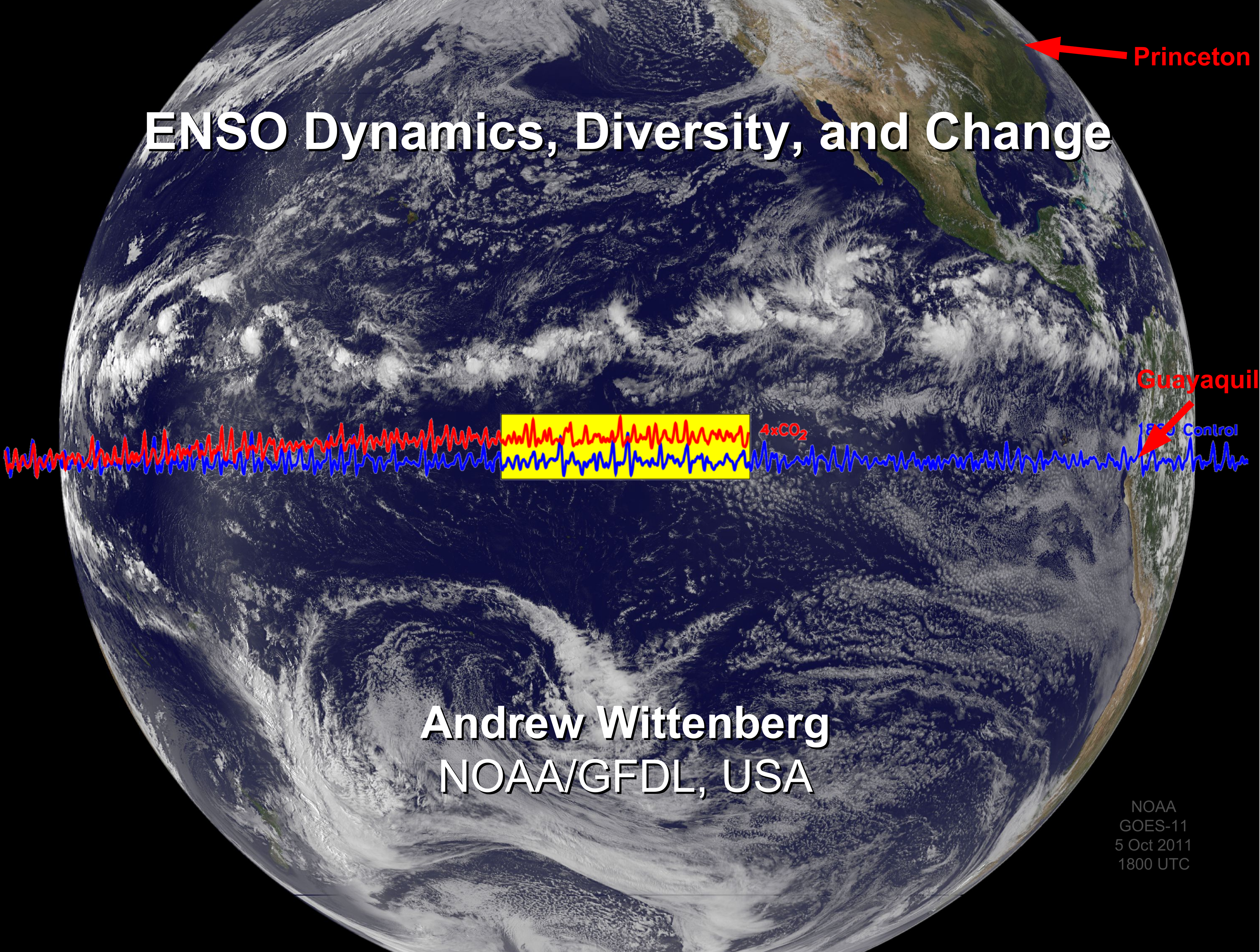
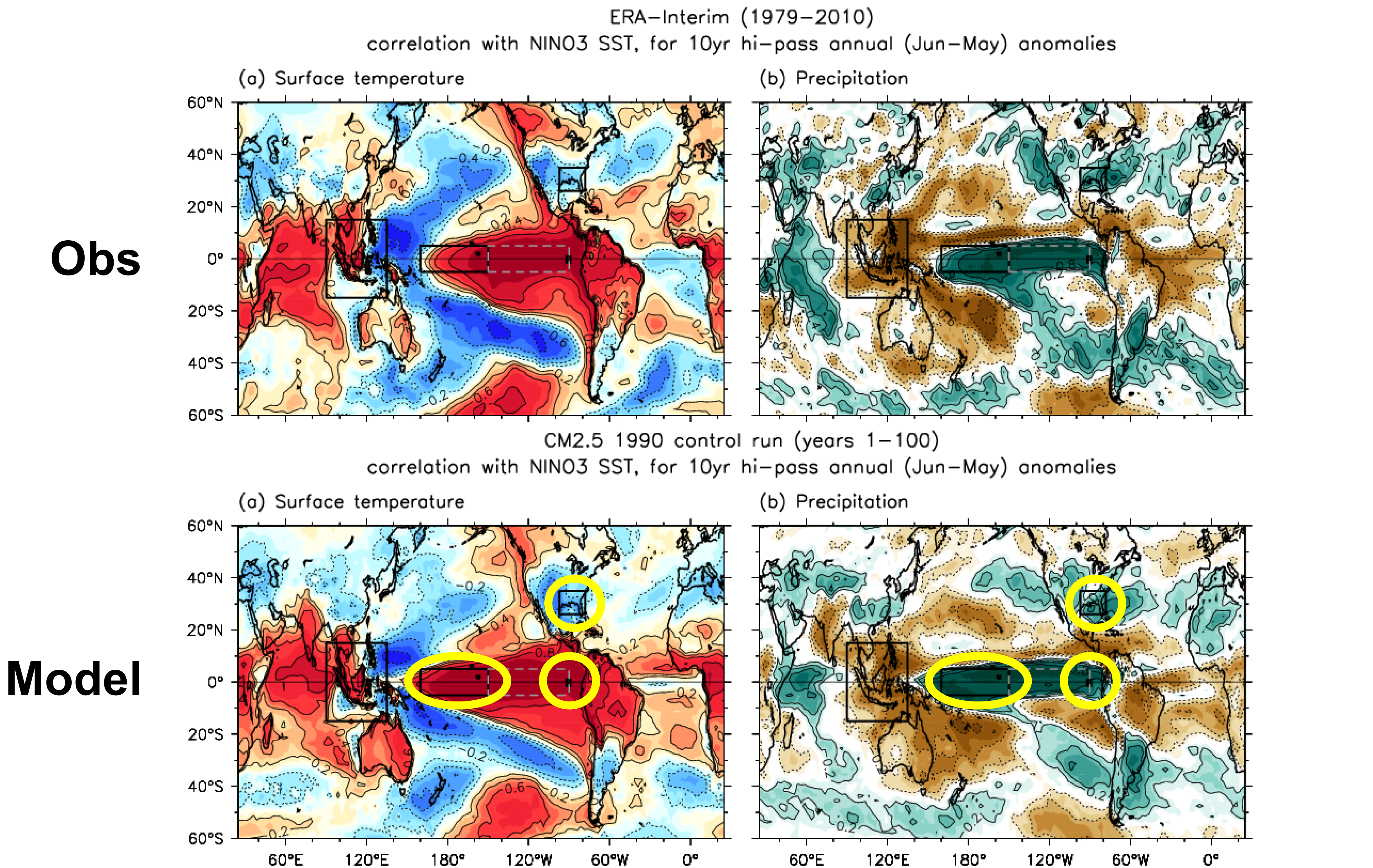
ENSO Dynamics, Diversity, and Change

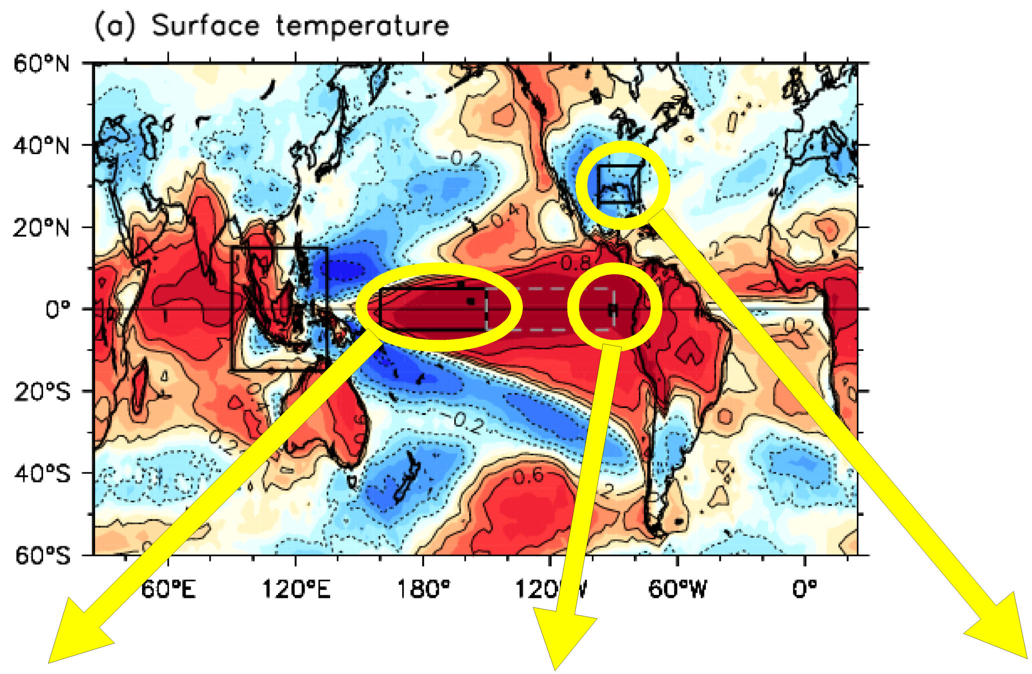


Andrew Wittenberg
NOAA/GFDL, USA

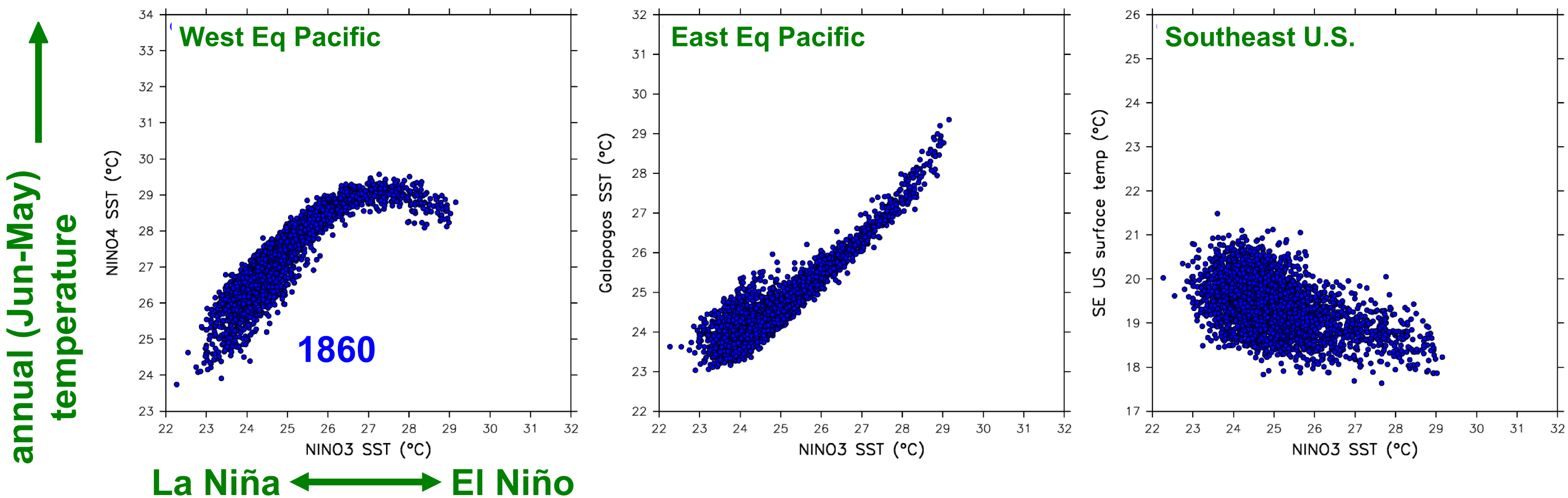
ENSO's impacts on regional climates



Extreme ENSO events have nonlinear impacts



Surface temperature teleconnections in CM2.1 (4000yr)



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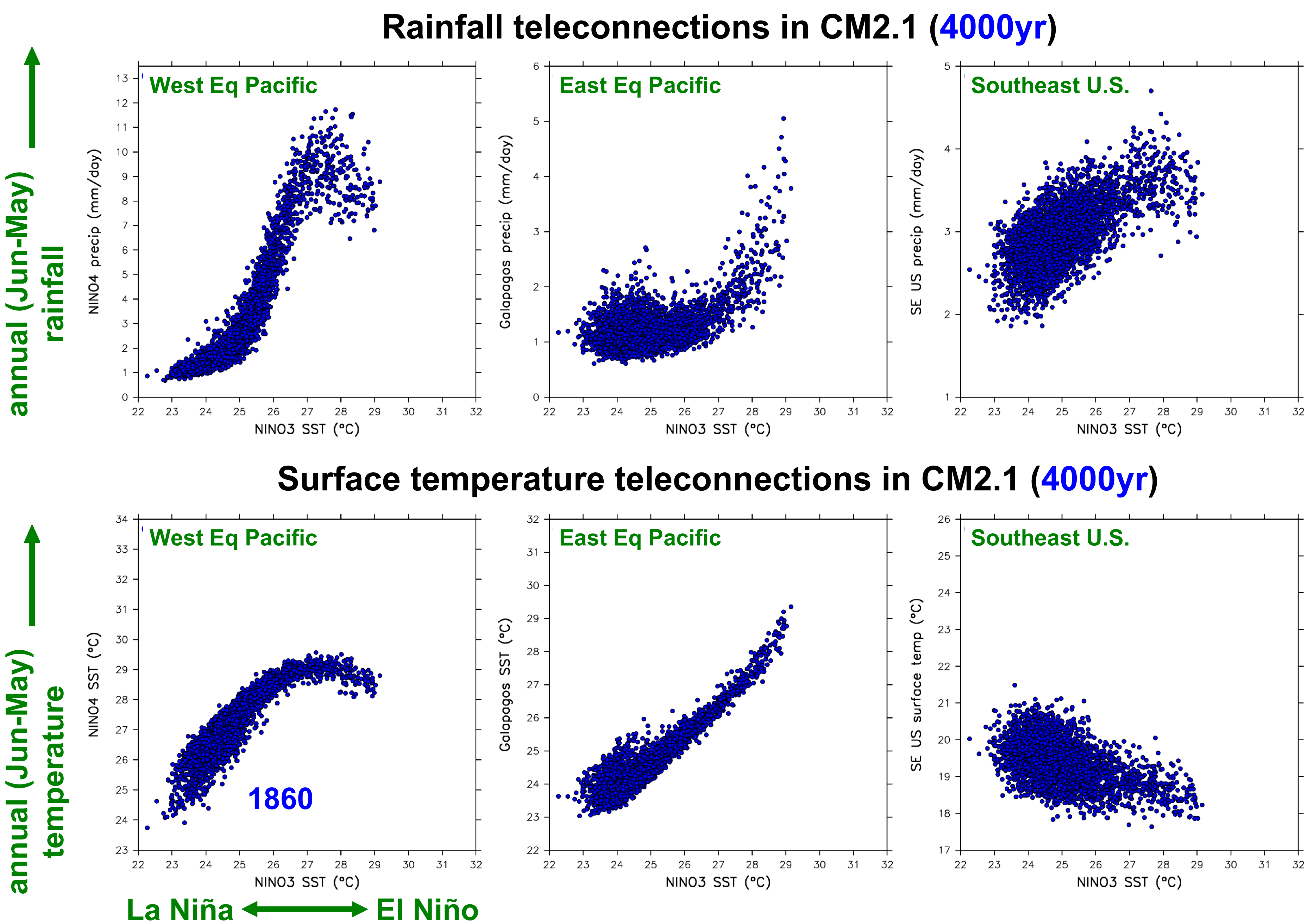
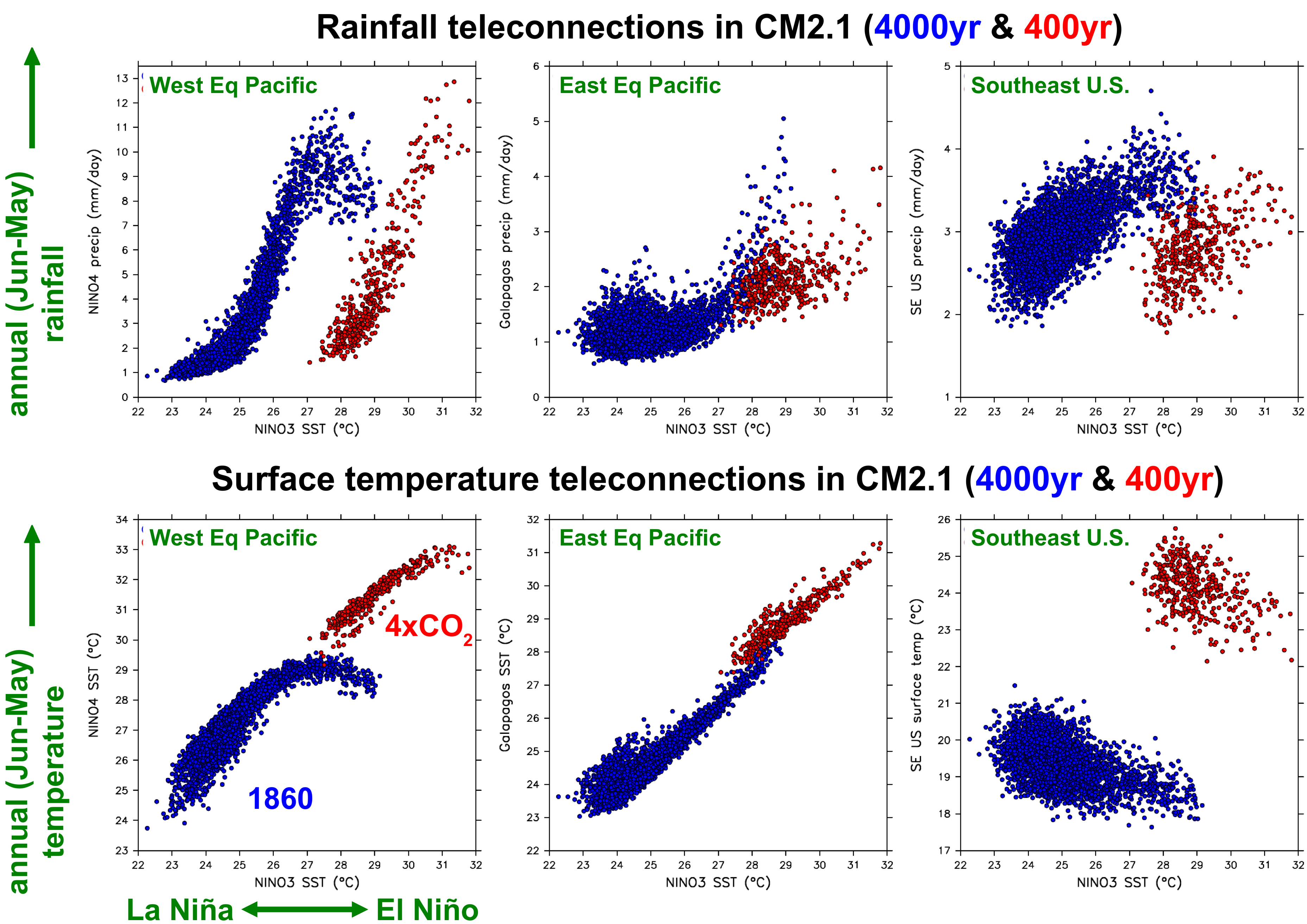
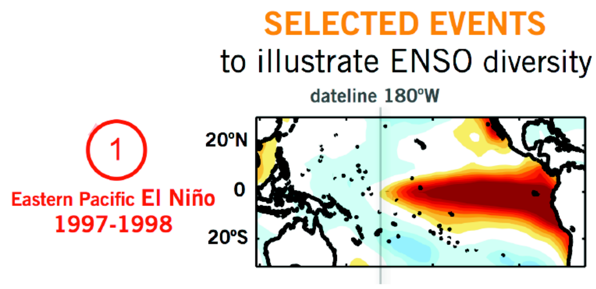
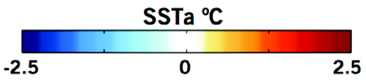


Increasing CO_2 alters ENSO impacts



ENSO diversity in observations

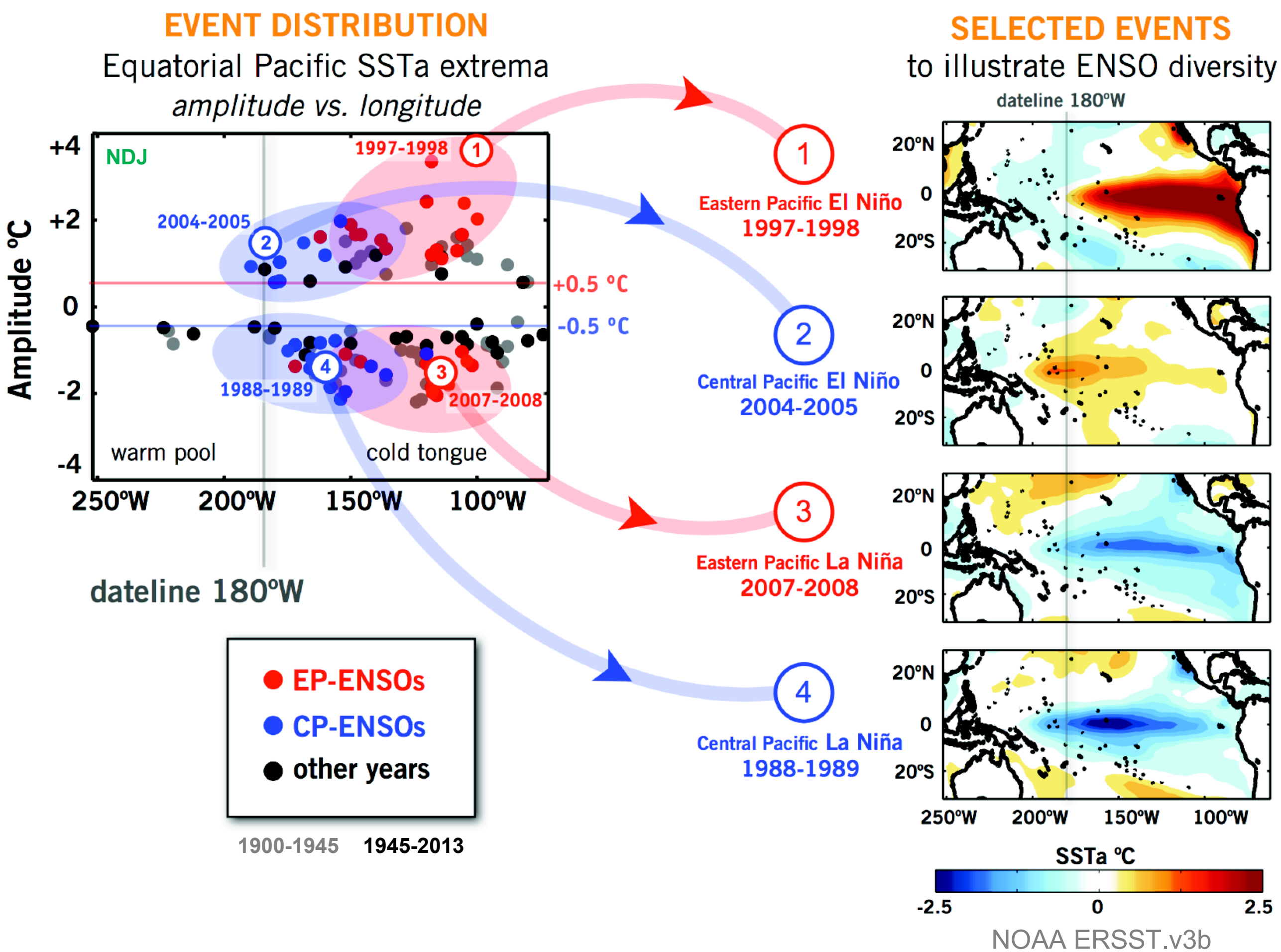




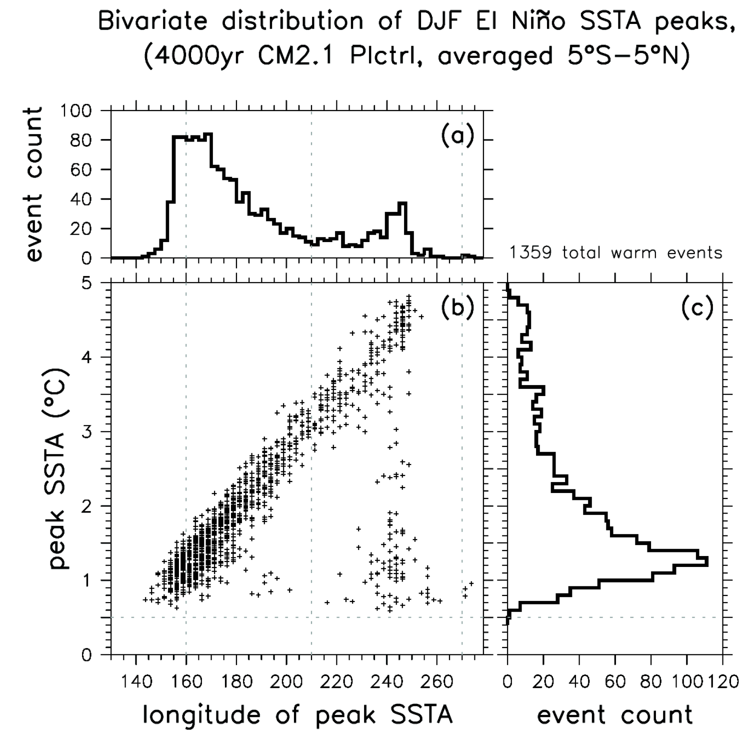
NOAA ERSST.v3b

U.S. CLIVAR Working Group on ENSO Diversity: *Capotondi et al. (BAMS 2015)*
Kug et al. (JC 2010); Graham et al. (CD subm.); Chen et al. (in prep); Atwood et al. (in prep)

ENSO diversity in observations & models



CM2.1 simulation



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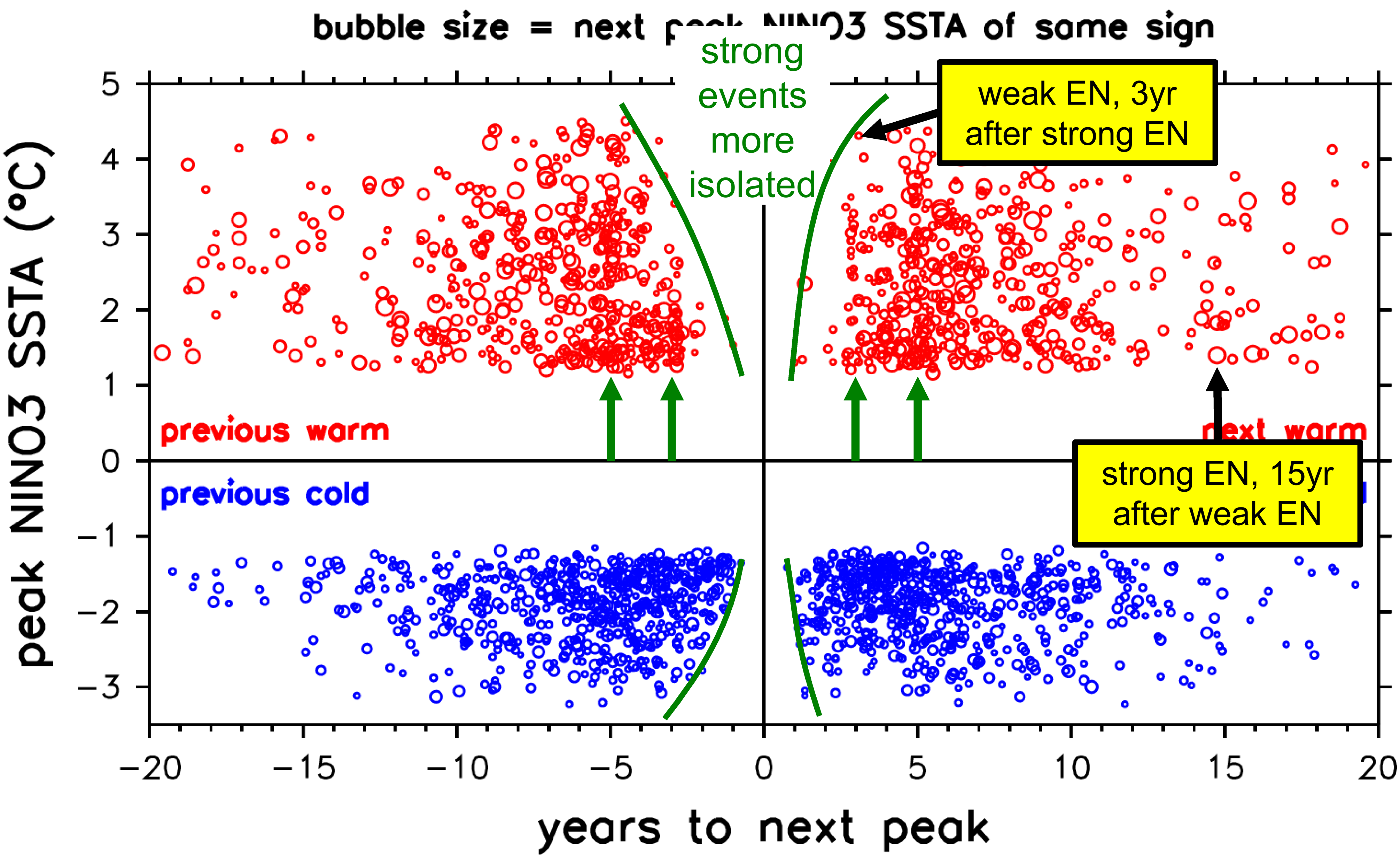
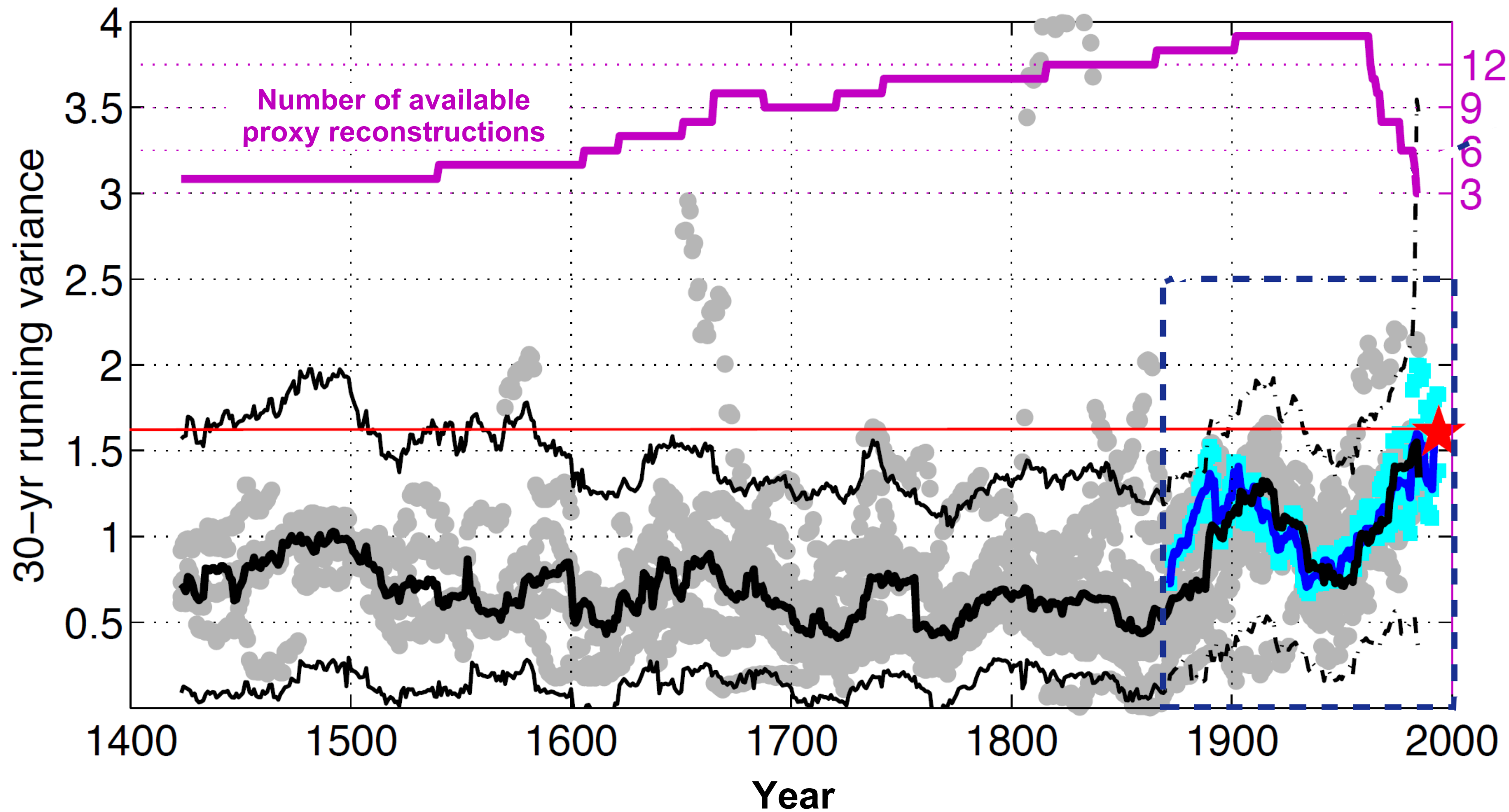
ENSO events and their nearest neighbors



CM2.1 simulation

Reconstructing past variations in ENSO

Proxy evidence suggests that ENSO has waxed & waned,
with significant amplification in recent decades.

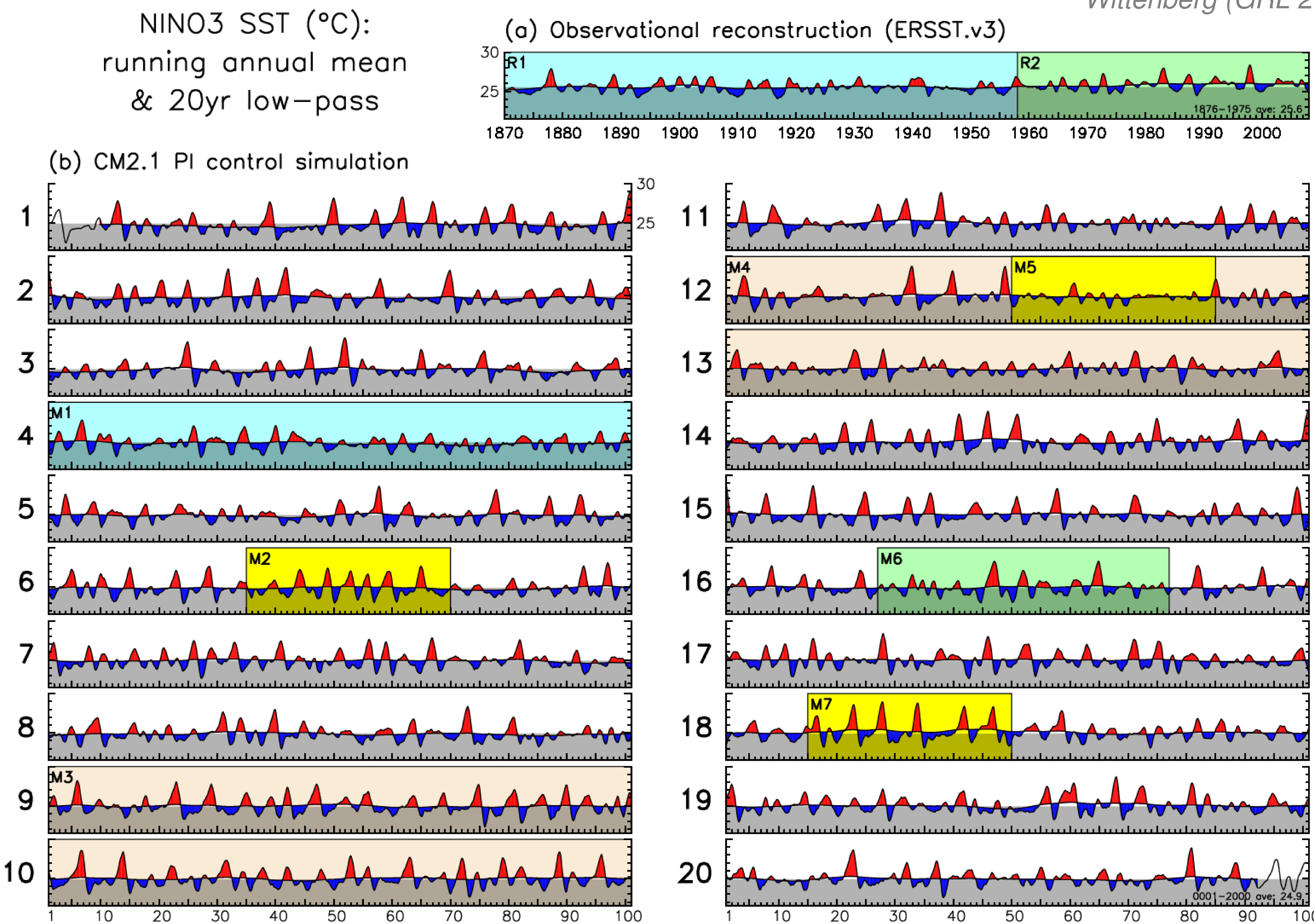


Multiproxy meta-reconstruction (from corals, tree rings, lake sediments & ice cores) of 30-year running variance of 10-yr lowpass July-June annual-mean NINO3.4 SSTs.

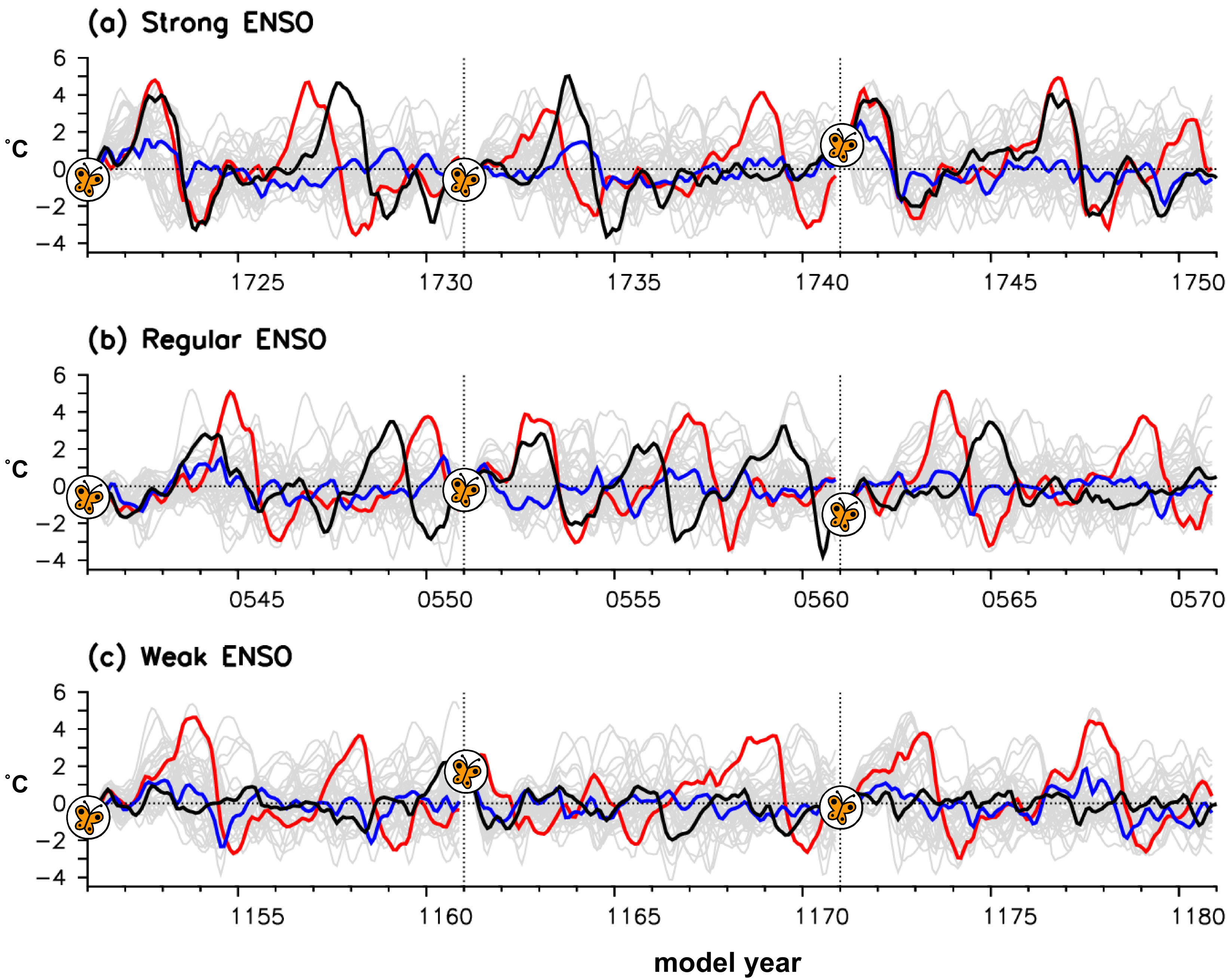
McGregor et al. (Clim. Past, 2013)

ENSO modulation in a 2000-year control simulation

Wittenberg (GRL 2009)



ENSO modulation: Is it decadally predictable?



NINO3 SSTA, for extreme-ENSO epochs simulated by CM2.1

External forcings **held fixed** at 1860 values.

Add a tiny perturbation...

"Perfect-model" reforecasts:

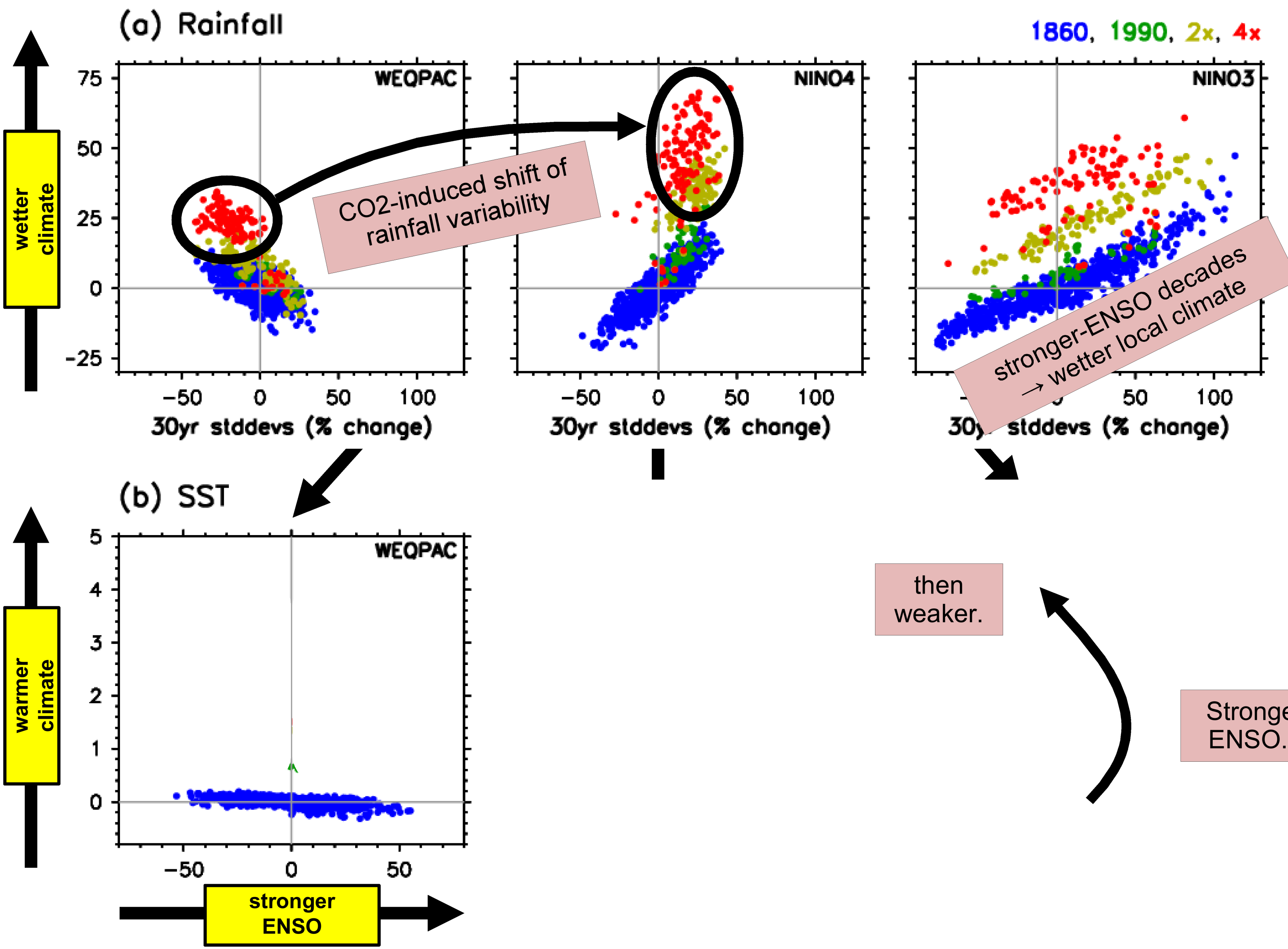
weakest,

strongest,

all 40 members

Wittenberg et al. (J. Climate, 2014)

ENSO response to increasing CO2



CM2.1 simulations show interplay of intrinsic ENSO modulation, decadal variation, and regional responses to increasing CO2

Vecchi & Wittenberg (2010)

Collins et al. (2010)

Xie et al. (2010)

DiNezio et al. (2012)

Watanabe & Wittenberg (2012)

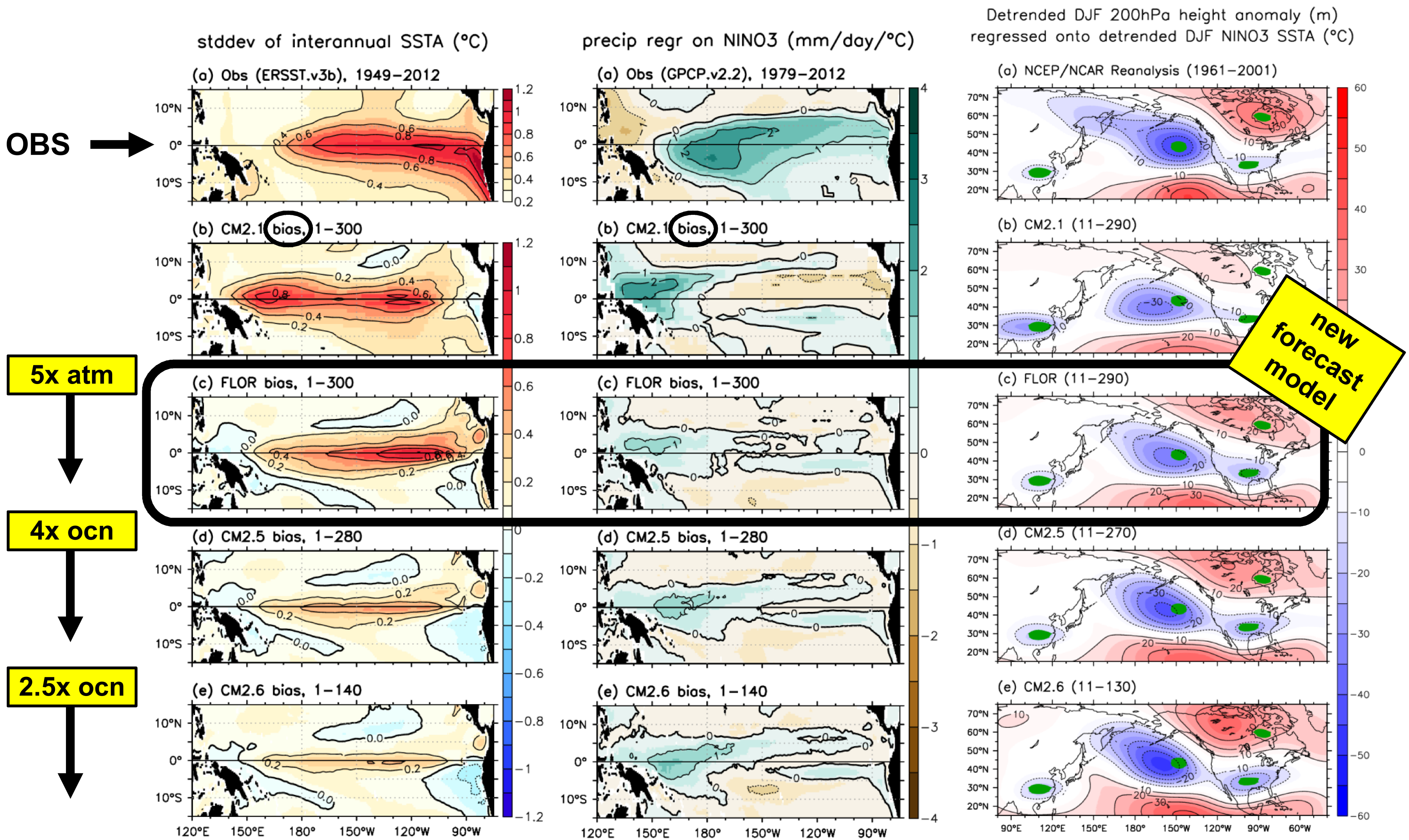
Watanabe et al. (2012)

Ogata et al. (2013)

Power et al. (2013)

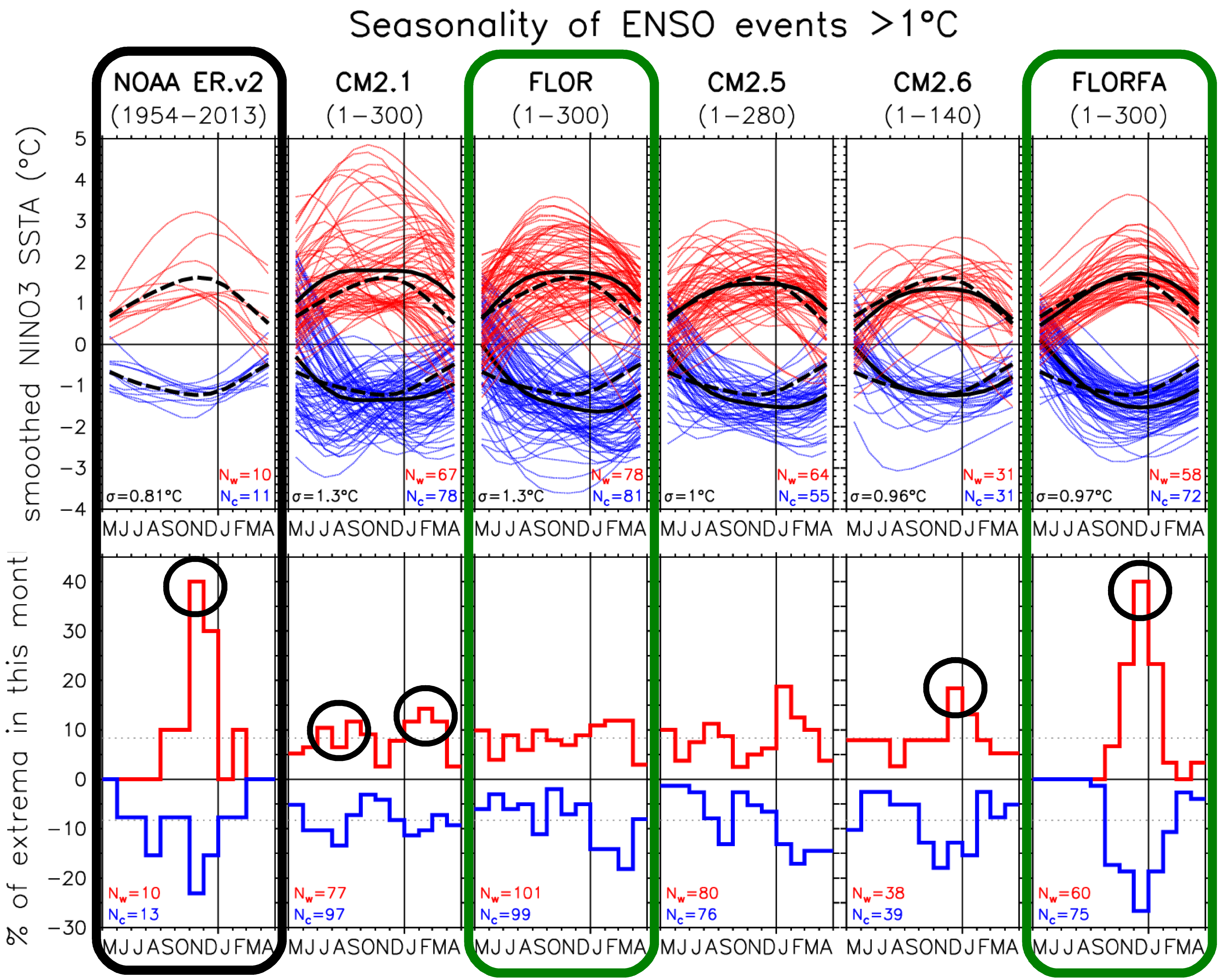
Cai et al. (2014)

ENSO improvements with increasing resolution



Delworth et al. (2012); Vecchi et al. (JC 2014); Jia et al. (JC 2015); Wittenberg et al. (in prep)

Seasonal synchronization of ENSO events



Obs events peak in Nov/Dec.

Coarse-res CM2.1 was *semiannually* synchronized!

Some improvements with increased atmos/ocean resolution, but...

Flux adjustment gives **major improvements**, due to improved SST/precip/wind, upwelling, and thermocline depth climatologies.

ENSO theory revisited

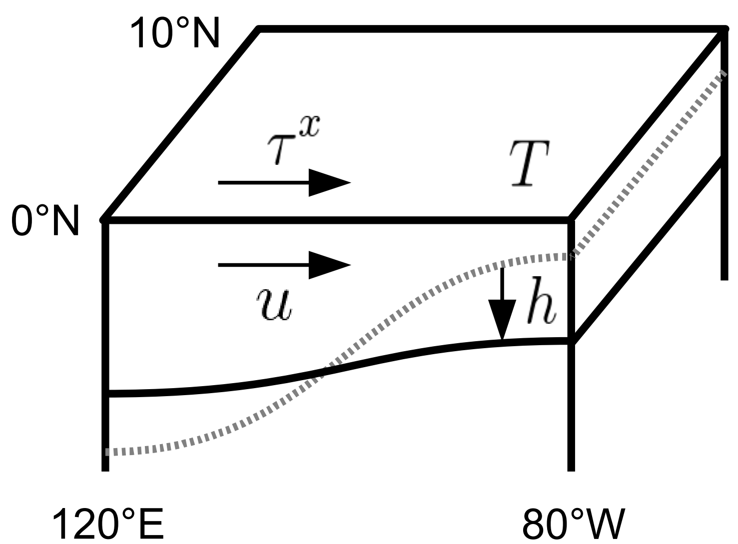
Existing conceptual models of ENSO have issues:

- Linear frameworks miss key asymmetries in obs (Choi et al. 2013)
- “BJ index” accumulates errors (Graham et al., CD 2014)
- “Unified Oscillator” at odds with obs & CGCMs (Graham et al., JC subm.)

Back to basics:

At ENSO time scales, a delayed oscillator with

$$\dot{T}(t) = \frac{T(t)}{6.25\text{mo}} - \frac{T(t-5\text{mo})}{5\text{mo}}$$



captures **94% of the variance** of obs NINO3 dT/dt. (Graham et al., JC subm)

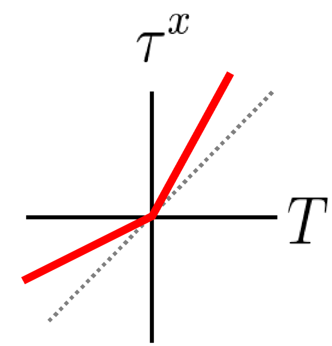
Good reference point... but what about ENSO nonlinearity?

Modified delayed oscillator

Choi et al. (J. Climate, 2013)

stronger wind response during warm events

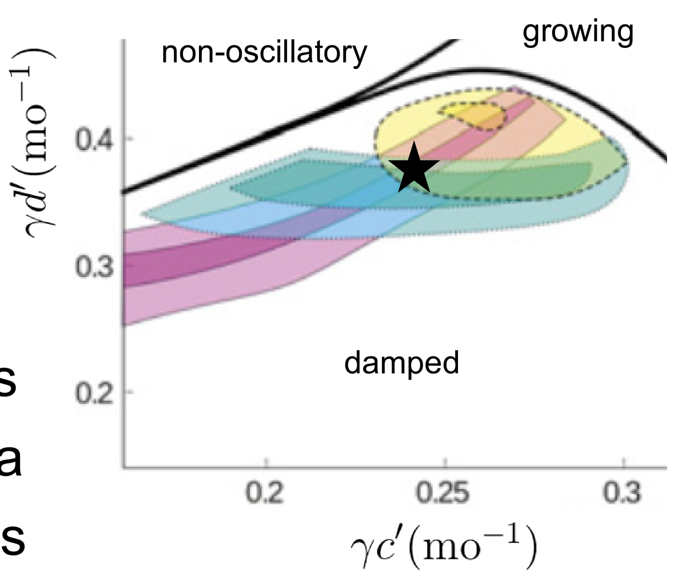
$$\tau^x = \gamma\,(T + r|T|) + \text{noise}$$



$$\dot{T}(t) = -bT(t) + c'\tau^x(t - t_1) - d'\tau^x(t - t_2)$$

local damping — local growth — delayed remote feedback

$$\dot{T}(t) \approx \tilde{c}\tau^x(t) - d'\tau^x(t - t_2)$$



Reproduces observed asymmetries in

- **Amplitude:** warm events stronger than cold events
- **Transition:** warm→cold more likely than vice versa
- **Duration:** cold events last longer than warm events

Stronger coupling during El Niño → stronger growth, faster transition & overshoot

Weaker coupling during La Niña → milder, slower, susceptible to noise

Summary

1. ENSO diversity

a. **Continuum of flavors;** strong El Niños are different

b. **Nonlinear regional impacts:** stakeholder-dependent
- various paleo proxies record different aspects of ENSO

c. **Intrinsic modulation:** may be unpredictable
- may dominate the ENSO we experience in the next few decades
- Have we observed long enough? How long must we run models?

2. ENSO changes

a. **Stronger ENSO** in past 30yr than previous 400yr

b. **Changing patterns of variability**, especially for rainfall

c. **Unprecedented climates:** Change in mean state vs. variance
- West Pacific SST; central Pacific rainfall

d. **Future vulnerability** depends on region & stakeholder

e. Competing feedbacks + optima + model biases → **uncertainty in projections**

3. ENSO models & dynamics

a. **CGCMs are improving:** teleconnections, dynamics, predictions
- atmospheric & oceanic formulations both matter
- correcting the climatology improves ENSO's seasonal timing

b. **Renewed attention to conceptual frameworks & metrics**
- e.g. nonlinear delayed oscillator → captures key ENSO asymmetries

Reserve Slides

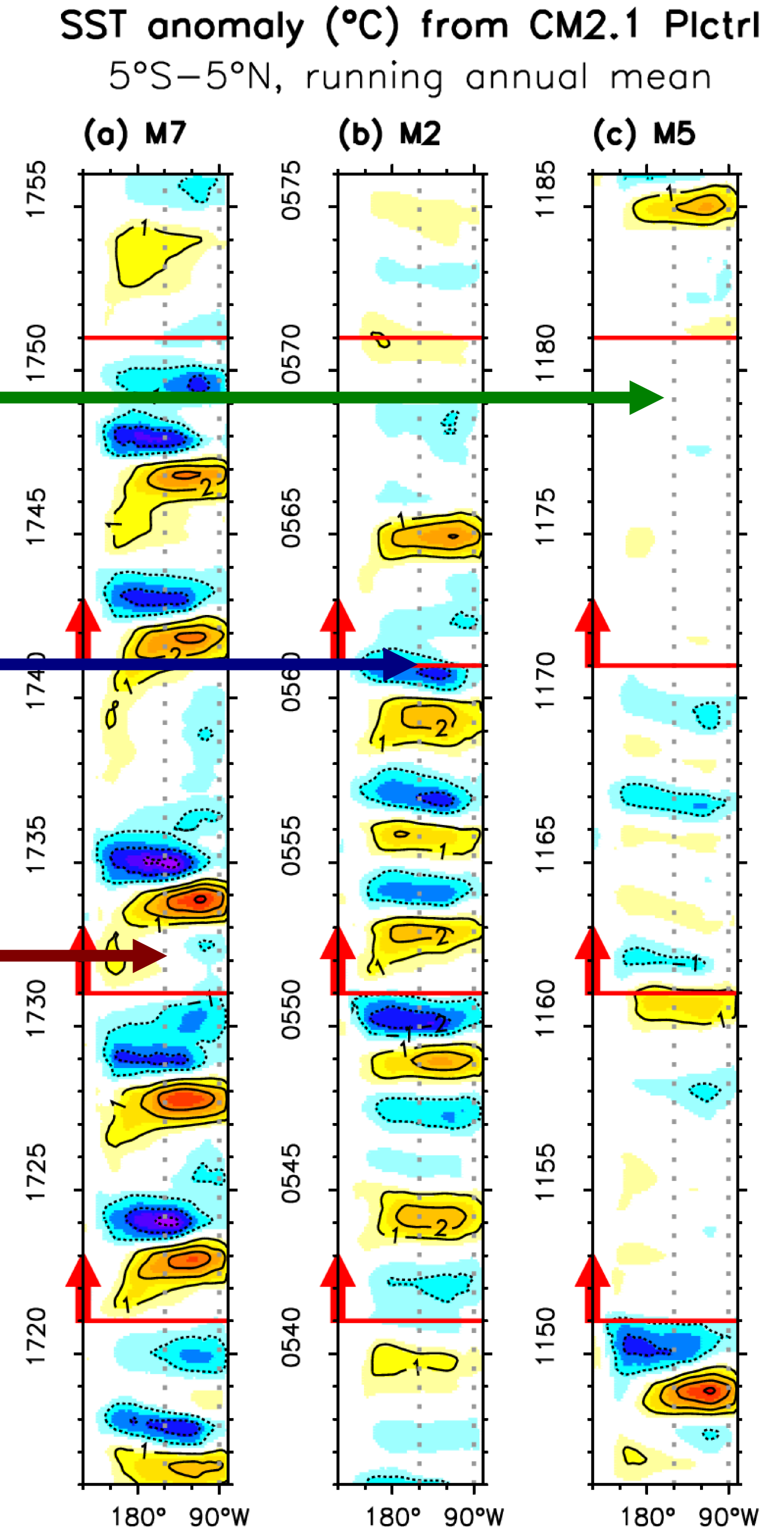
Epochs of unusual ENSO behavior

weak, biennial, “Modoki” (early 1990s & 2000s)

regular, westward propagating (1960s & 70s)

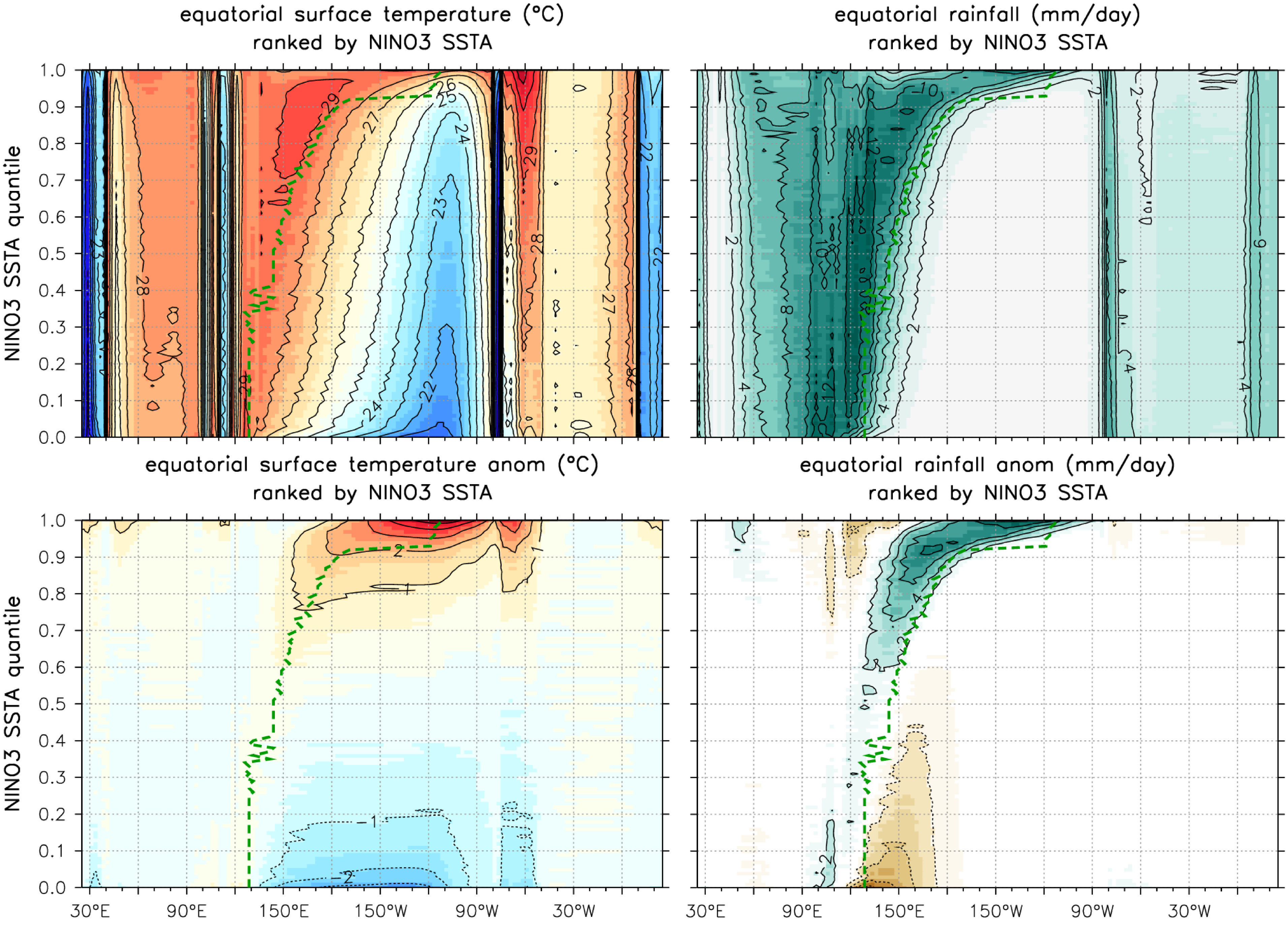
strong, skewed, long period, eastward propagating (1980s & late 1990s)

All from a simulation with **unchanging** forcings!



Wittenberg et al. (J. Climate, 2014)

Equatorial SST & rainfall, ranked by NINO3 SSTA



Key ENSO feedbacks