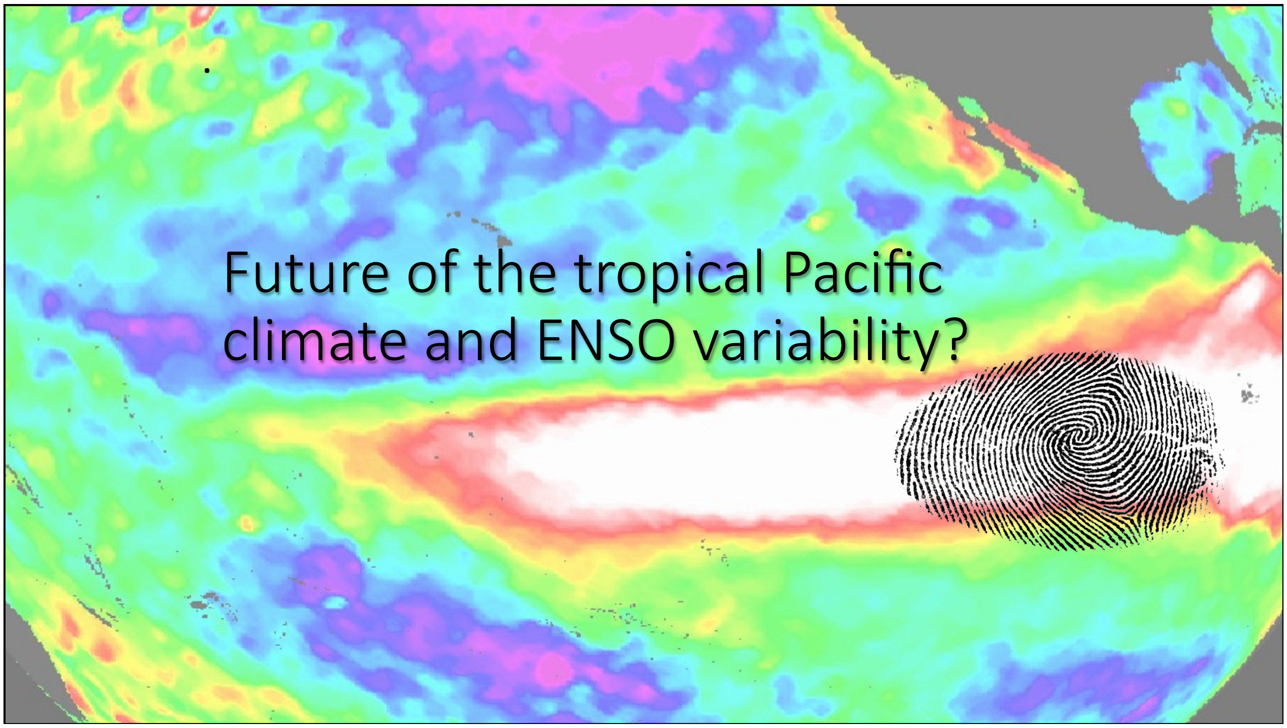
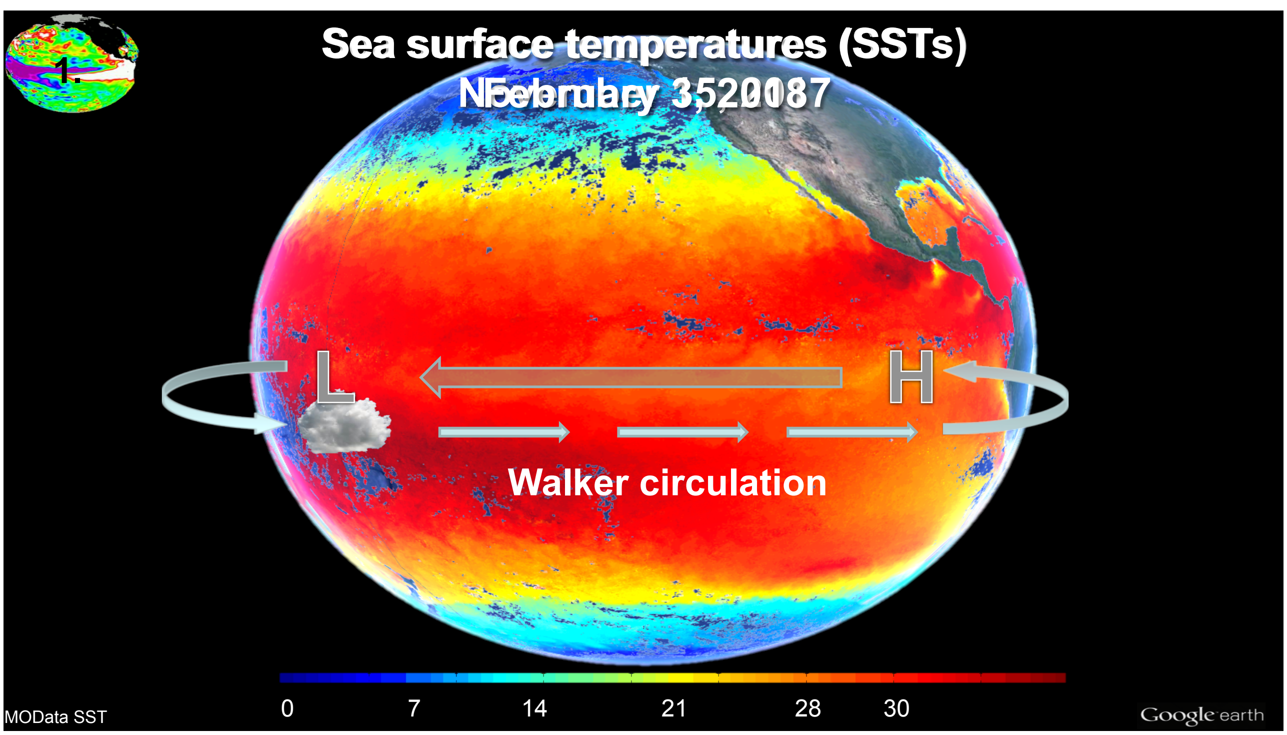

Future of the tropical Pacific climate and ENSO variability?


Sea surface temperatures (SSTs)
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Walker circulation
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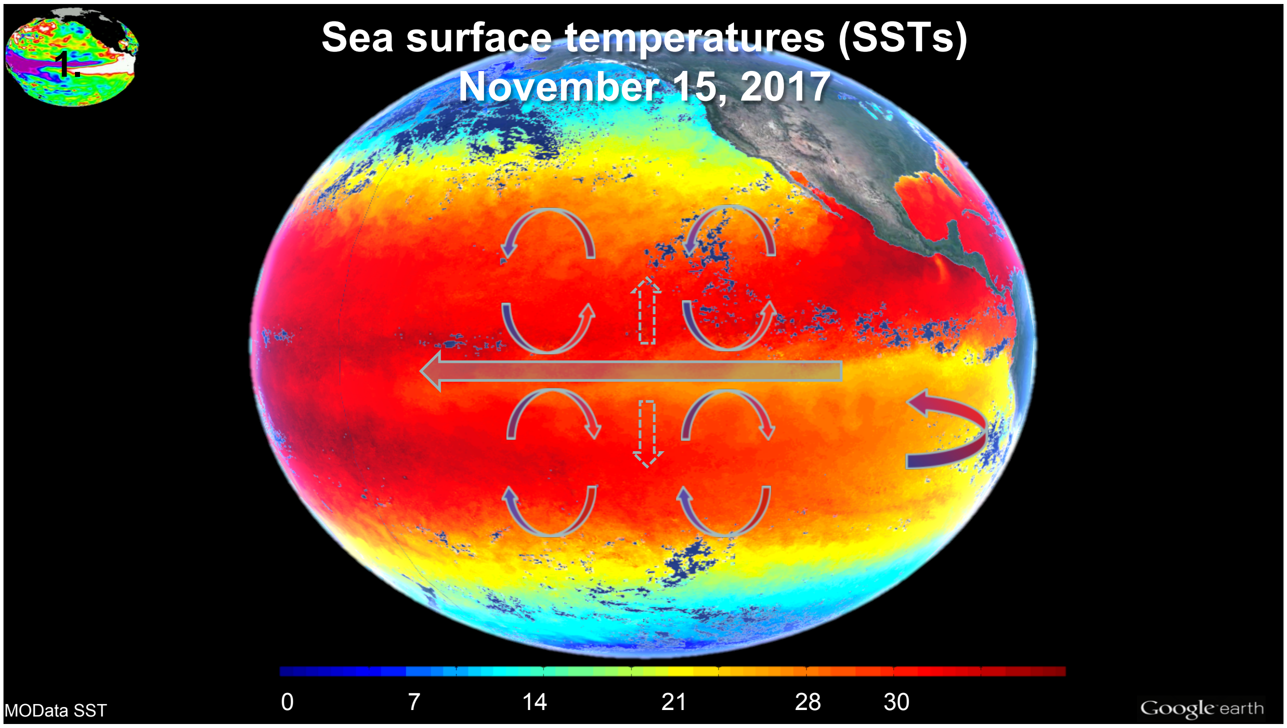
MOData SST
Google earth


Sea surface temperatures (SSTs)
November 15, 2017
1.
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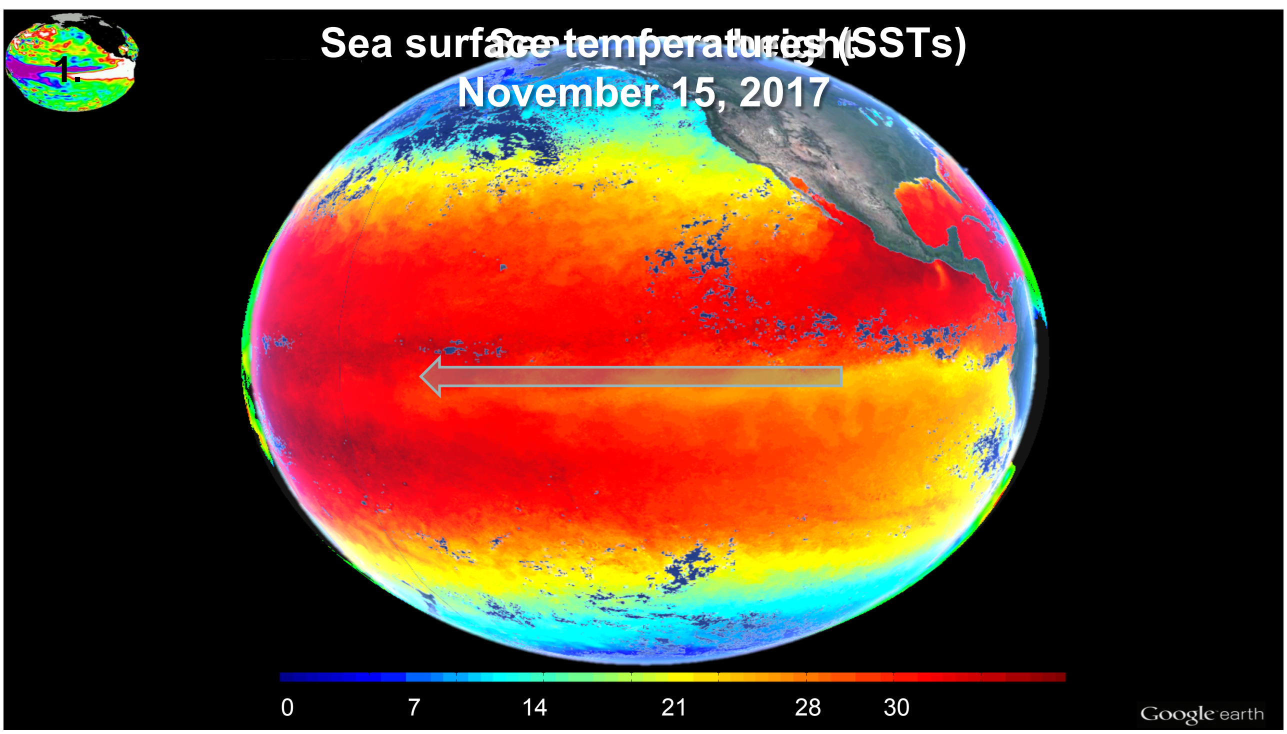
Google earth


Sea surface temperatures (SSTs)
November 15, 2017
1.
0
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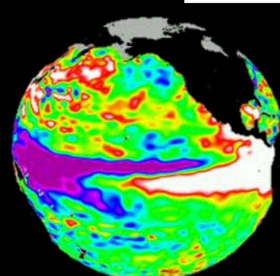
21
28
30
Google earth

Overarching questions

As our climate system continues to warm, will we see changes to the:

1. ***background state*** of the tropical Pacific?
2. ***frequency*** of ENSO events?
3. ***spatial pattern*** of ENSO events? (last week)
4. ***intensity*** of ENSO events? (last week)

Background state



Weaker Walker

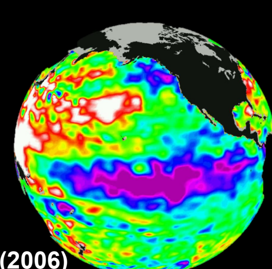
"El Niño-Like"

Vecchi et al. (2006)

Ocean Thermostat

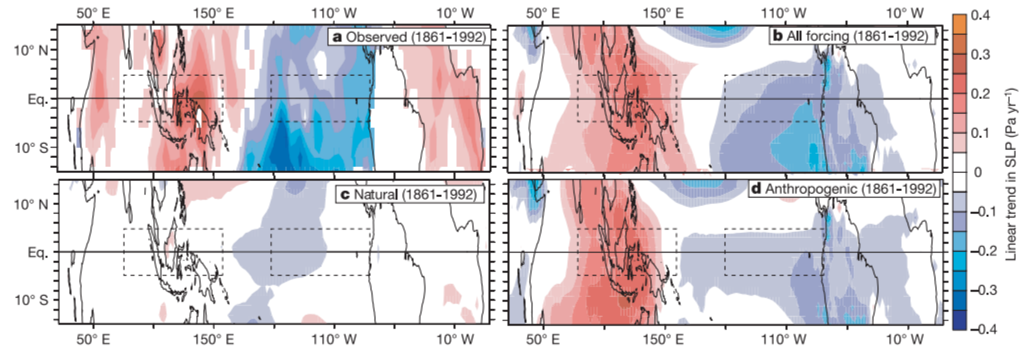
"La Niña-Like"

Clement et al. (1996) , Clement et al. (2006)



"Weaker walker" hypothesis

Observed and simulated sea-level pressure trends (blue: decreasing SLP; red: increasing SLP)



Vecchi et al. 2006

Clausius–Clapeyron

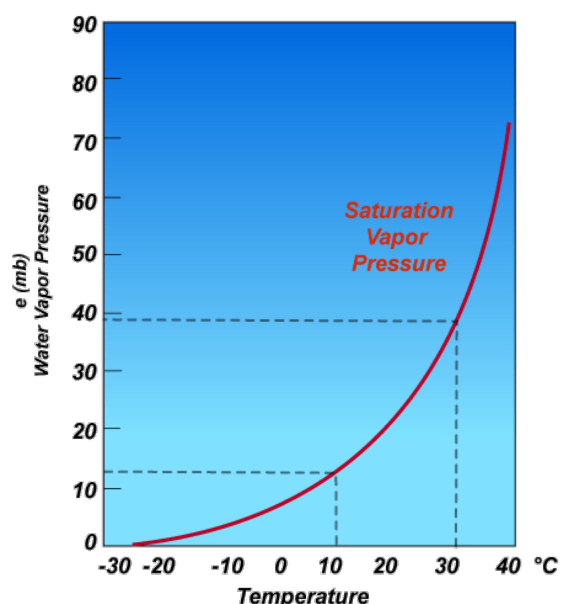
- Saturation vapor pressure: how much water vapor is needed to make air saturated at any temperature
- Saturation pressure increases exponentially with temperature:

$$e_s \cong 6.11 * exp\left\{\frac{L}{R_v}\left(\frac{1}{273} - \frac{1}{T}\right)\right\}$$

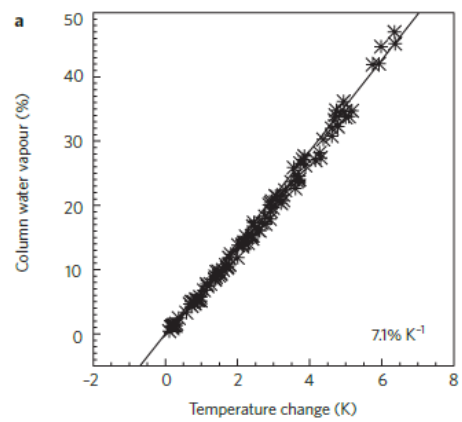
- Saturation pressure depends primarily on temperature as defined by the Clausius–Clapeyron equation:

$$\frac{de_s}{dT} = \frac{L}{T\,(\alpha_v - \alpha_l)}$$

L: latent heat of evaporation =2.453 × 10^6 J/kg
α: specific volume (of vapor & liquid)
R_v = Gas constant for moist air = 461 J/(kg*K)



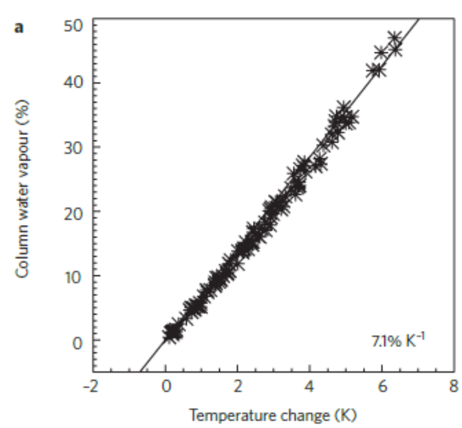
“Weaker walker” hypothesis

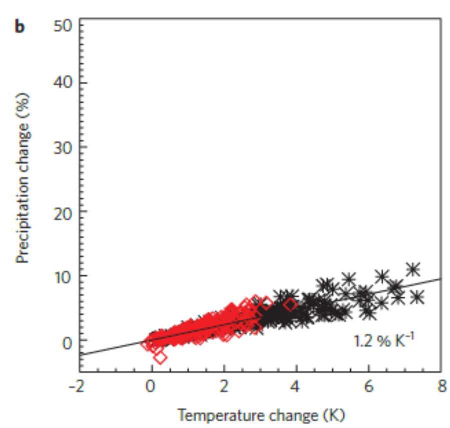


Clausius–Clapeyron dictates that the water-holding capacity of the atmosphere increases by about 7% for every 1°C rise in temperature (C-C is linear over ΔT of a few degrees if RH = constant)

Collins et al. 2010

“Weaker walker” hypothesis





Collins et al. 2010

Why would the Walker Circulation slow down?

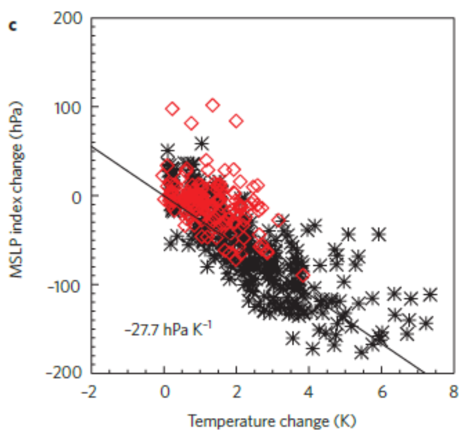
"Weaker walker" hypothesis

- slow increase of precipitation relative to boundary water vapor (humidity) implies that the rate of transport of moisture from the boundary layer to higher levels where it rains out ***must go down***
- One way to do this is to decrease the strength of large scale circulations like the Walker and Hadley circulations

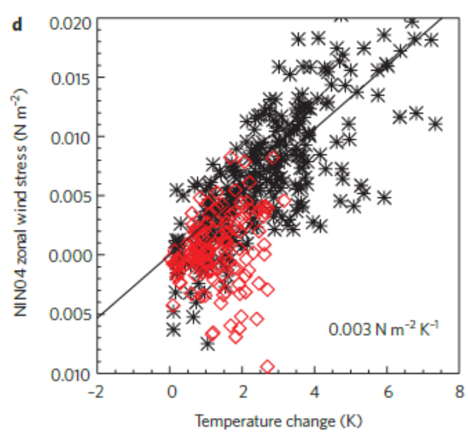
"On a weakening of the Walker Circulation"

"Weaker walker" hypothesis

Change in the mean sea-level-pressure (MSLP) gradient

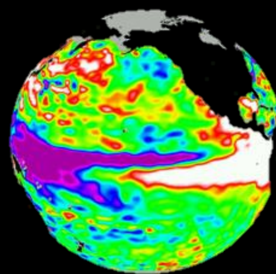


Changes in the mean wind stress averaged in the NINO4 region [positive values = weaker easterlies]



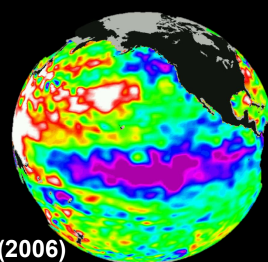
Collins et al. 2010

Background state

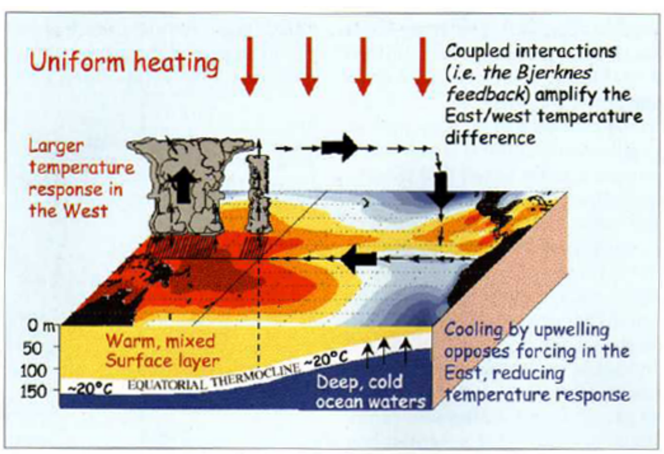


Weaker Walker
"El Niño-Like"
Vecchi et al. (2006)

Ocean Thermostat
"La Niña-Like"
Clement et al. (1996) , Clement et al. (2006)



"Ocean thermostat" hypothesis

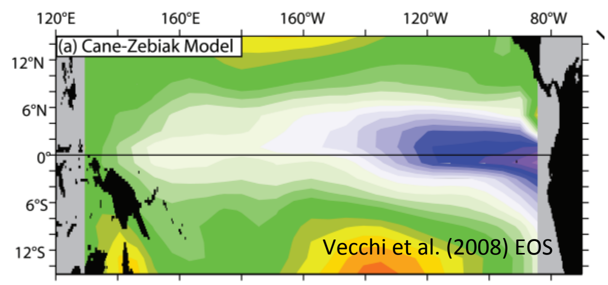


Supported by simulations of mid-Holocene (Clement et al. 2000) and millennial variability (Clement and Cane 1999) as a response to solar and volcanic forcing (Mann et al. 2005)

Clement et al. (1996) *J. Clim.*, Clement et al. (2006) PAGES

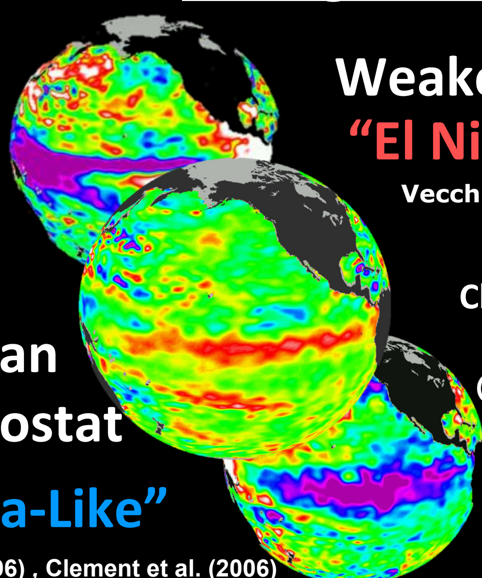
“Ocean thermostat” hypothesis

- Using the ***Cane-Zebiak model*** Clement et al. [1996] find a La Niña-like state in response to warming– “ocean thermostat mechanism” dominates
- Note: in the Cane-Zebiak model, representation of atmospheric processes is simplified (atmospheric circulation does not weaken in response to a warming)



Clement et al. (1996) *J. Clim.*

Background state



Weaker Walker

“El Niño-Like”

Vecchi et al. (2006)

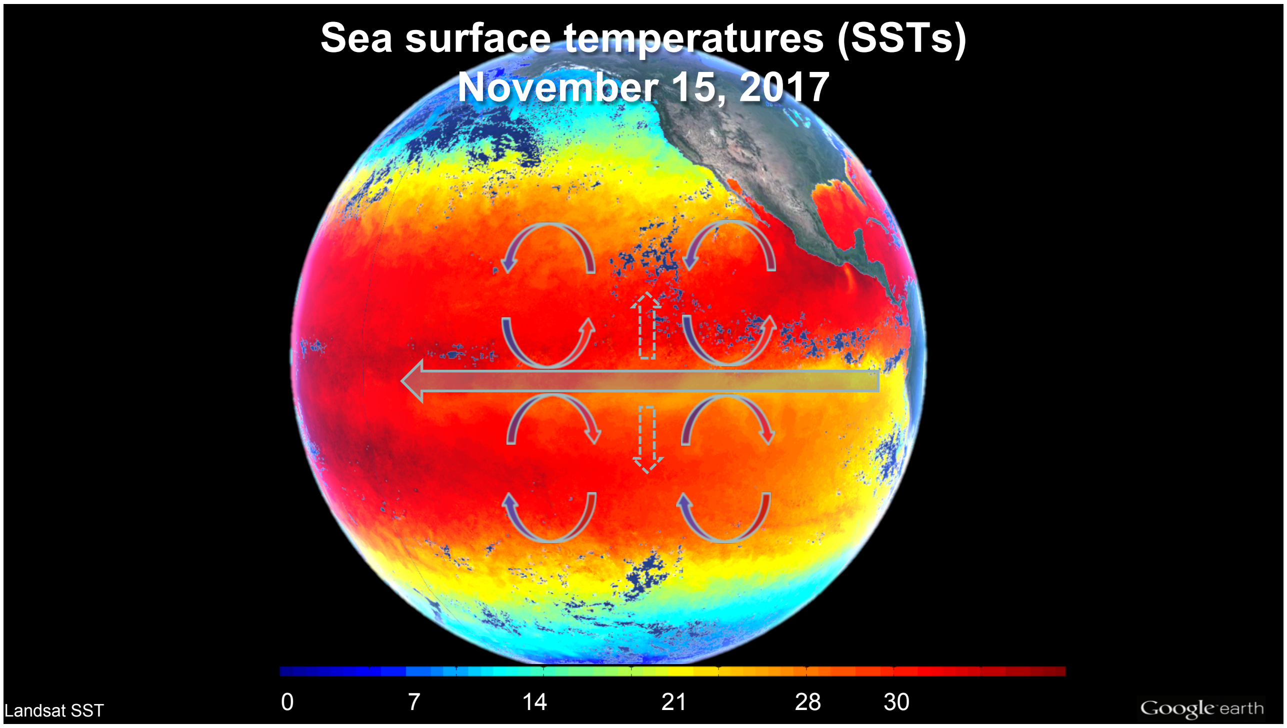
Climate change ≠ ENSO

(e.g., DiNezio et al. 2009, Collins et al. 2010)

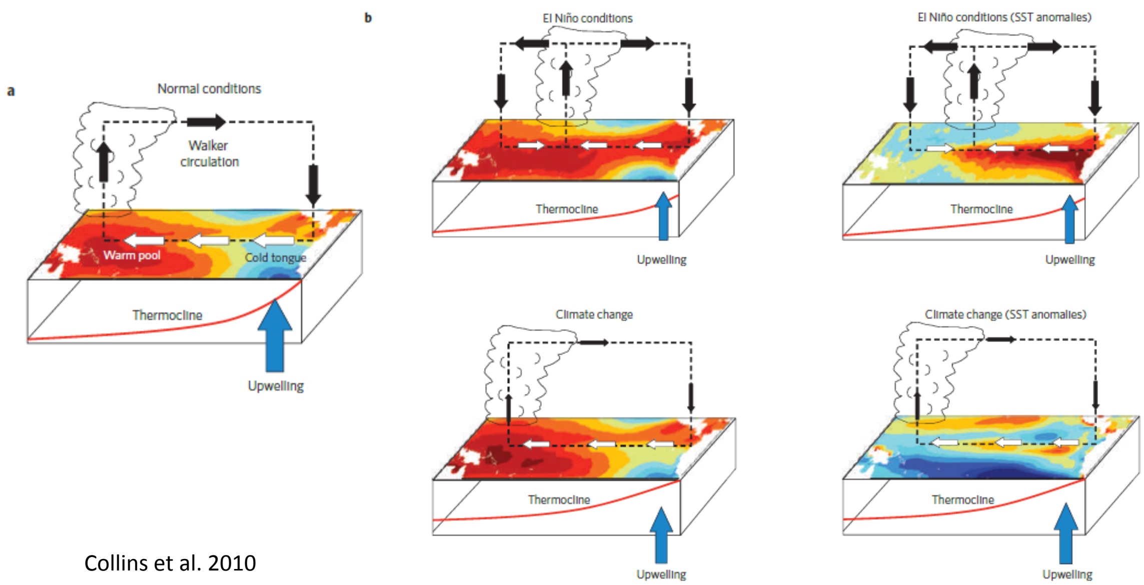
Ocean Thermostat

“La Niña-Like”

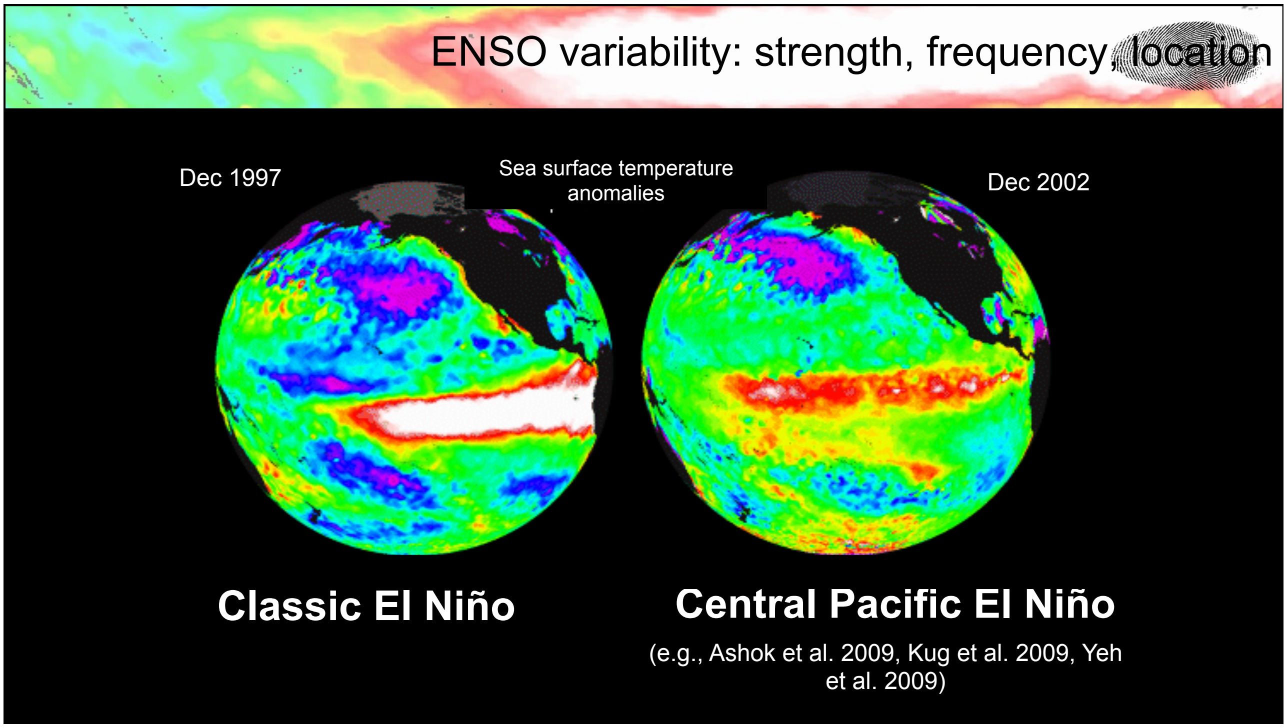
Clement et al. (1996) , Clement et al. (2006)



Climate change vs. ENSO



Collins et al. 2010



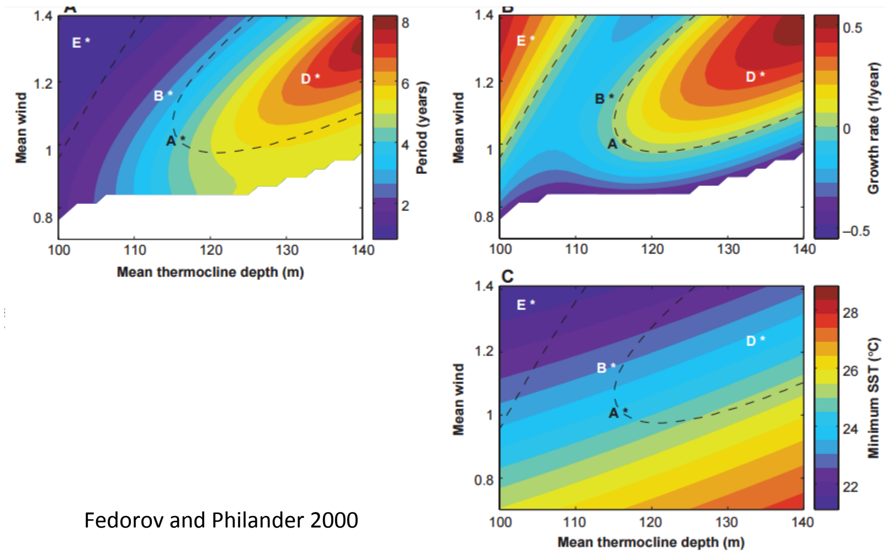
Overarching questions

As our climate system continues to warm, will we see changes to the:

1. ***background state*** of the tropical Pacific?
2. ***frequency*** of ENSO events?
3. ***spatial pattern*** of ENSO events? (last week)
4. ***intensity*** of ENSO events? (last week)

Relationship between ENSO variance and background state

- background zonal wind exceed a certain intensity required to be unstable
- An increase in ΔT, and mean thermocline depth (beyond a certain value) are stabilizing

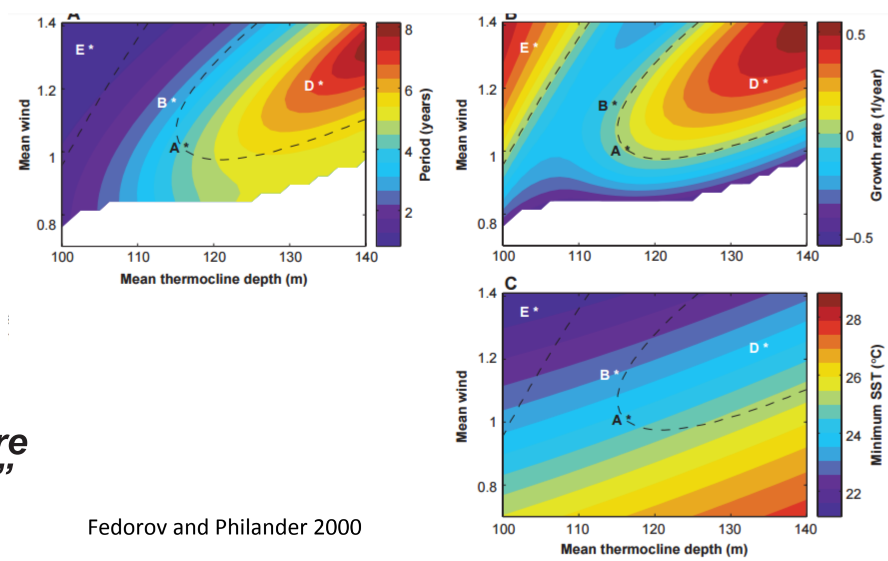


Fedorov and Philander 2000

Relationship between ENSO variance and background state

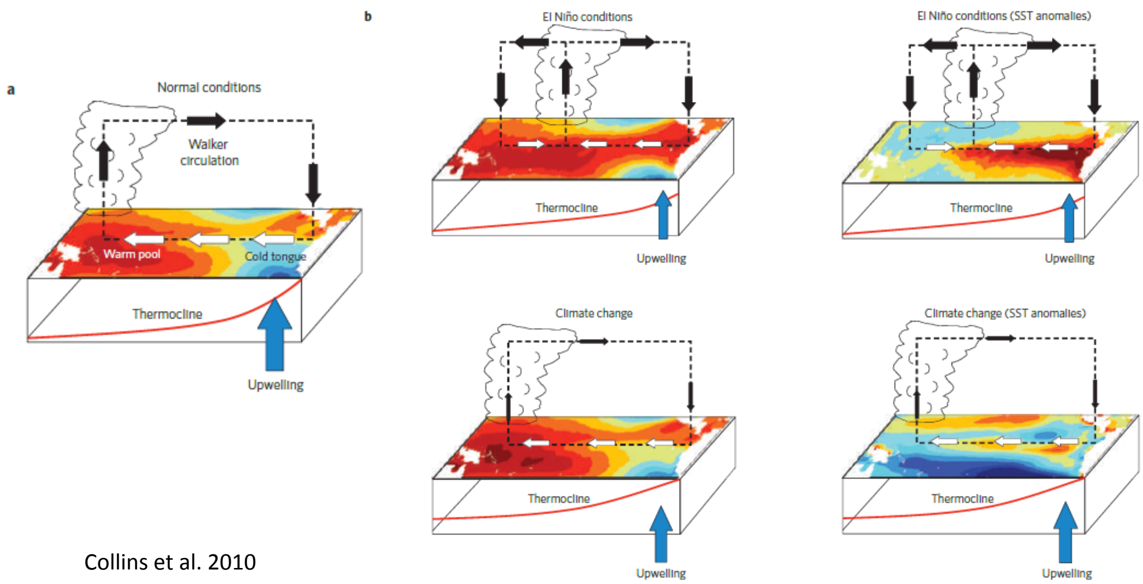
"ENSO tends to ***weaken*** as the zonal-mean ***depth*** of the equatorial ***thermocline increases***…

but ***strengthen*** as the zonal ***thermocline tilt*** or the near-surface vertical ***temperature contrast increase***"



Fedorov and Philander 2000

Climate change vs. ENSO



Collins et al. 2010

Summary of expected response to climate change

1. Weakening of trade winds & walker circulation (why?)
2. Zonally symmetric warming (why?), with maximum warming on the equator (why?)
3. Shoaling and flattening of the thermocline (why?)
4. Amplifying and dampening feedbacks for ENSO may partially cancel each other out: ENSO response remains uncertain

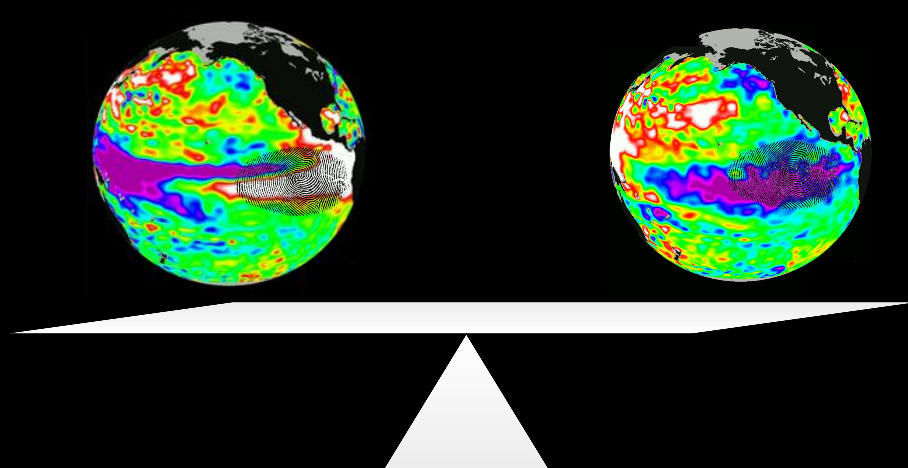
Overarching questions

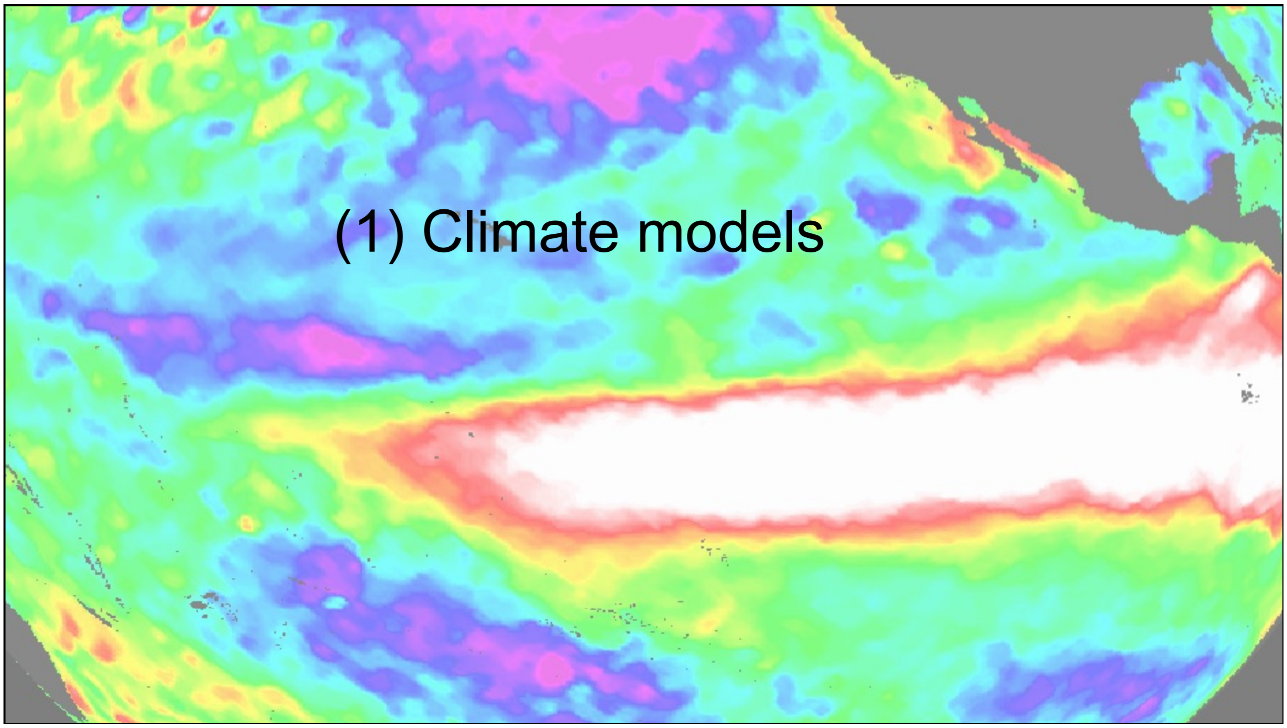
As our climate system continues to warm, will we see changes to the:

1. ***background state*** of the tropical Pacific?
2. ***frequency*** of ENSO events?
3. ***spatial pattern*** of ENSO events? (last week)
4. ***intensity*** of ENSO events? (last week)

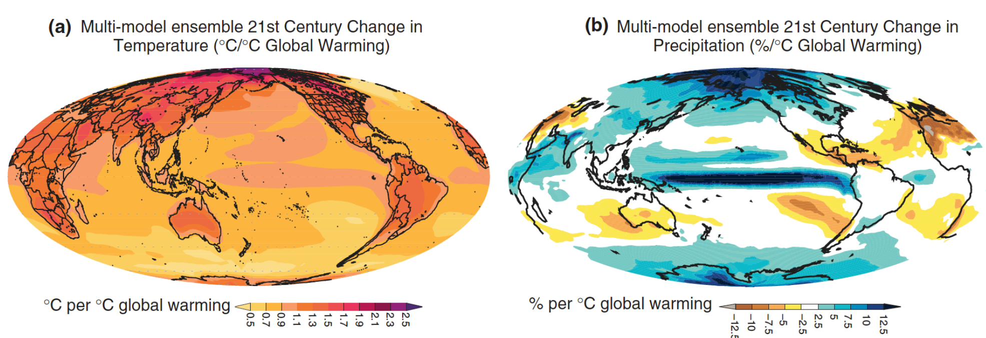
What is the fingerprint of warming in the tropical Pacific?? 

Fingerprint of warming: balance of evidence





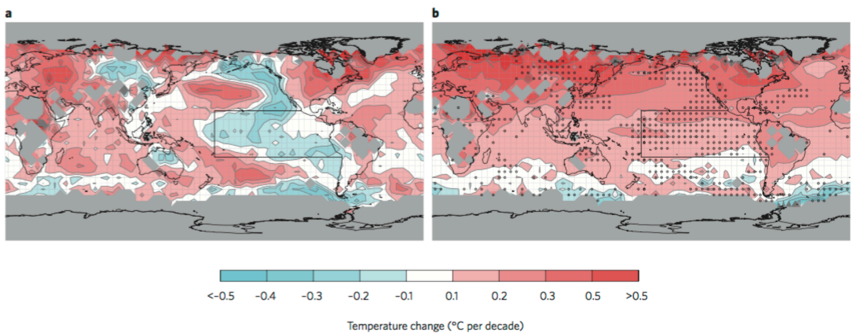
Change in background state?



Vecchi and Wittenberg 2010

Change in background state?

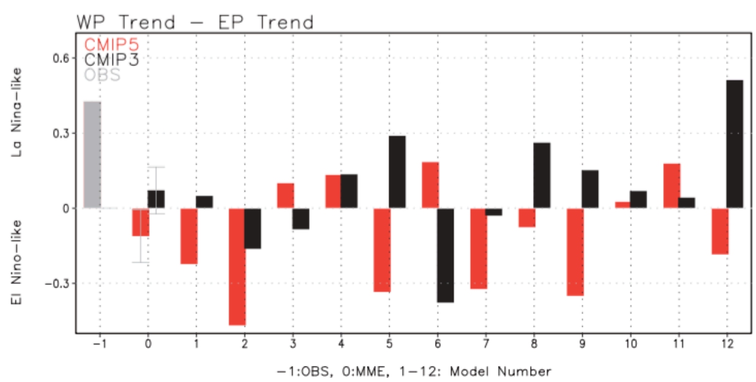
a, Observed trends. **b**, Average simulated trends from 117 simulations of the climate by 37 CMIP5 models



Fyfe and Gillett 2014

Change in background state?

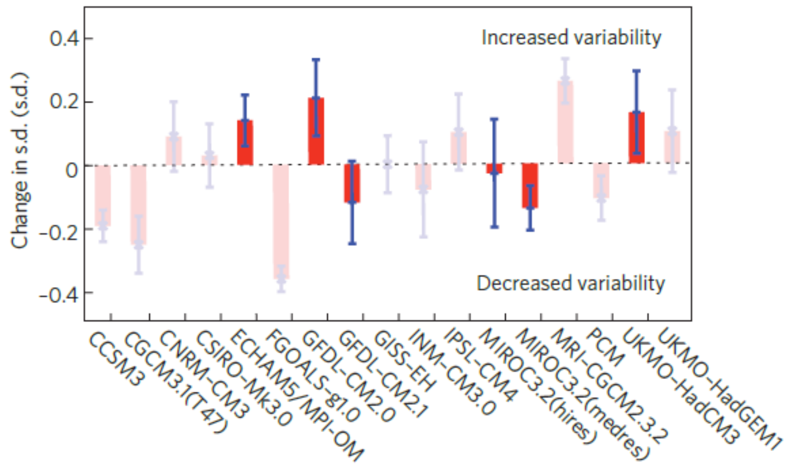
- La Niña–like structure in CMIP3
- El Niño–like structure in CMIP5



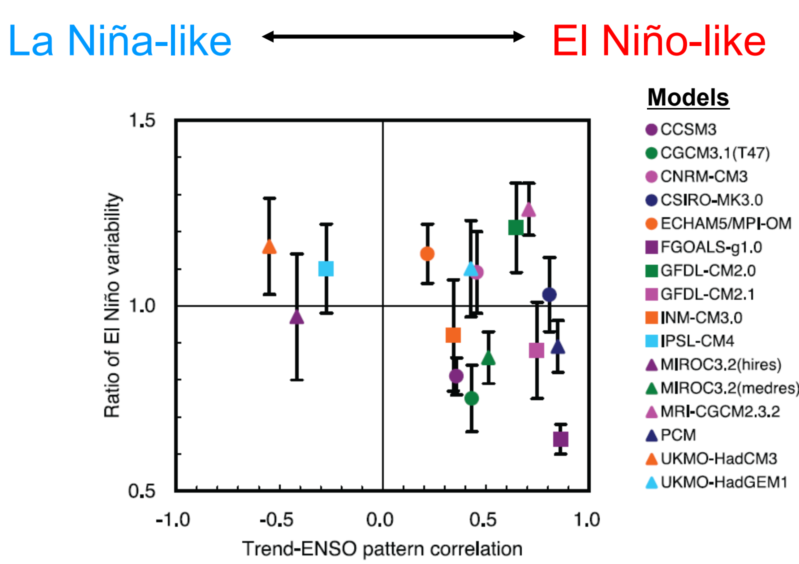
Yeh et al. 2012

Change in ENSO variability?

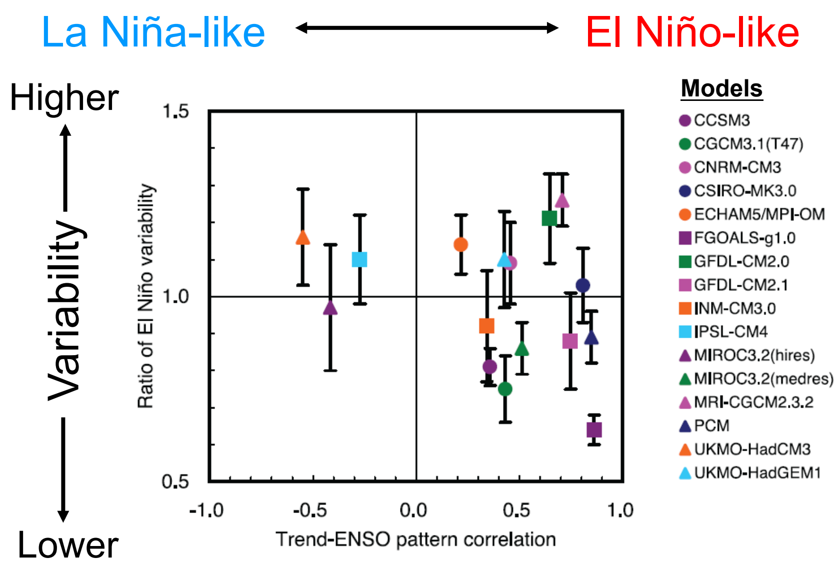
- Bold: models that have the best simulation of present-day ENSO characteristics and feedbacks
- no consistent picture of changes in ENSO amplitude or frequency in the future



Collins et al. 2010



IPCC 2007



IPCC 2007

Impact of warming on ENSO variability?

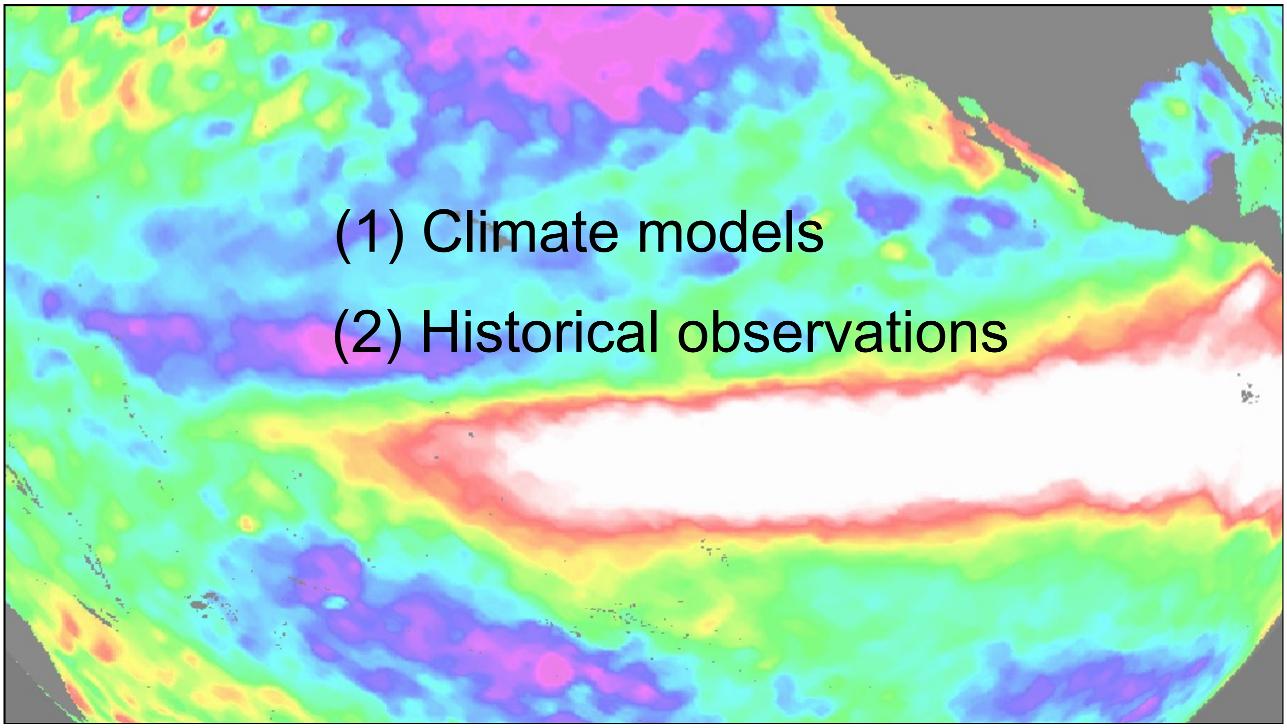
Recall: "ENSO tends to ***weaken*** as the zonal-mean ***depth*** of the equatorial ***thermocline increases***…

but ***strengthen*** as the zonal ***thermocline tilt*** or the near-surface vertical ***temperature contrast increase***"

1. GCMs project both a ***reduced depth*** and a ***reduced zonal tilt*** of the equatorial Pacific thermocline, which have rather opposing impacts on ENSO variability.
2. Because increased greenhouse gases act to warm the ocean from above, GCMs also project ***increased vertical ocean temperature stratification***
3. GCMs project a ***reduced atmospheric sensitivity to SST*** which tends to offset the influence of increased oceanic temperature stratification

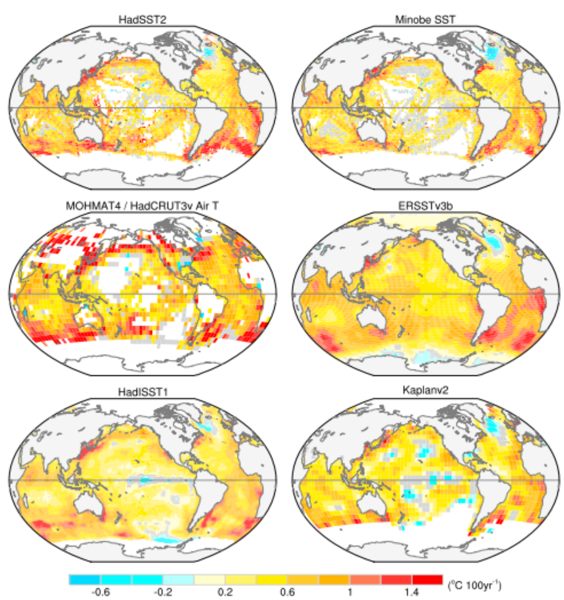
"Thus, the net effect on ENSO is the result of ***numerous large and canceling influences***, making it a challenge to simulate and resulting in ***ambiguous projections for El Niño change*** in climate models."

Vecchi and Wittenberg 2010



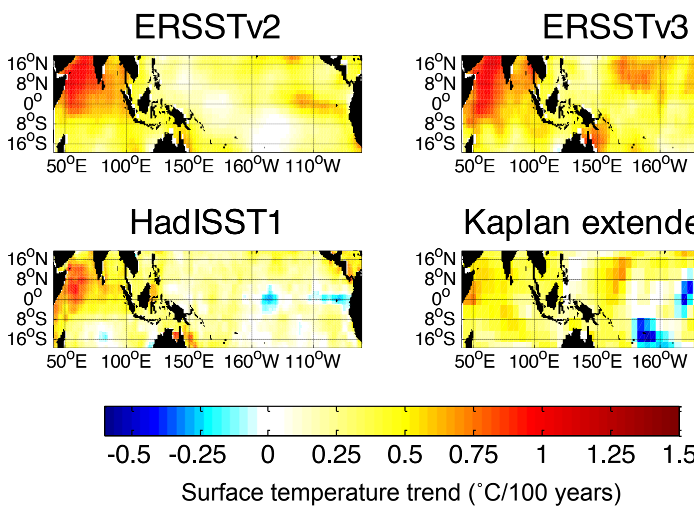
Historical temperature trends (1890-1990)

“Weaker walker” or “ocean thermostat” over the 20th century??

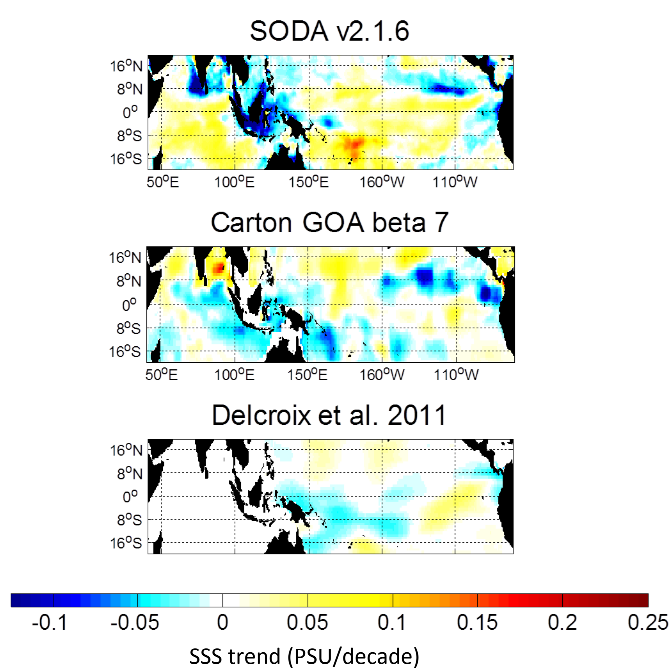


Deser et al. 2010

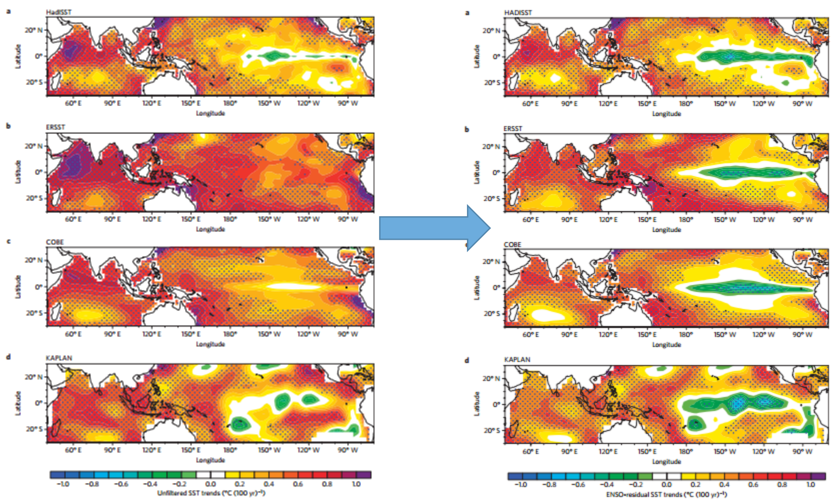
Historical temperature trends (1890-1990)



Historical salinity trends (1958-2001)



Effect of ENSO on trends

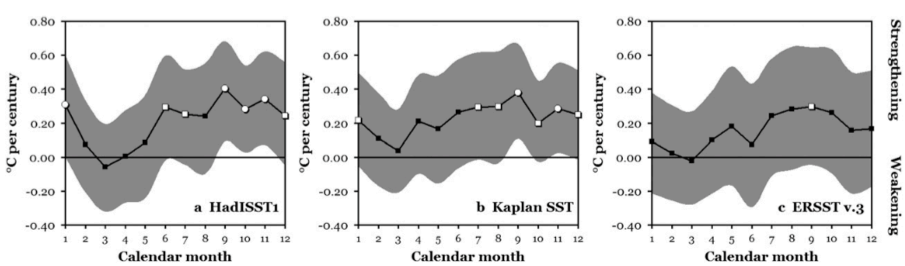


- remove space- and time varying ENSO anomalies from the ocean temperature data record
- uncertainty In SST trends can be explained by disparate estimates of ENSO variability
- removing this variability results in consistent trends

Solomon and Newman 2012

Effect of seasonality

- all agree that the equatorial Pacific zonal SST gradient has strengthened from 1880 to 2005 during the boreal fall when this gradient is normally strongest
- Support of ocean thermostat hypothesis during season of strongest upwelling



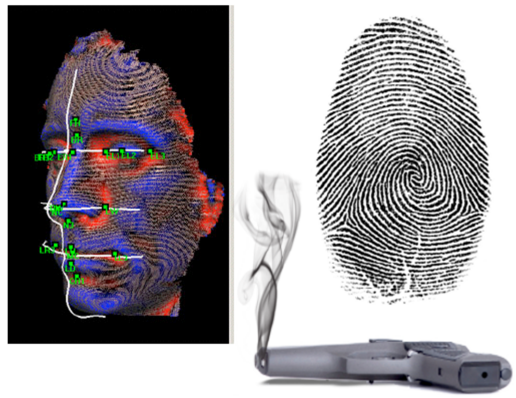
Karnauskus et al. 2009

8. Detection & Attribution

Detection

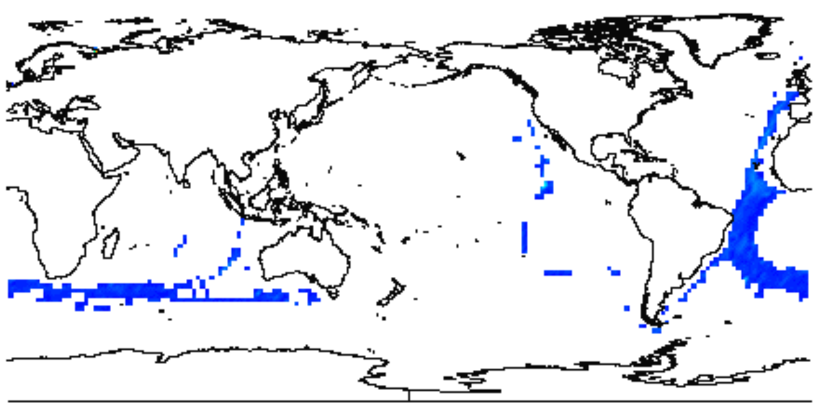
"What happened?"

Attribution



"Who did it?"

Detection and attribution challenges



1854

Changes in ENSO variability??

1. Amplitude?

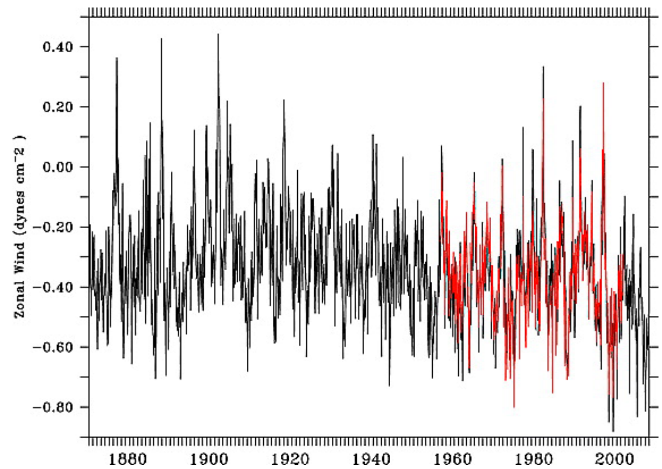
2. Spatial pattern?

3. Frequency?

Using new ***ocean reanalysis*** data product: Simple Ocean Data Assimilation (SODA)

Advantages & disadvantages of using reanalysis for this question?

Giese and Ray 2011; Ray and Giese 2012

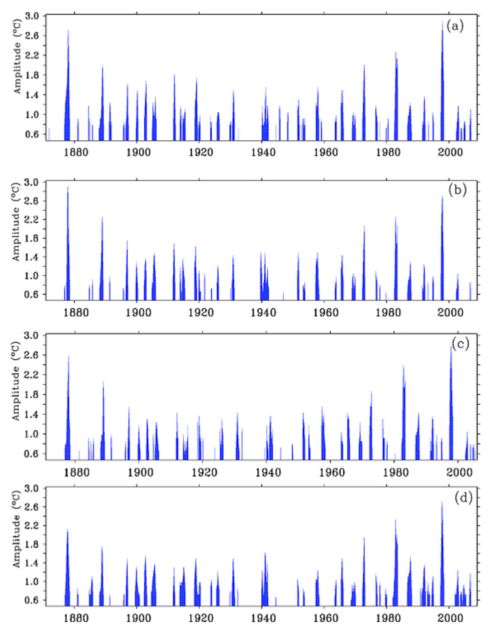


Zonal wind stress in dyn cm−2 in the Nino 4 (160°E–150°W and 5°S–5°N) region for the 20CRv2 (black line) and for ERA-40 (red line).

Changes in ENSO variability??

1. Amplitude?

SST anomalies greater than 0.5°C constructed from (a) SODA 2.2.4, (b) ERSST v3, (c) HadISST, and (d) Kaplan v2.

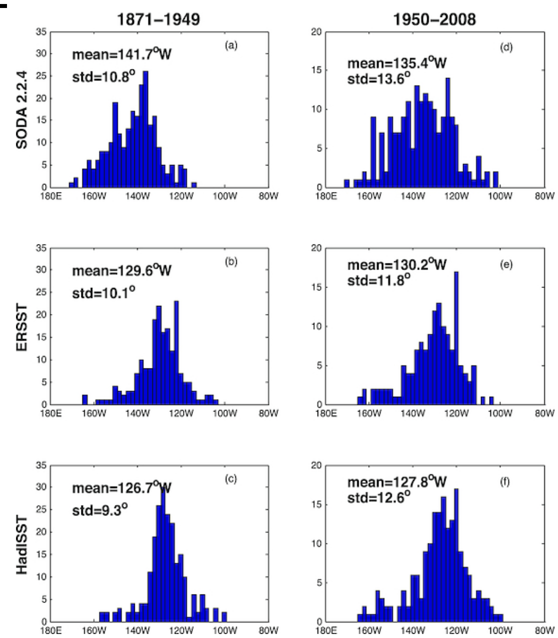


Ray and Giese 2012

Changes in ENSO variability??

2. Spatial pattern?

Histograms El Niño event longitude shown separately for (a, b, c) 1871–1949 and for (d, e, f) 1950–2005 periods as constructed from SODA 2.2.4, ERSST, and HadISST. The distribution of location of El Niño events is shown in each plot with the mean location.

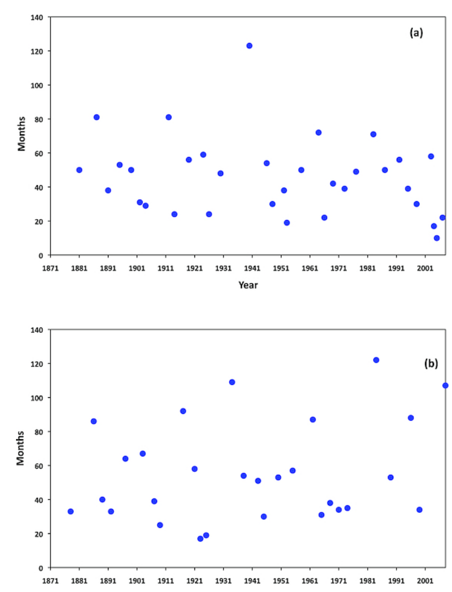


Ray and Giese 2012

Changes in ENSO variability??

3. Frequency?

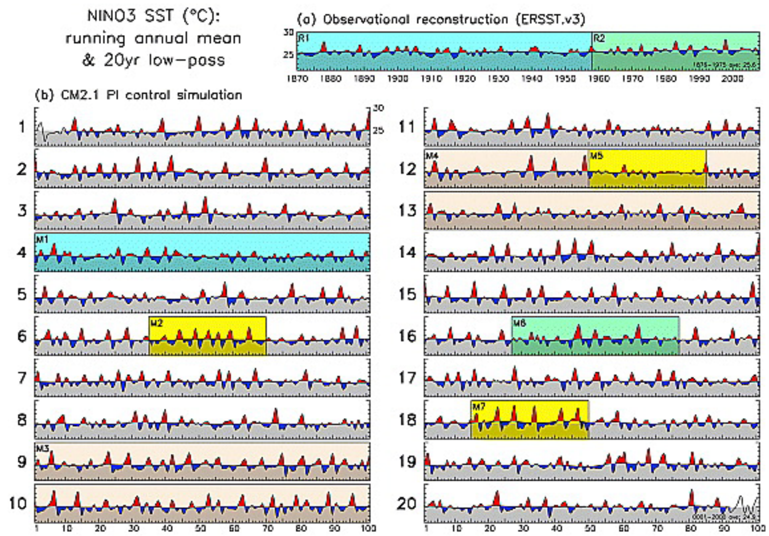
Number of months since the preceeding (a) El Niño and (b) La Niña events over the period 1871–2008.



Ray and Giese 2012

Detection and attribution challenges

- ENSO strength and frequency changes in the absence of forcing
- detection and attribution of ENSO changes over the short historical record a huge challenge



Wittenberg et al. 2009