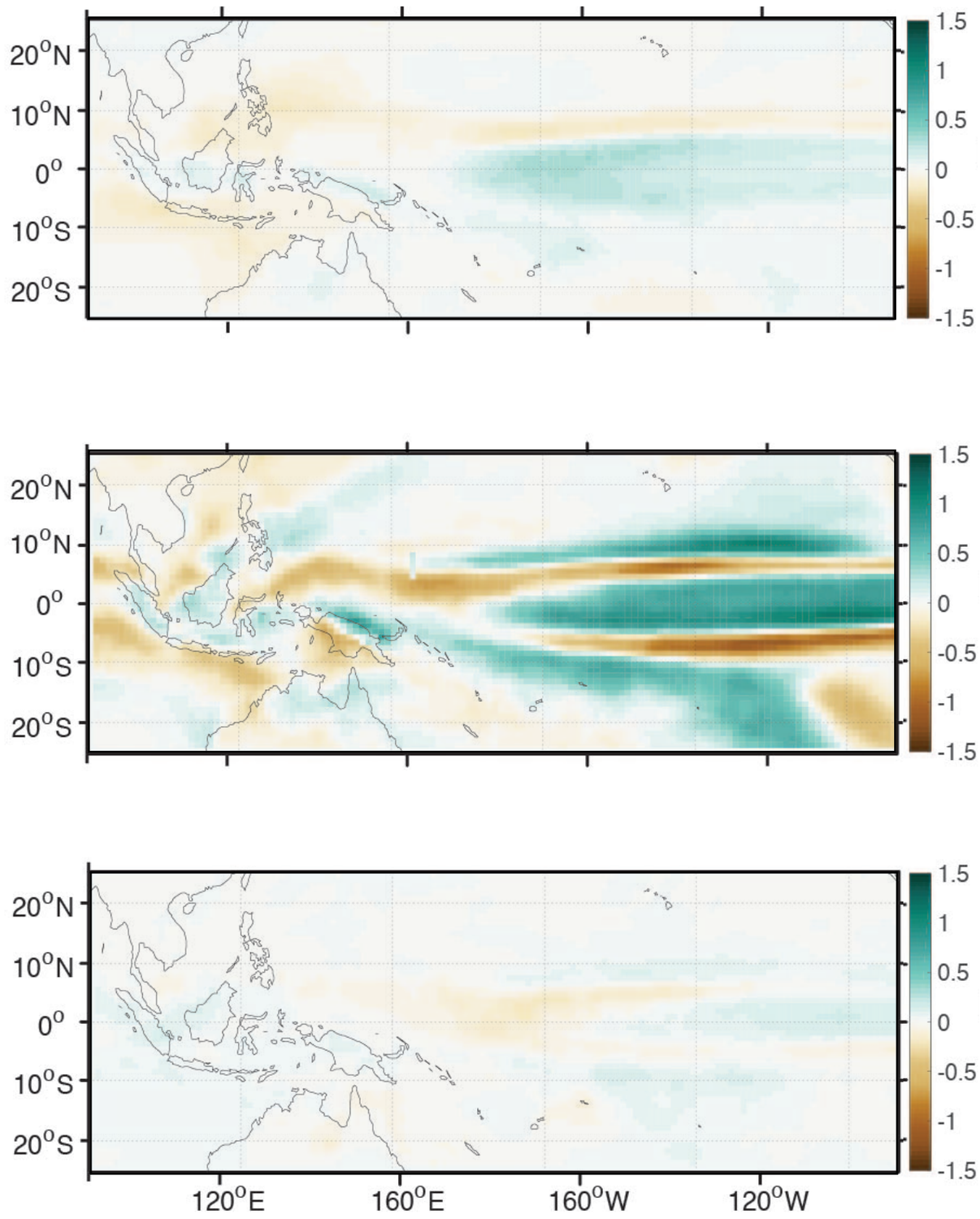
Change in SSTA

$$\int f_0 \Delta C(T')dT'$$

Change in precip sensitivity to SSTA

$$\int \Delta f \Delta C(T')dT'$$

Nonlinear interactions between precip/ SSTA



Change in precip during El Nino due to each component of PDF decomposition (mm/day)

Stevenson et al. 2018, submitted

ESM2M LENS: precip:SSTA sensivity and SSTA changes both matter

$$\int \Delta f C_0(T')dT' \cdot$$

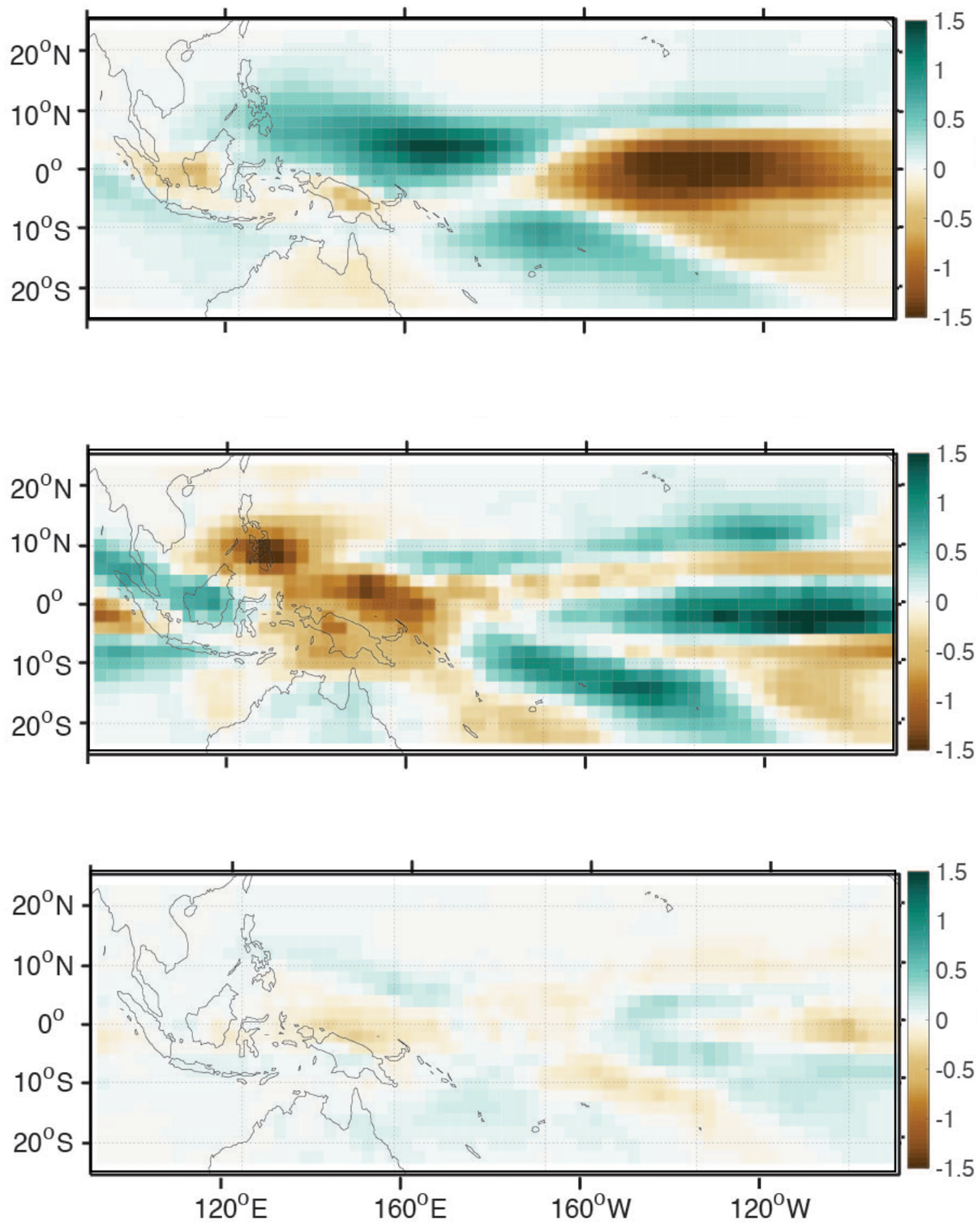
Change in SSTA

$$\int f_0 \Delta C(T')dT'$$

Change in precip sensitivity to SSTA

$$\int \Delta f \Delta C(T')dT'$$

Nonlinear interactions between precip/ SSTA

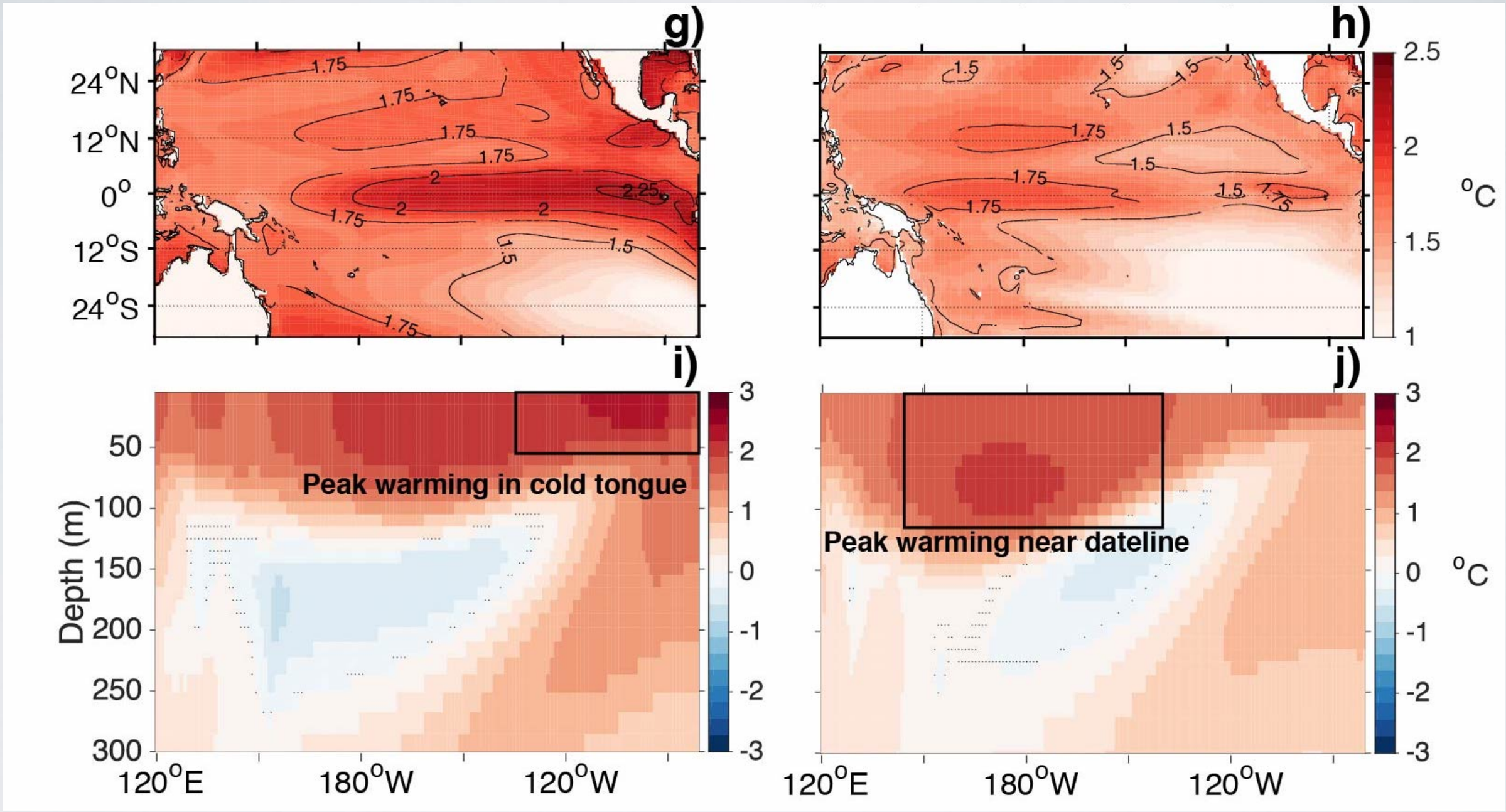


Change in precip during El Nino due to each component of PDF decomposition (mm/day)

Stevenson et al. 2018, submitted

Differential mean-state responses critical for extreme El Nino

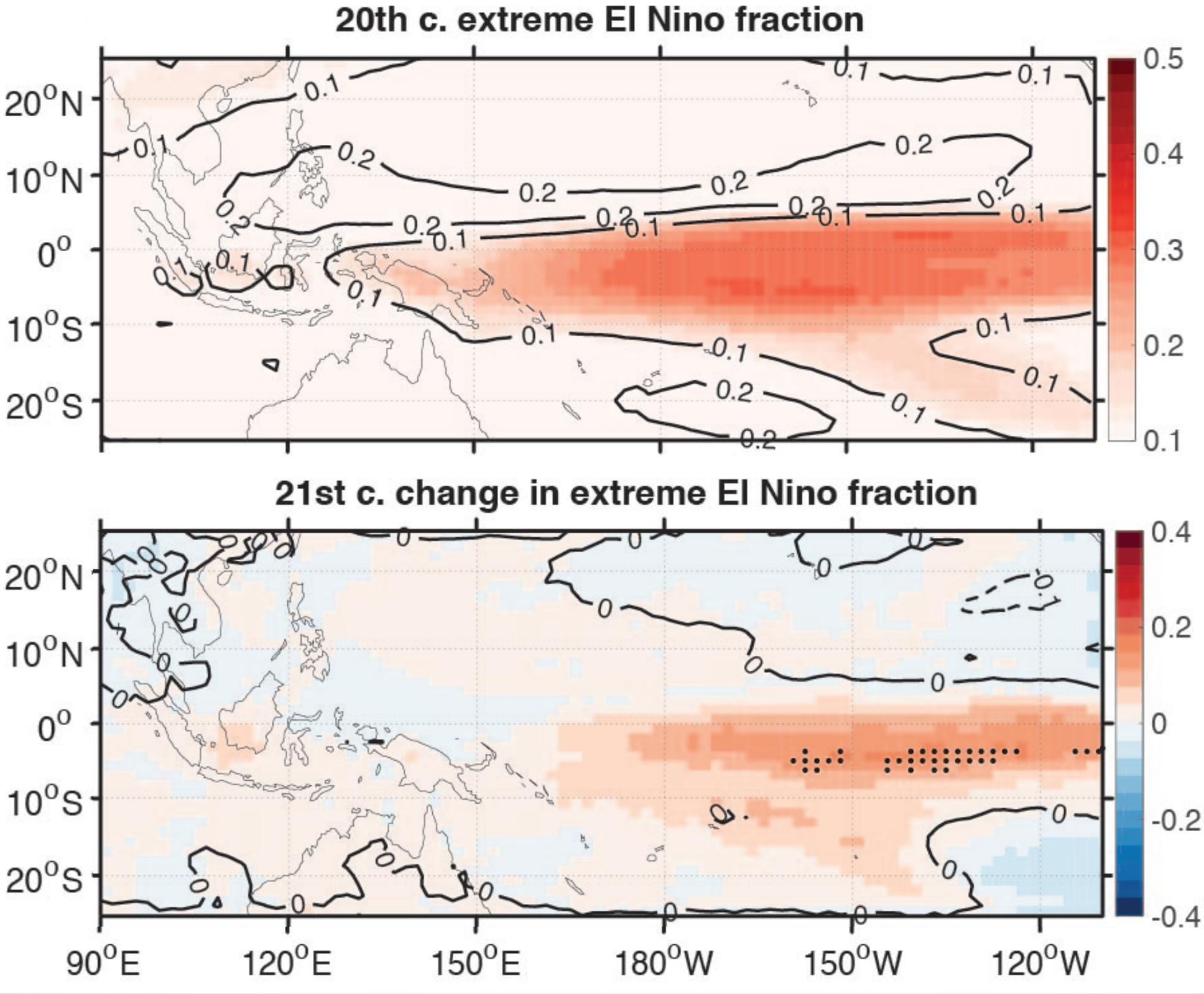
CESM LENS | **ESM2M LENS**



Stevenson et al. (2018), submitted

Top: SSTA differences, bottom: 2S-2N T(z) differences, 21st c. vs 20th c.

CMIP5: large inter-model diversity in extreme El Nino



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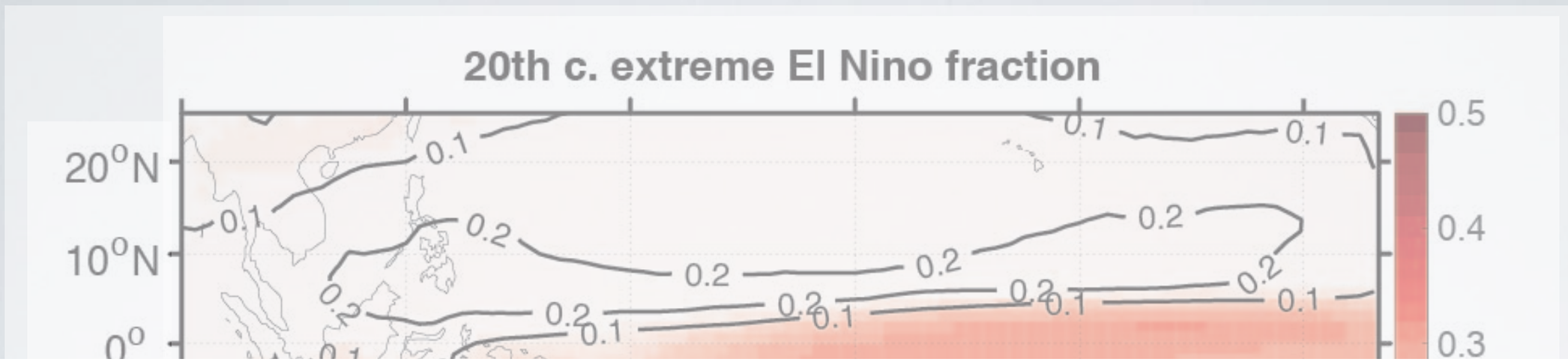
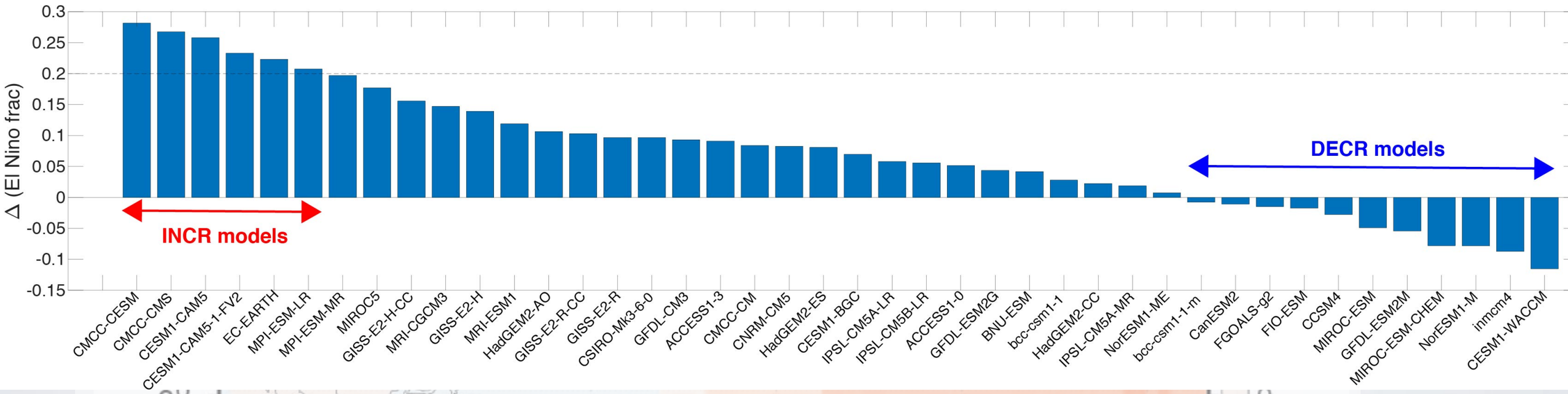


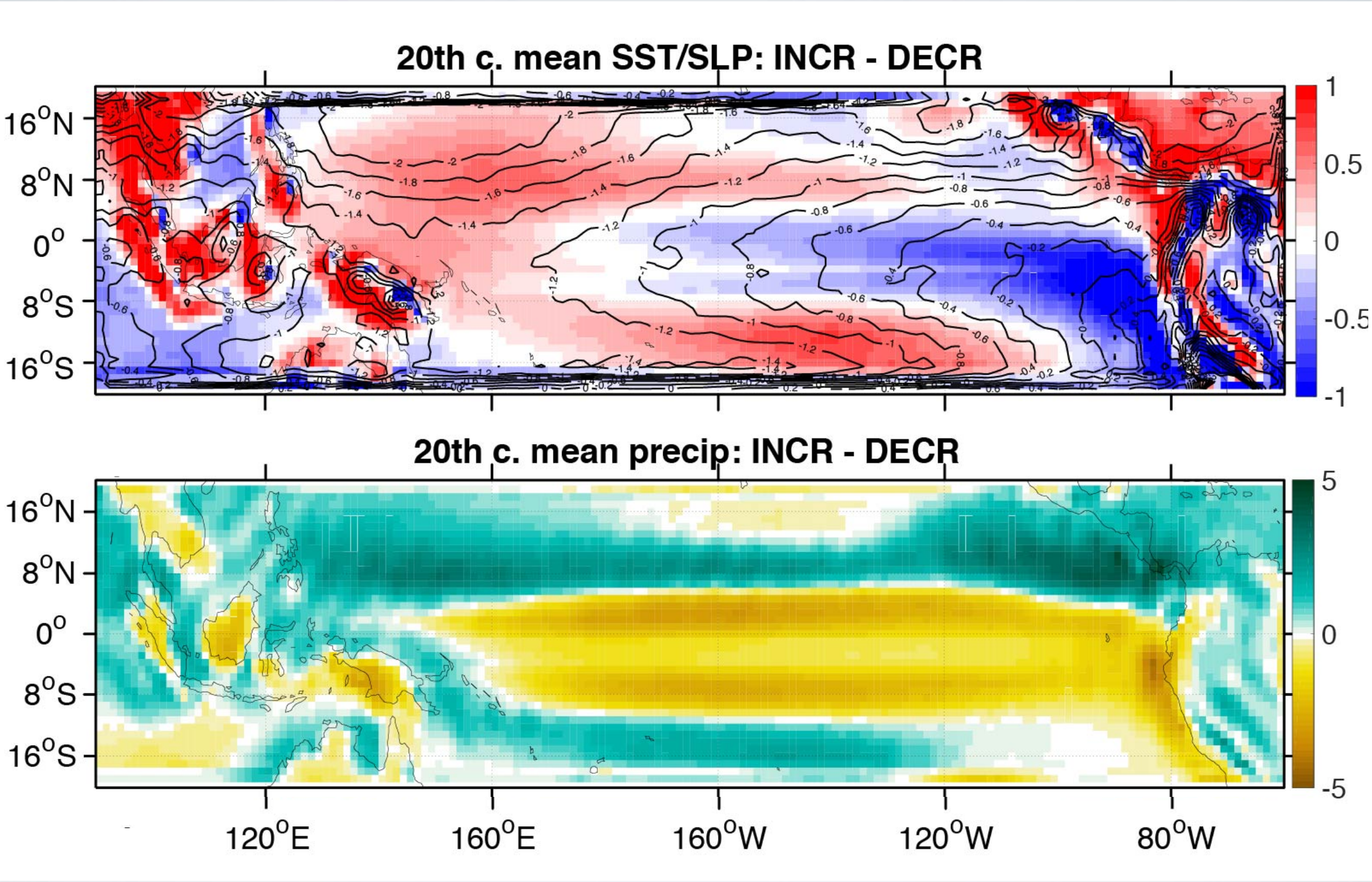
Extreme (wet) El Nino fraction over NINO3, CMIP5: % difference, 21st c - 20th c.



Multi-model mean shows increased extreme El Nino; but differences of opinion are large

Stevenson et al. (2018), submitted

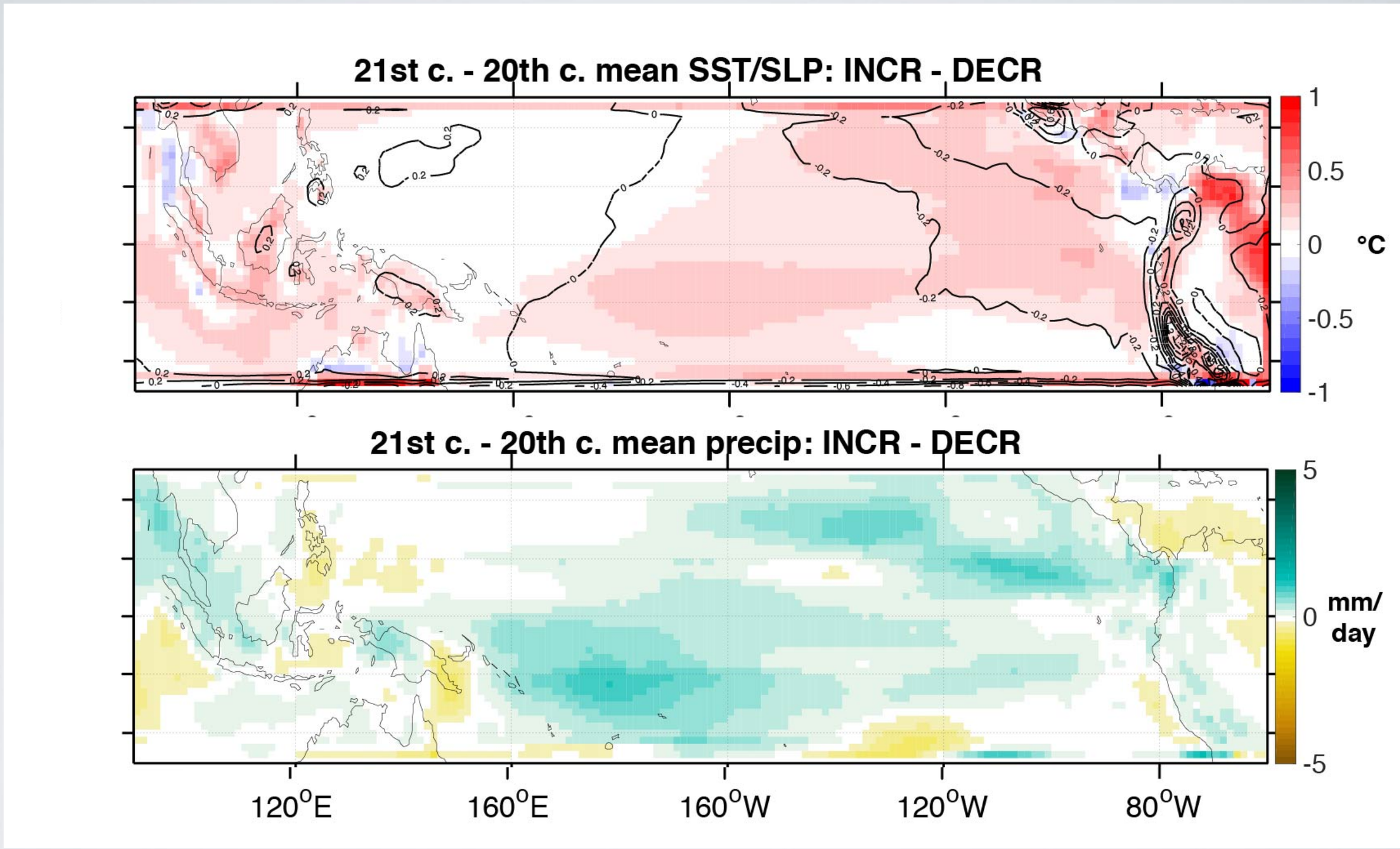
Extreme El Nino increase: favored when 20th c. colder/drier



INCR: models where NINO3 extreme El Nino increases more than 20%
DECR: models where NINO3 extreme El Nino decreases

Stevenson et al. (2018), submitted

Extreme El Nino increase: favored when 21st c. trend is 'El Nino-like'



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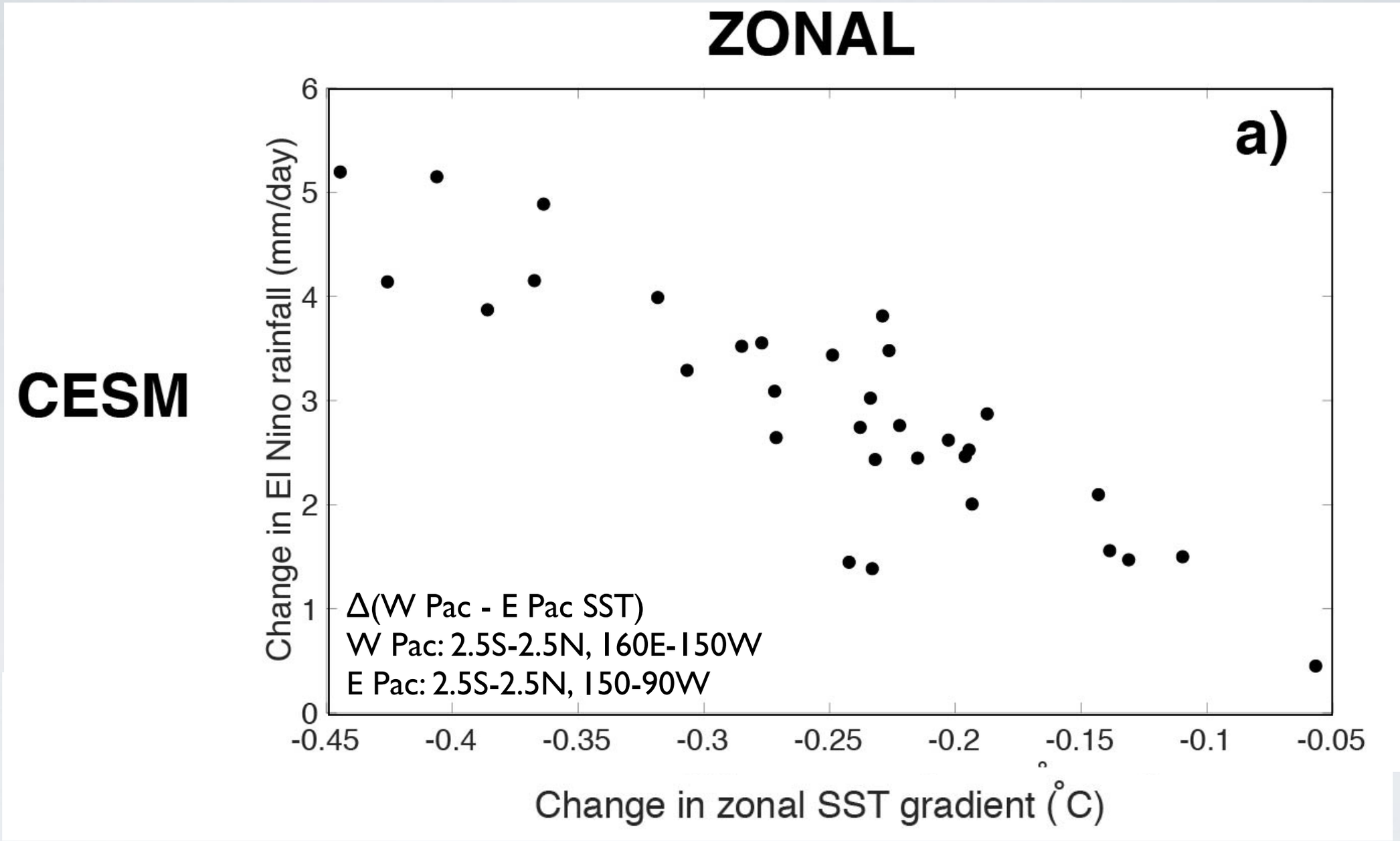
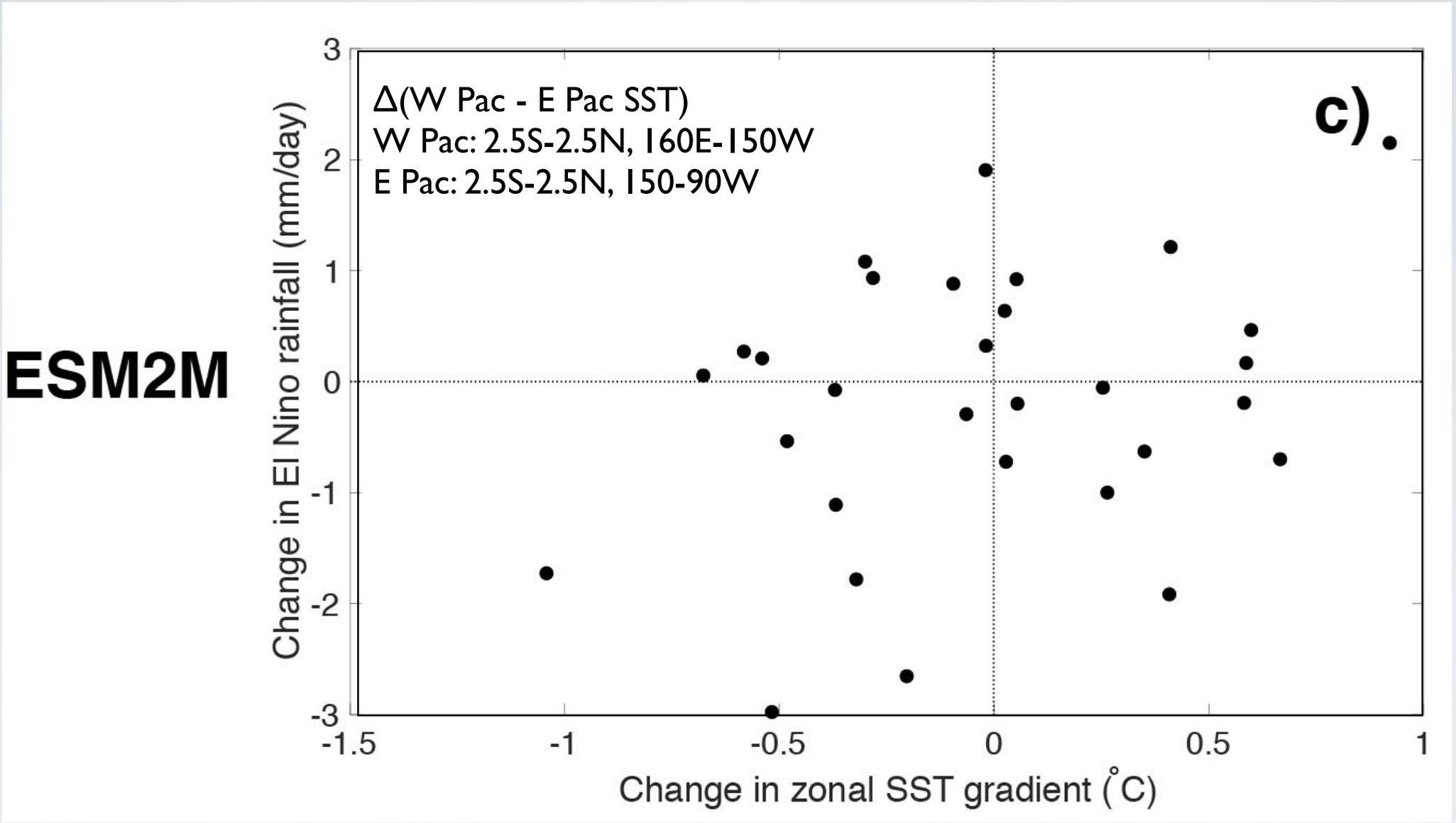
Zonal SST gradient seems to matter most…



Stevenson et al. (2018), submitted

Relationship between 21st - 20th c. ensemble-member changes in rainfall anomaly during El Nino and the zonal SST gradient (difference between east and west equatorial Pacific)

Zonal SST gradient seems to matter most… but its importance changes



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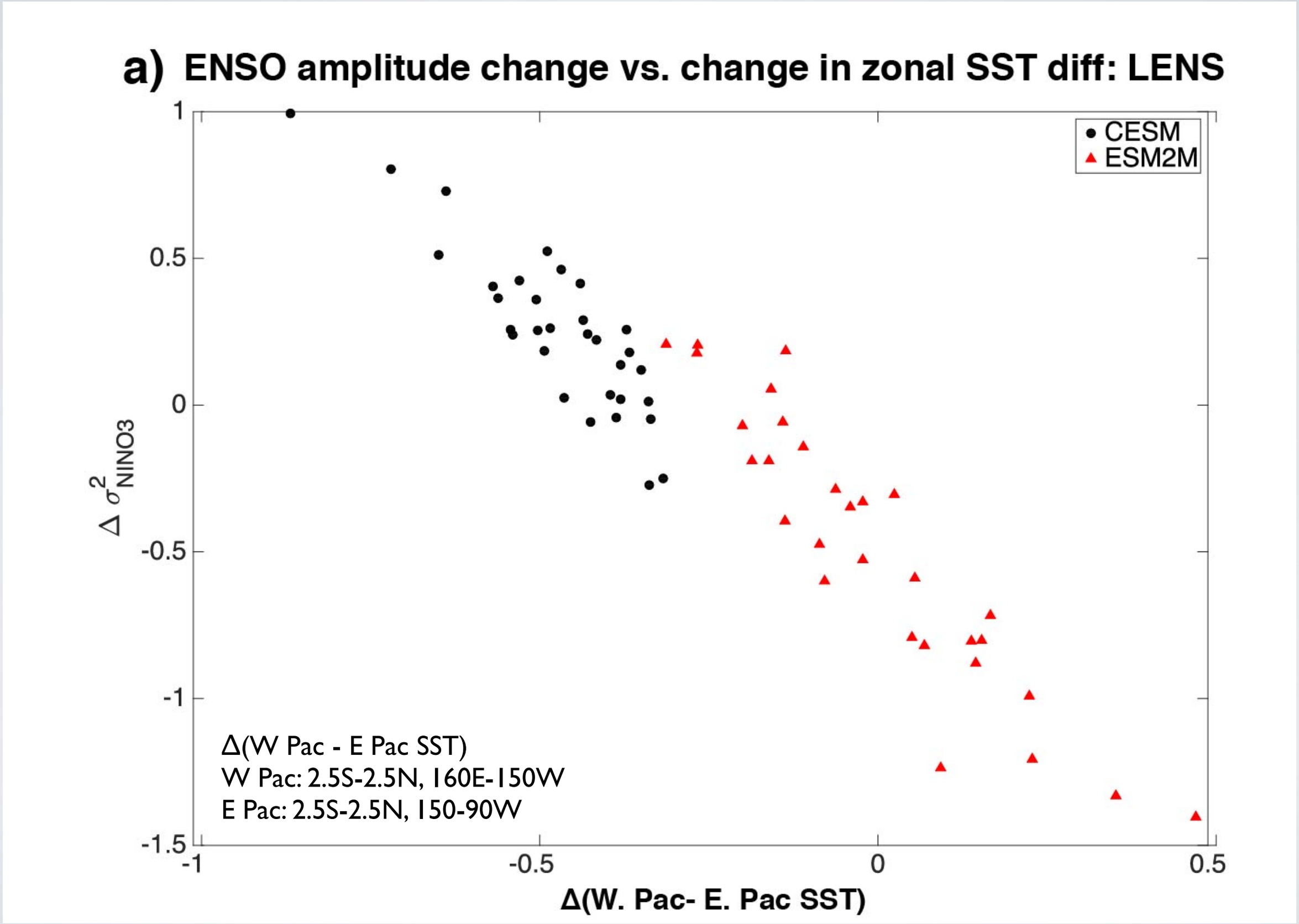
Relationship between 21st - 20th c. ensemble-member changes in rainfall anomaly during El Nino and the zonal SST gradient (difference between east and west equatorial Pacific)

Zonal SST gradient also strongly related to ENSO amplitude



Stevenson et al. (2018), submitted

Conclusions

Still no agreement on projected 21st c. changes to El Nino SST anomalies; diversity in precipitation-based extremes as well

- CESM, ESM2M large ensembles present divergent extreme El Nino futures; in CMIP5 the multi-model mean tends towards more frequent extremes, but models are split on the question

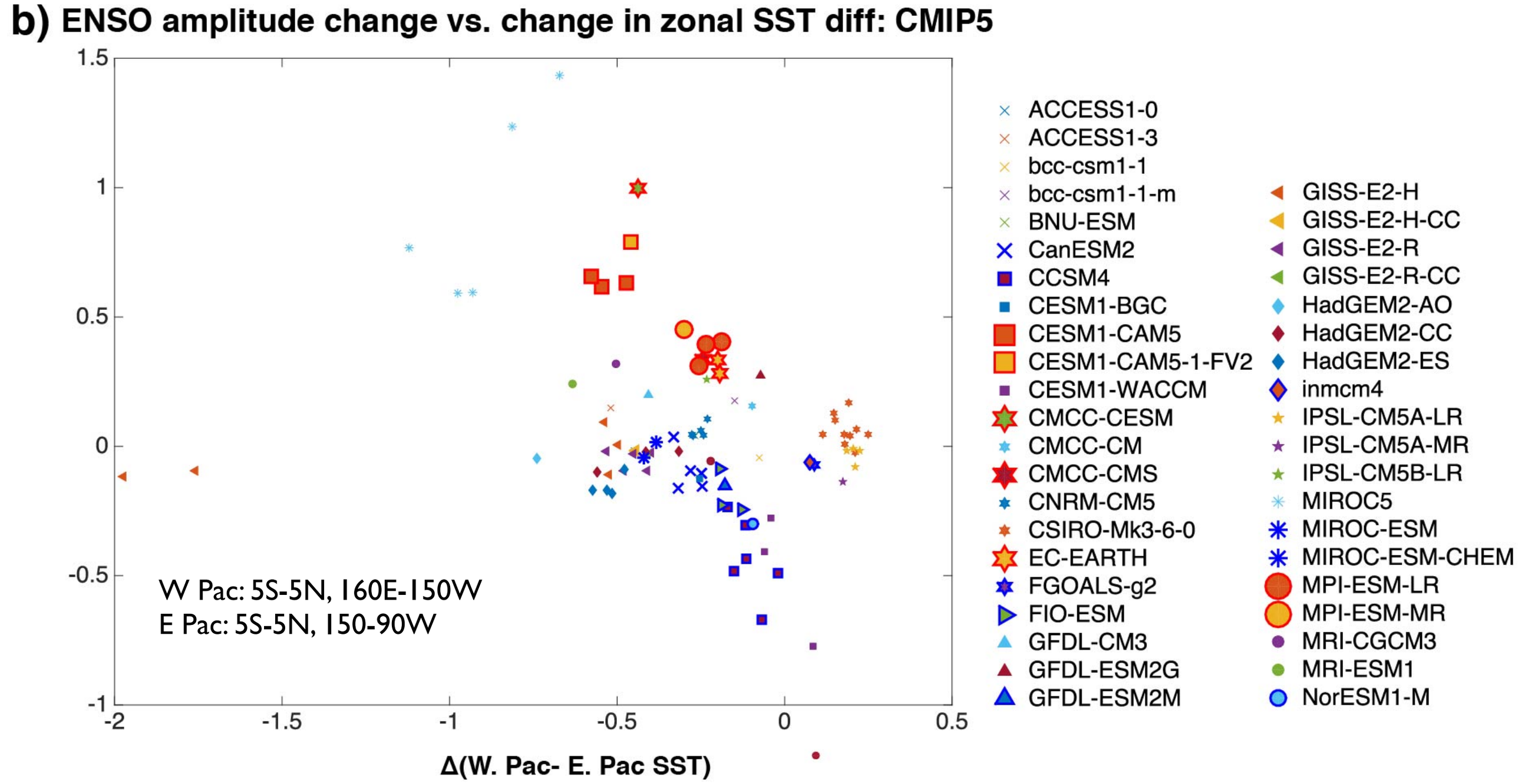
- Relative contribution of SSTA, precipitation:SSTA sensitivity to extreme El Nino precipitation also differs across models, possibly a result of differences in physical parameterizations

- Extreme El Nino changes over NINO3 systematically related to mean climate: some relationship with 20th century, but 21st c. trends play a huge role

- The zonal SST gradient is the mean-state parameter most strongly correlated with inter-model diversity in both precipitation extremes and ENSO amplitude

Understanding ENSO extremes requires understanding mean climate sensitivity to forcing, role of model physical parameterizations in climate variability

Zonal SST gradient seems to matter most



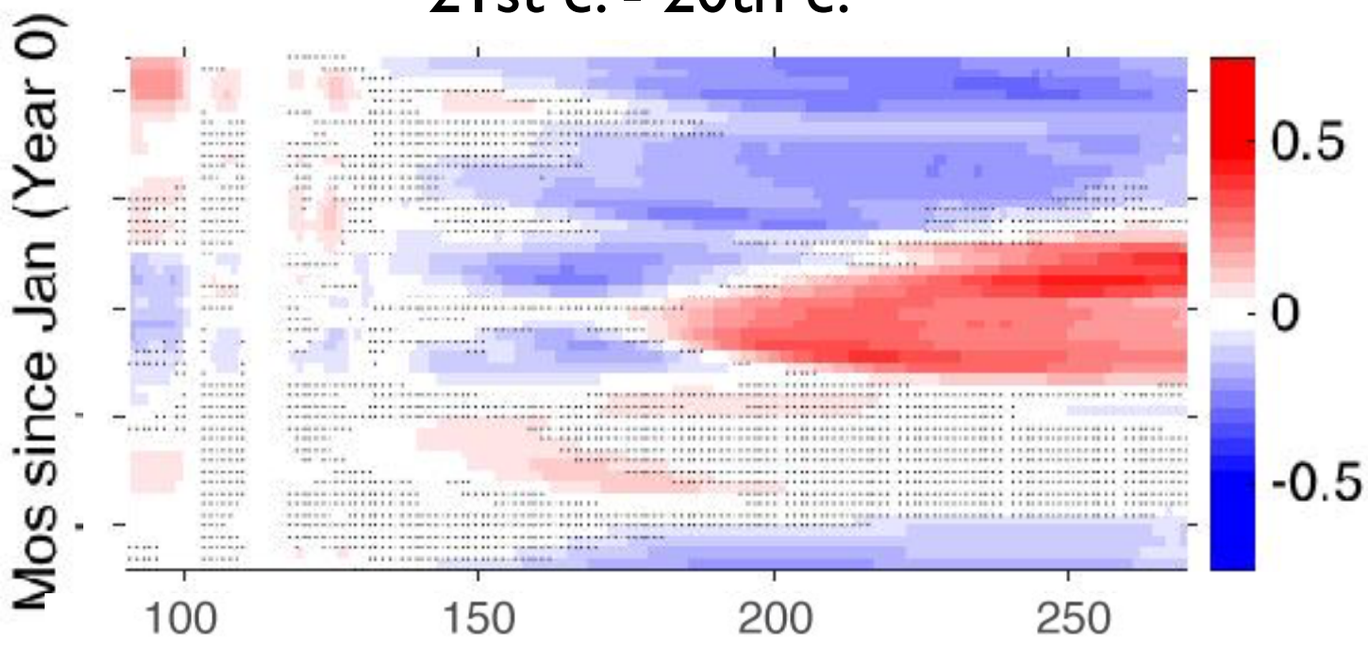
Stevenson et al. (2018), submitted

ENSO amplitude changes linked with changes in El Nino evolution

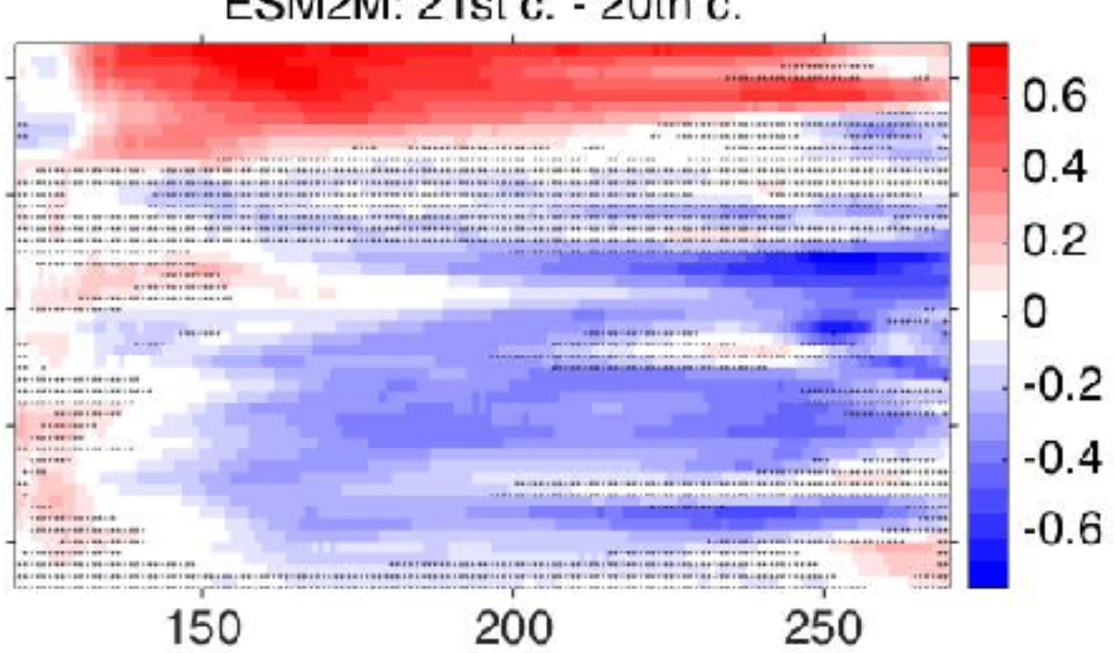
2S-2N SSTA vs. longitude, time:
0 = January of event peak year

CESM

21st c. - 20th c.



ESM2M



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