Global decadal climate variability and the Interdecadal Pacific Oscillation (IPO)

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Biological and Energy Research

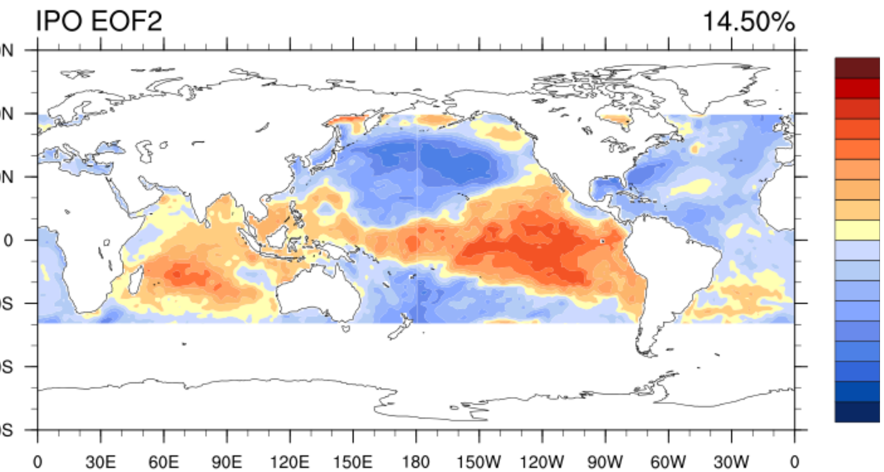
Regional and Global Climate Modeling Program

NCAR

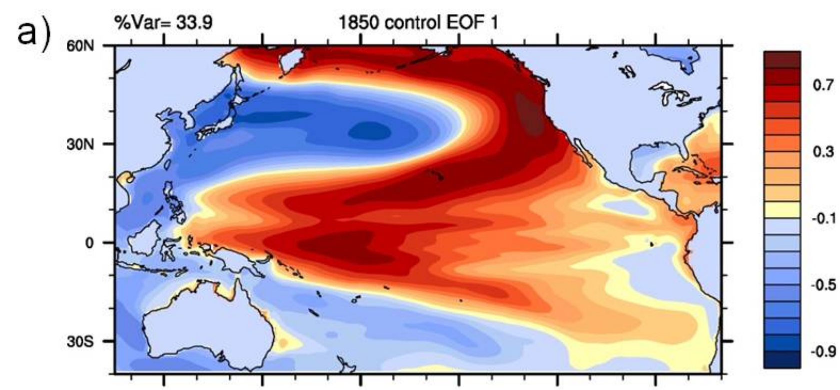
Following Zhang, Wallace and Battisti (1997, J. Climate) the **Interdecadal Pacific Oscillation** (IPO, Power et al., 1999) defined for entire Pacific; the Pacific Decadal Oscillation PDO (Mantua et al 1997, BAMS) is defined for the North Pacific but patterns are comparable

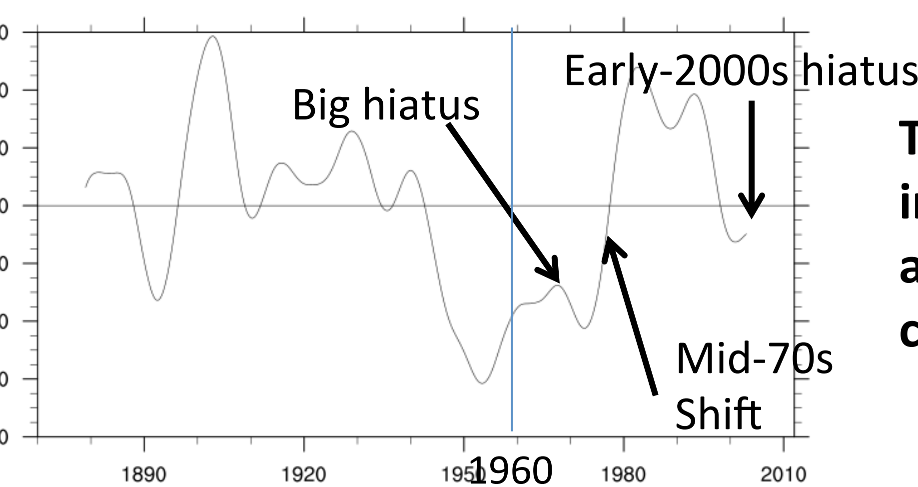
Climate model simulations indicate IPO is internally generated

Observations



Unforced model control run (CCSM4)





The observed IPO pattern resembles internally-generated decadal pattern from an unforced model control run (pattern correlation= +0.63)

(Meehl et al., 2009, J. Climate; Meehl and Arblaster, 2011, J. Climate)

Some CMIP5 uninitialized models actually simulated the hiatus

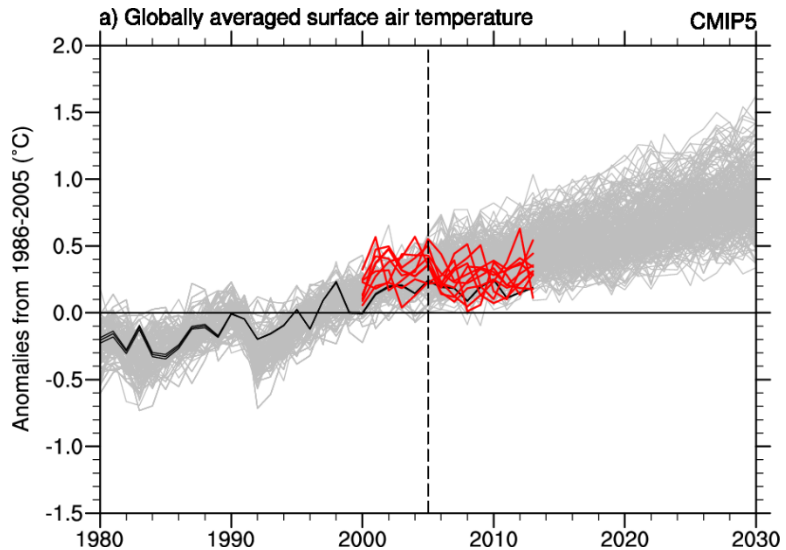
Tend to be characterized by a **negative phase of the IPO**

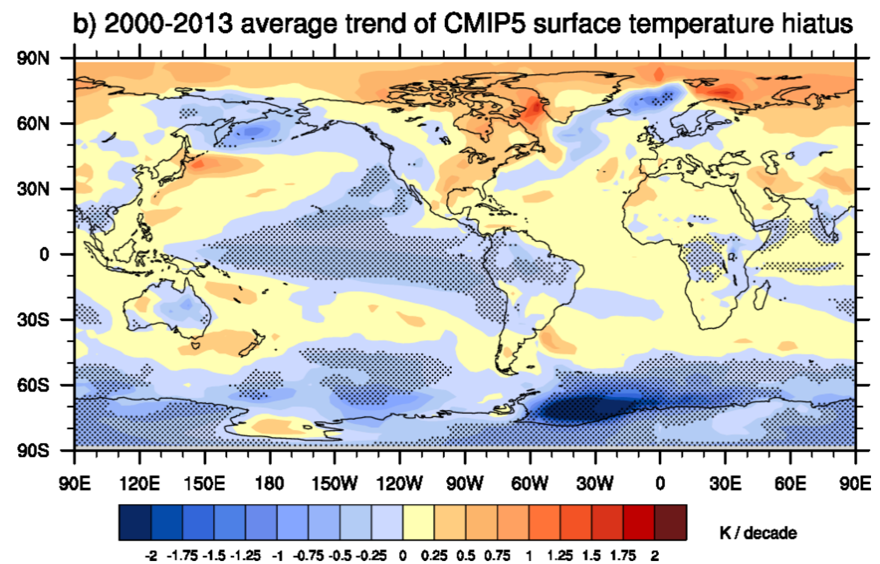
internally generated variability in those model simulations happened to sync with observed internally generated variability

Total: 262 possible simulations
2000-2012 hiatus: 21
2000-2014 hiatus: 9
2000-2015 hiatus: 6
2000-2016 hiatus: 6
2000-2017 hiatus: 1
2000-2018: 1

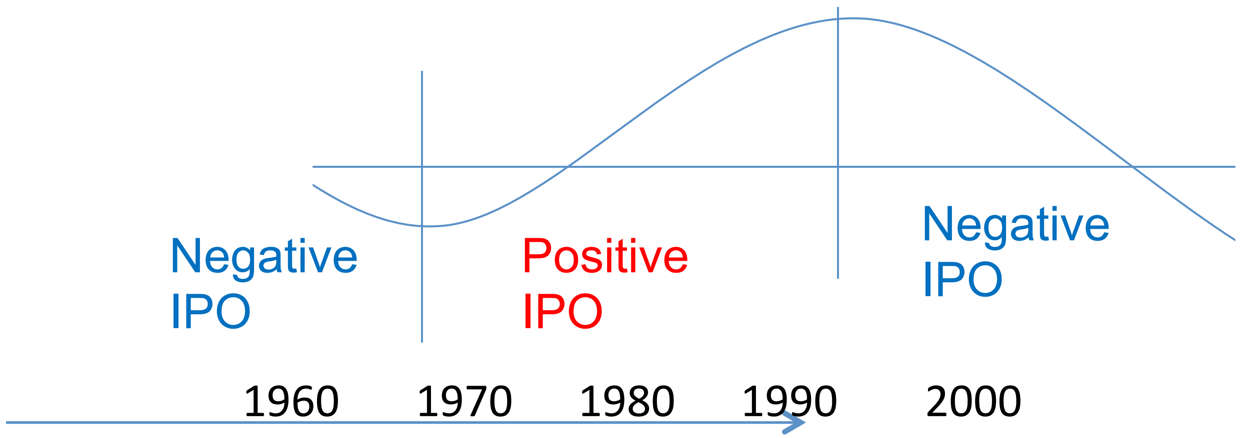
(Meehl et al., 2014, Nature Climate Change)

Hiatus as observed from 2000-2013:
10 members out of 262 possible realizations





How can we quantify prediction skill with very few samples?



There are few samples of observed initial base states for Pacific

In comparing a prediction to a previous climate state, there could be several outcomes

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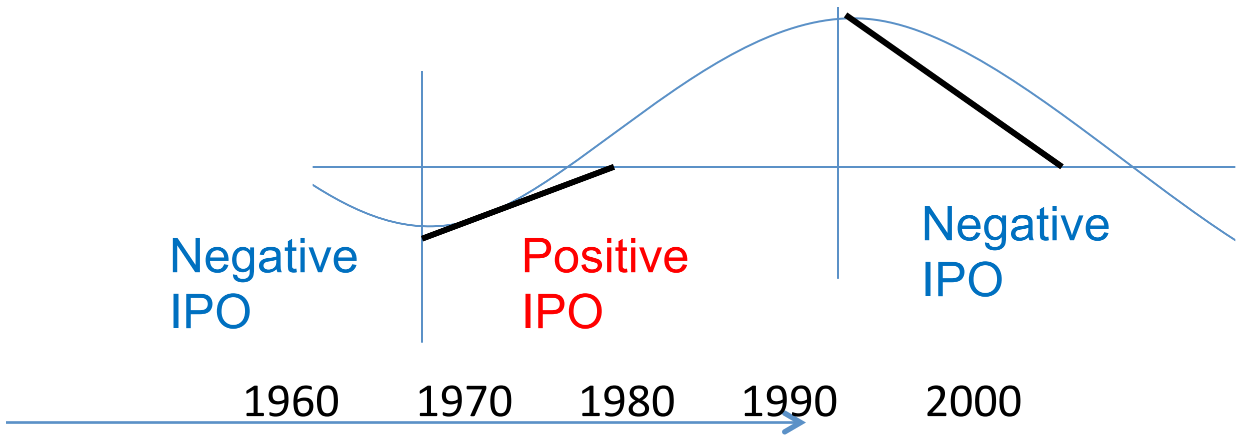

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In comparing a prediction to a previous climate state, there could be several outcomes:

1. The initialized model tries to return to its climo, thus giving the impression of an IPO transition and apparent skill

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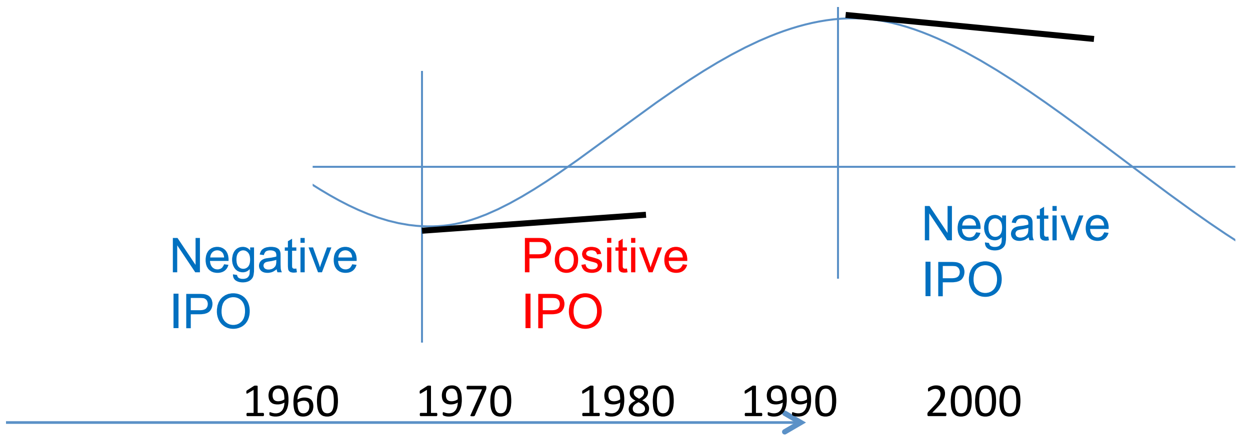

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2. The initialized heat content anomalies in the ocean persist and don't evolve, thus giving the impression of no skill

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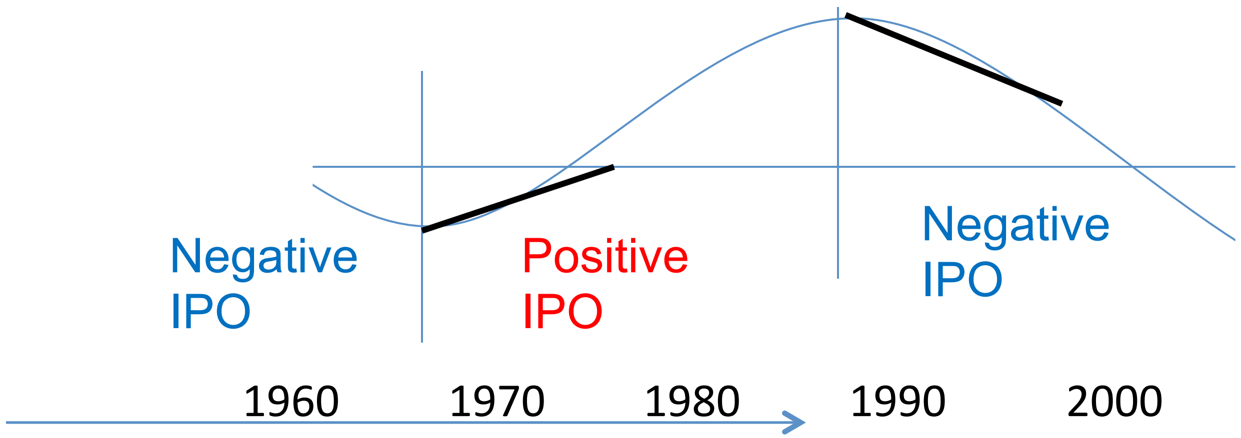

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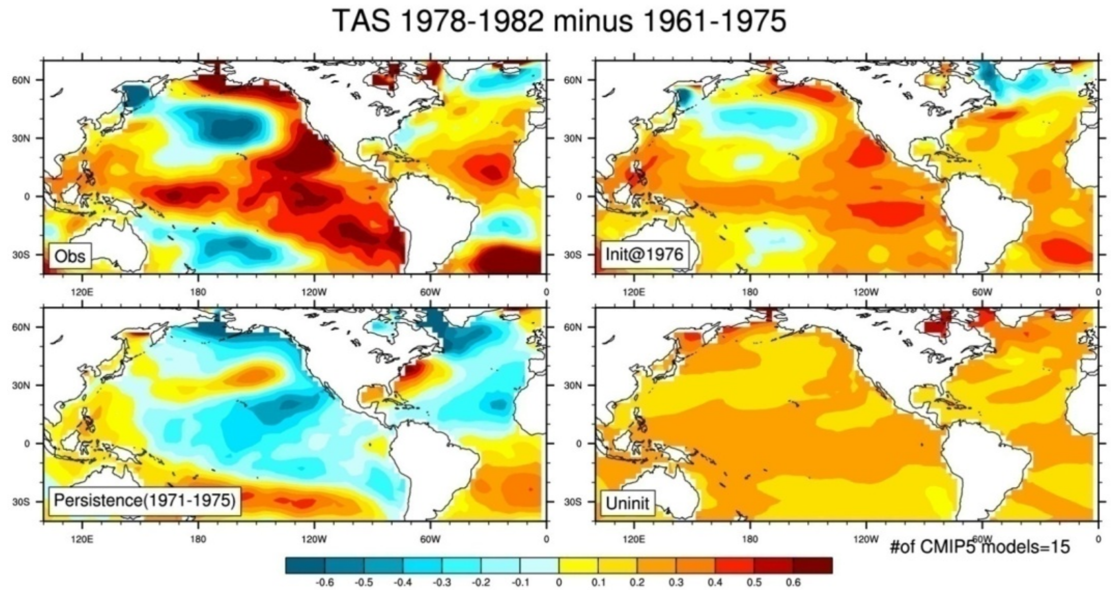
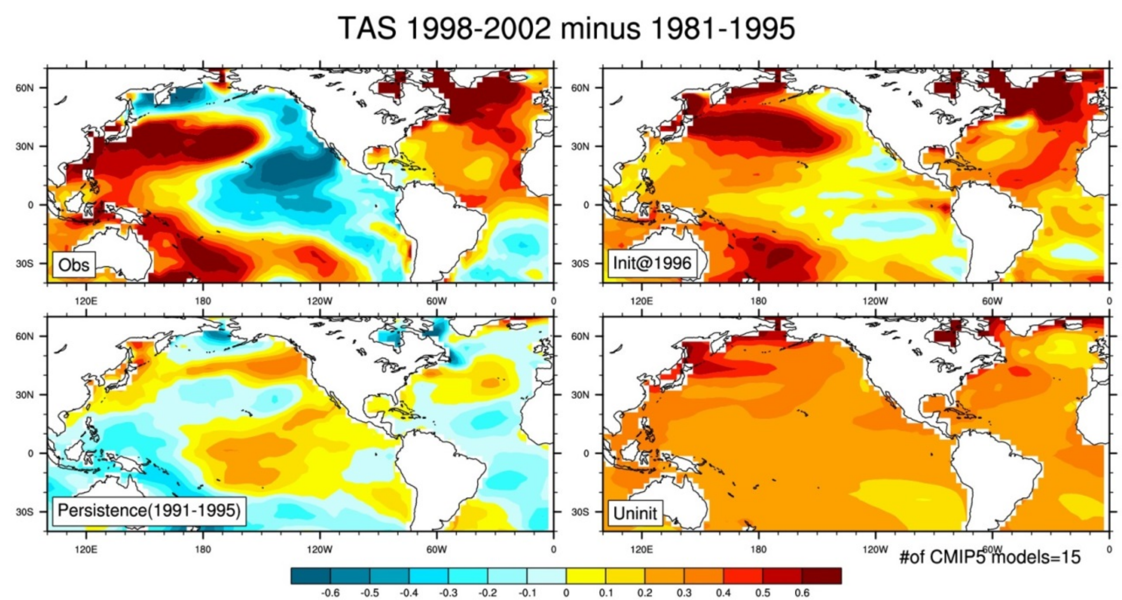
In comparing a prediction to a previous climate state, there could be several outcomes:

1. The initialized model tries to return to its climo, thus giving the impression of an IPO transition and apparent skill
2. The initialized heat content anomalies in the ocean persist and don't evolve, thus giving the impression of no skill
3. The system actually does simulate the internally generated processes, giving actual skill

Year 3-7 average predictions for the mid-1970s climate shift (to positive IPO) from 15 CMIP5 models



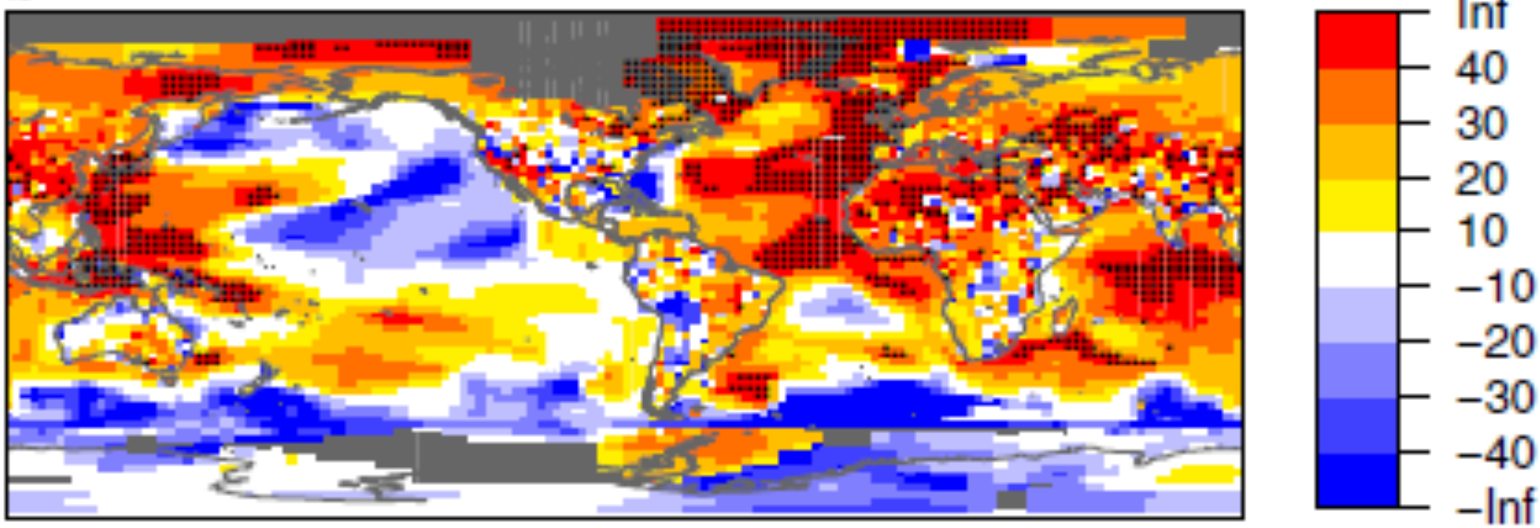
Year 3-7 average predictions for the early-2000s hiatus (to negative IPO) from 15 CMIP5 models

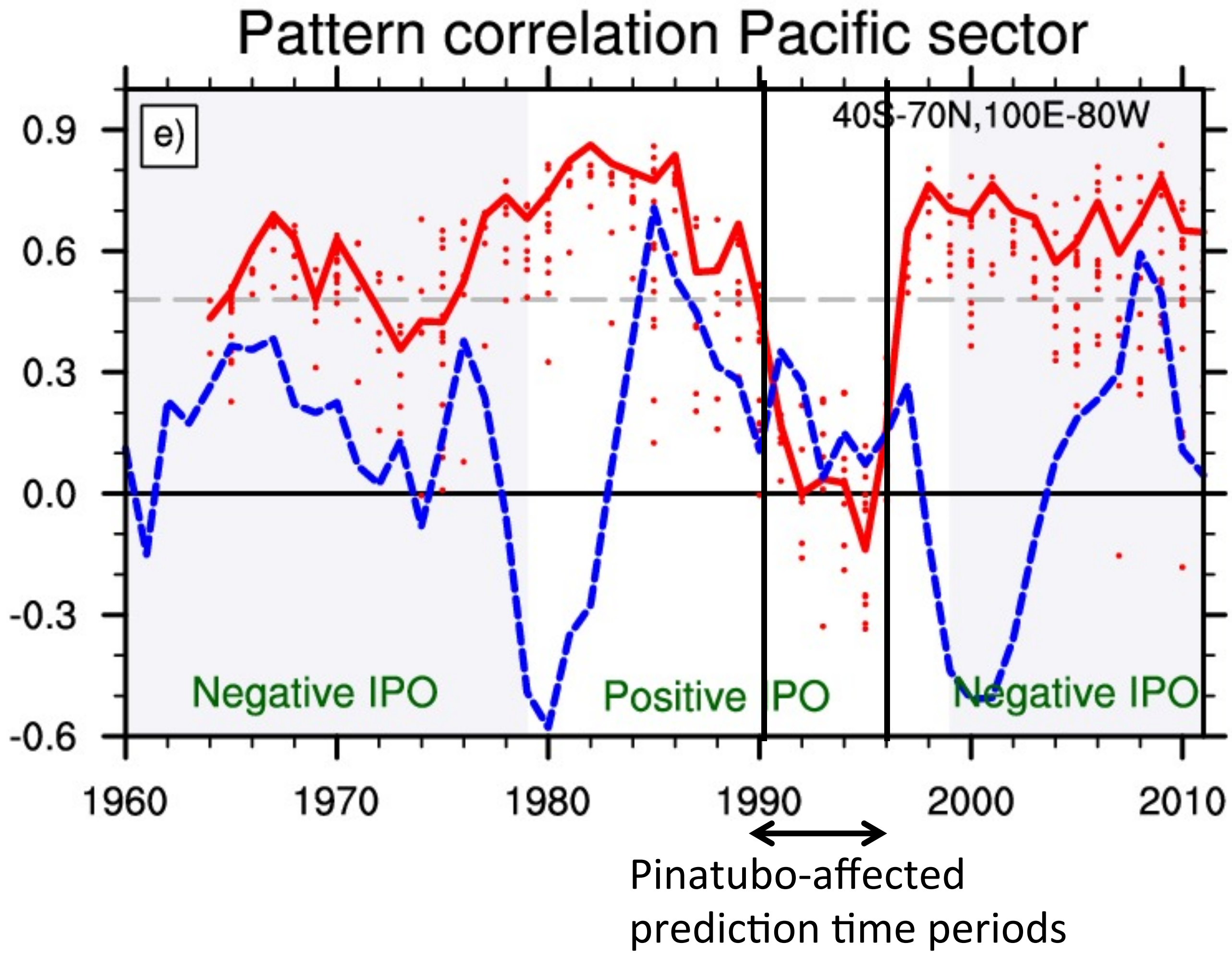


Doblas-Reyes et al., 2013

Years 6-9

b





Mt. Pinatubo year of eruption: 1991
First year after eruption: **1992**
Third year after eruption: **1994**
3-7 year predictions affected by climate effects following Mt. Pinatubo eruption:
1988-**1992** (central year *1990*, ***first prediction period below statistically significant IPO skill***)
1994-1998 (central year *1996*, ***last prediction period below statistically significant IPO skill***)

(Meehl et al., 2014, Nature Climate Change)

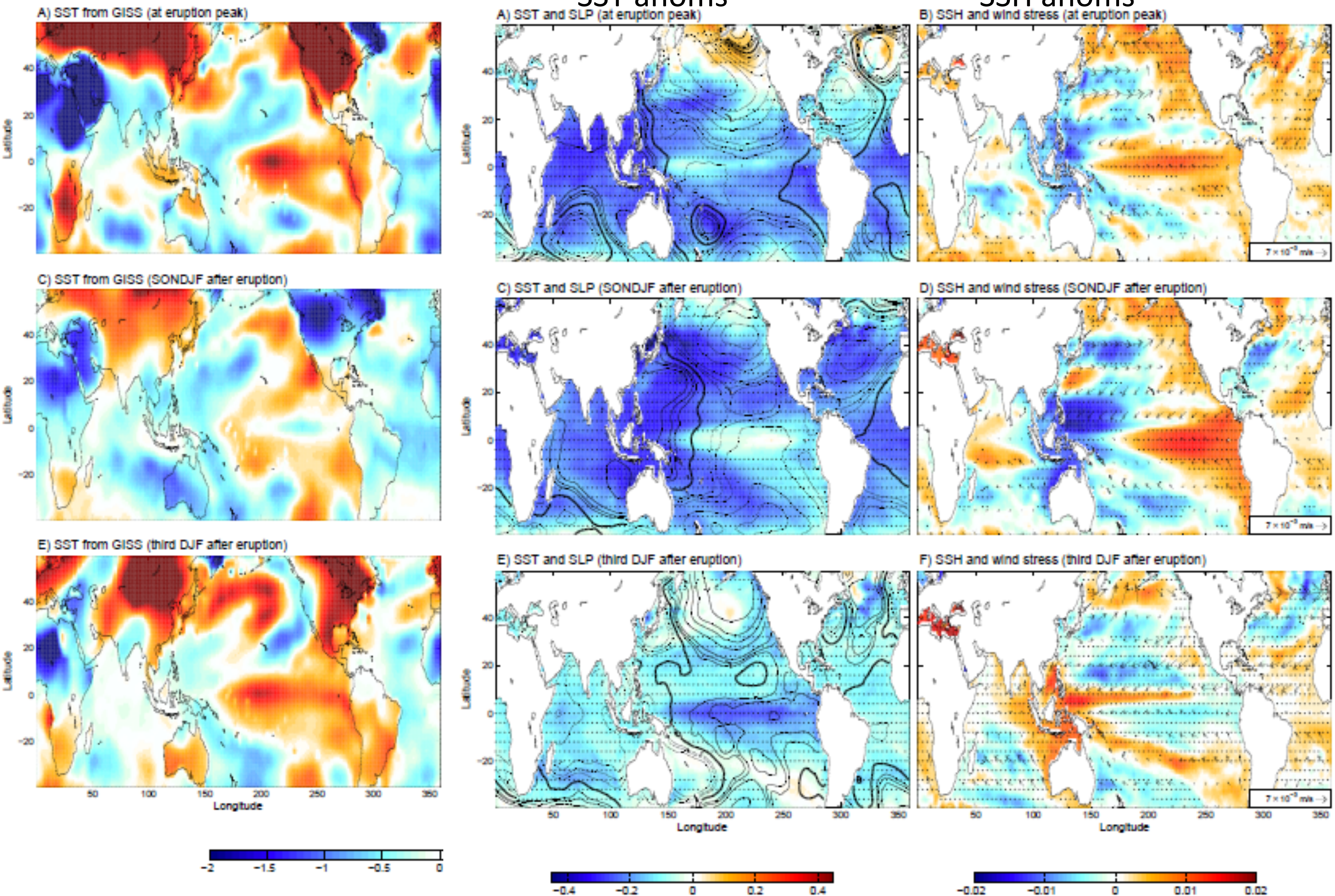
Anomalies relative to the five year average before eruption
(Maher et al., 2015, GRL, under review)

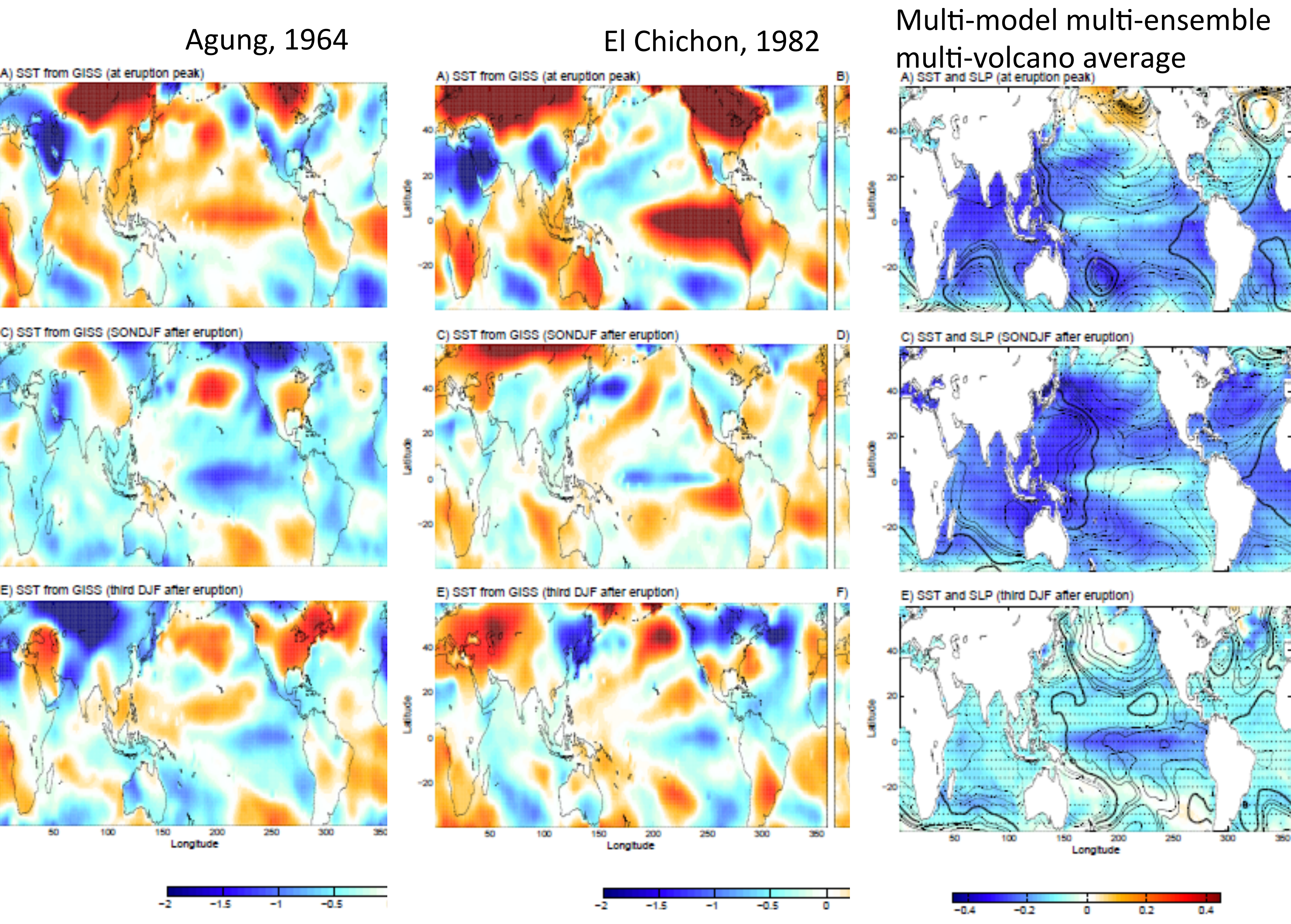
Pinatubo, 1991

Multi-model multi-ensemble multi-volcano average

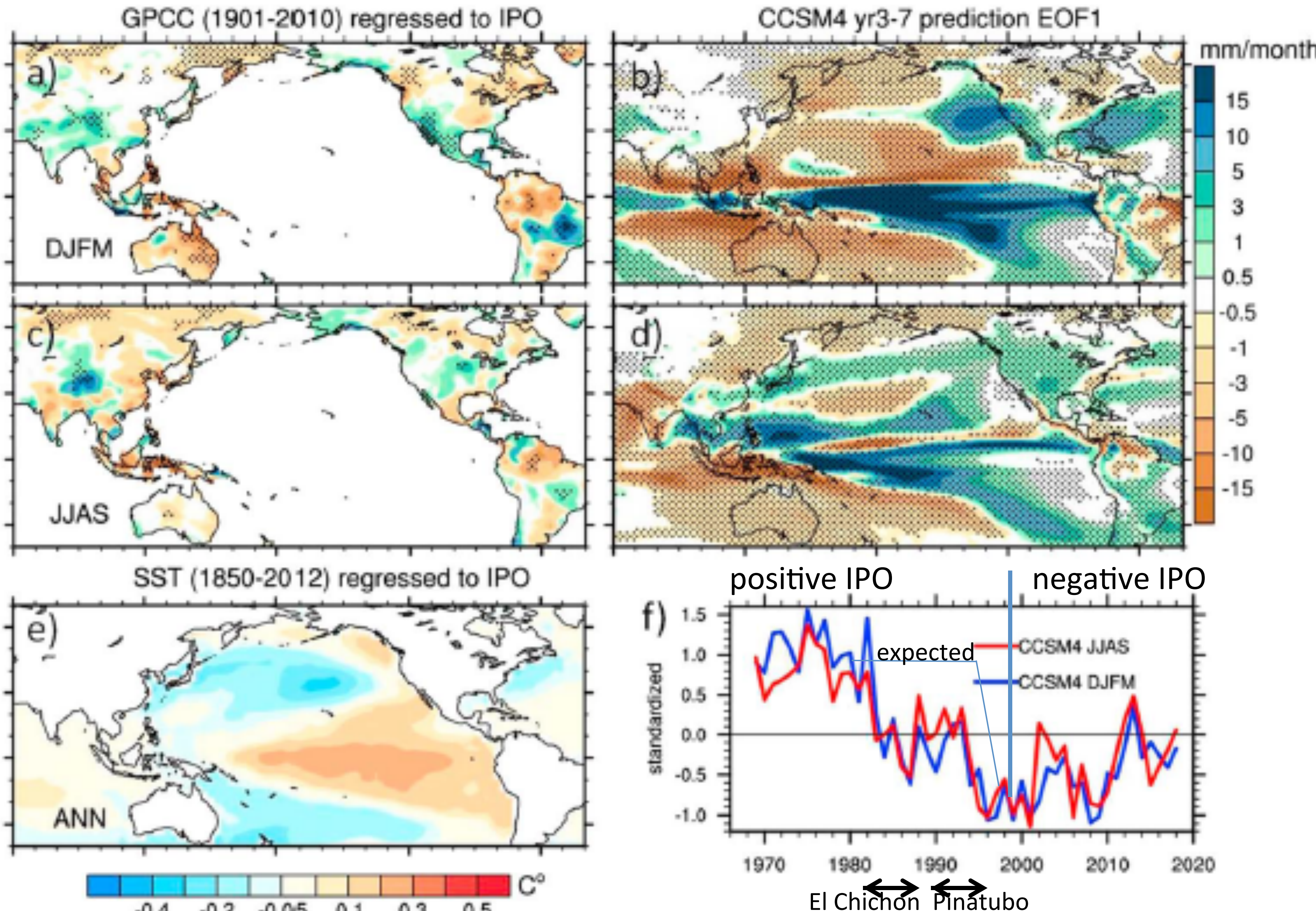
SST anoms

SSH anoms





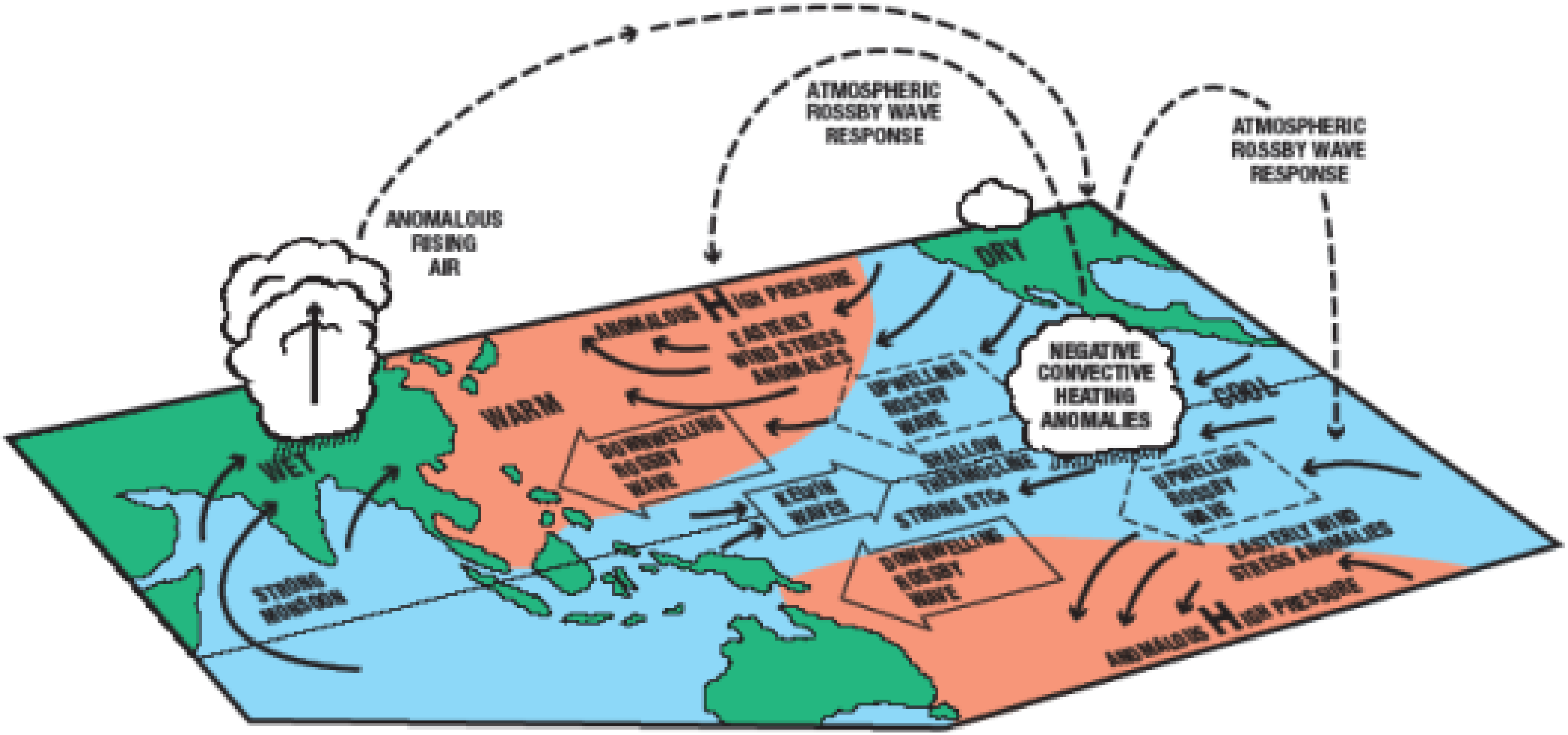
Agung, 1964
El Chichon, 1982
Multi-model multi-ensemble
multi-volcano average
A) SST from GISS (at eruption peak)
C) SST from GISS (SONDJF after eruption)
E) SST from GISS (third DJF after eruption)
A) SST and SLP (at eruption peak)
C) SST and SLP (SONDJF after eruption)
E) SST and SLP (third DJF after eruption)
Latitude
Longitude



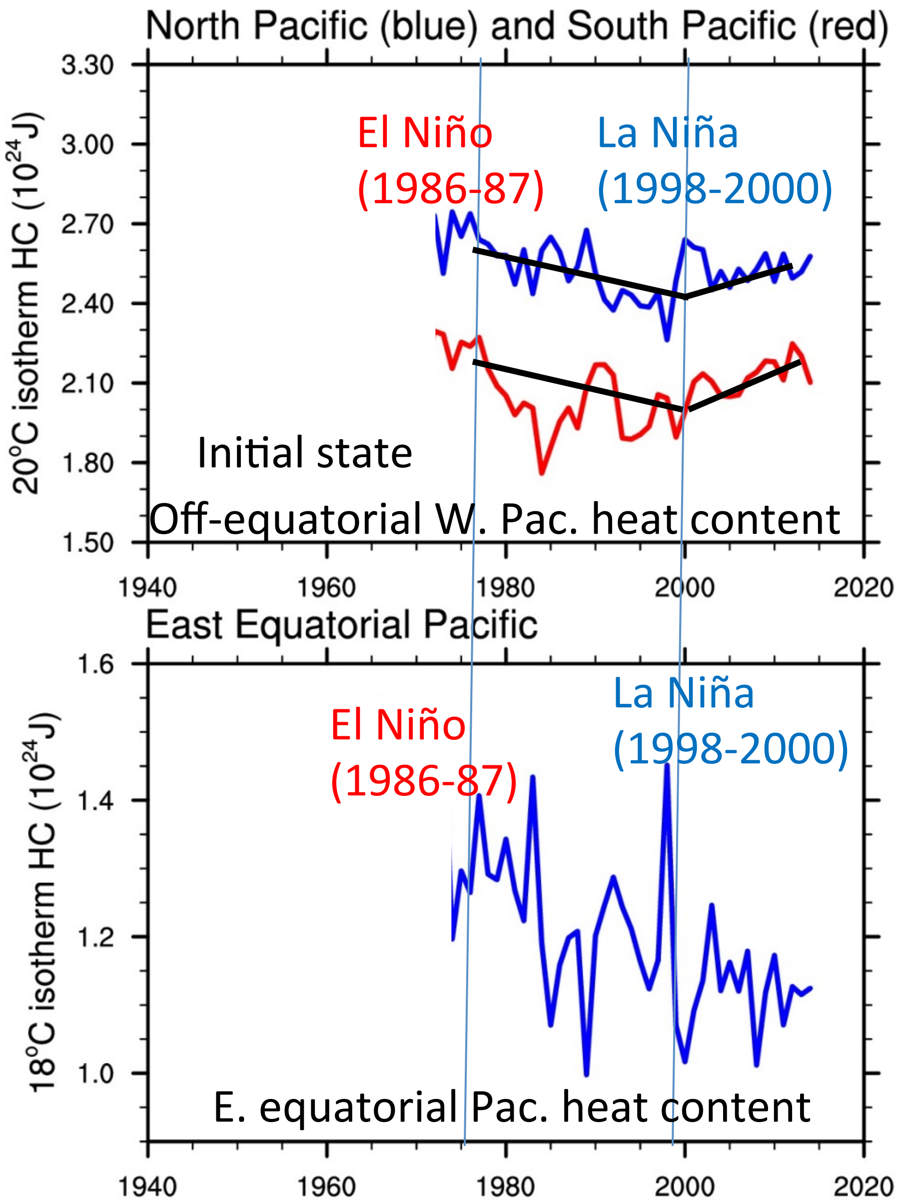
Use model EOFs (no observations) for hindcast verification

(Meehl and Teng, 2014, GRL)

What is the mechanism for the IPO?



It could involve coupled air-sea tropical-midlatitude processes as proposed by Meehl and Hu, 2006, J. Clim. (above) or related variants (e.g. White et al., 2003, JGR; McGregor et al., 2007, 2008, J. Climate)
--or– chaotic amplitude modulation of ENSO (e.g. Jin, 2001, J. Climate)
--or—driven by decadal variability from the Atlantic (e.g. McGregor et al., 2014)



North Pacific (5N-30N,125E-180E)
South Pacific (30S-5S,150E-160W)
East Equatorial Pacific (5S-5N,160W-80W)

Build-up of large magnitude western tropical Pacific off-equatorial heat content; El Niño (1986-87) associated with transition to positive IPO and decreasing trend of W. Pac. heat content

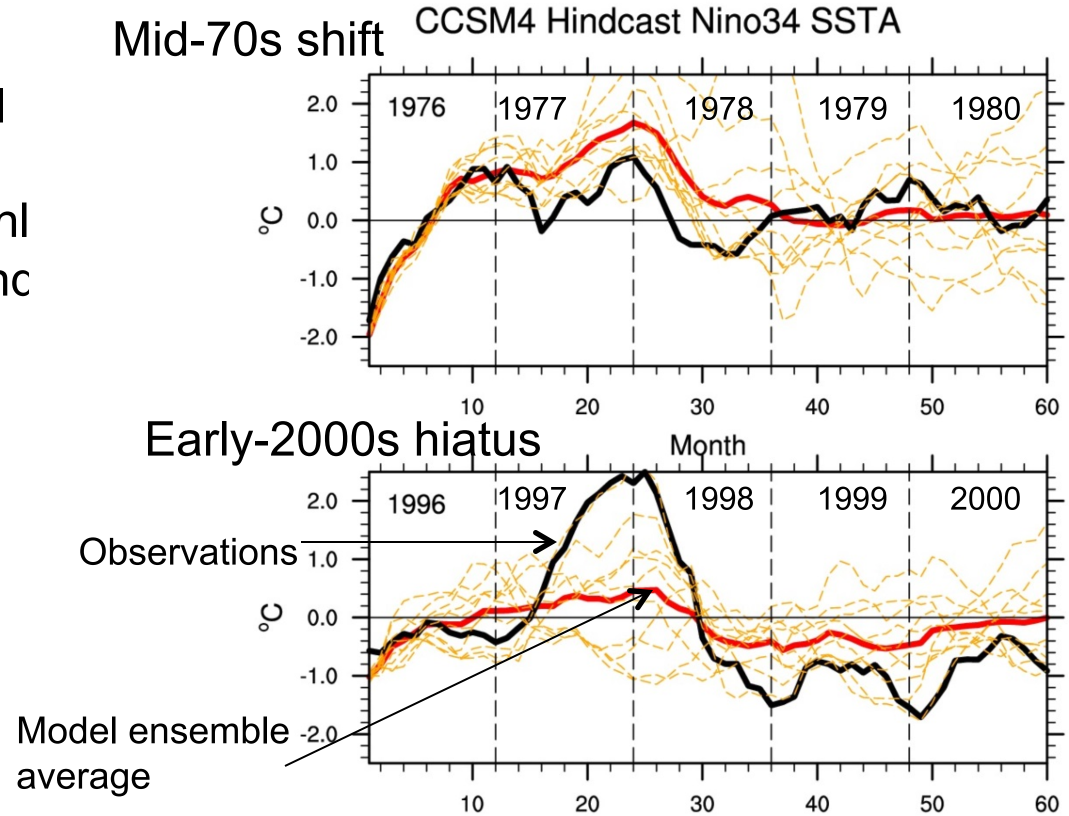
Build-up of low magnitude western tropical Pacific off-equatorial heat content; La Niña (1998-2000) associated with transition to negative IPO and increasing trend of W. Pac. heat content

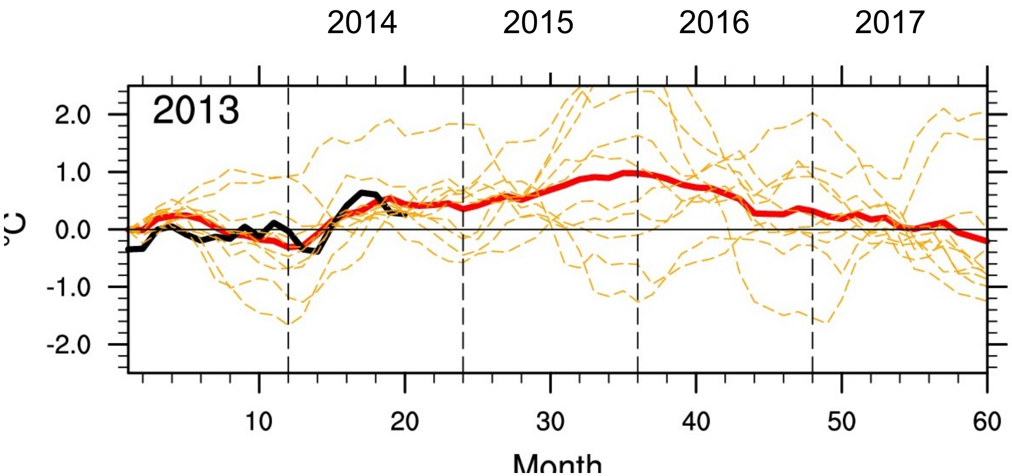
Speculation that ENSO interannual variability played a role in the late-1990s IPO transition (e.g. Meehl and Teng, 2012, 2014; Trenberth anc Fasullo, 2013)

Could ENSO trigger an IPO transition? (like MJO westerly wind bursts can sometimes help trigger an El Niño event):

Can an interannual timescale event trigger a change in the decadal base state?

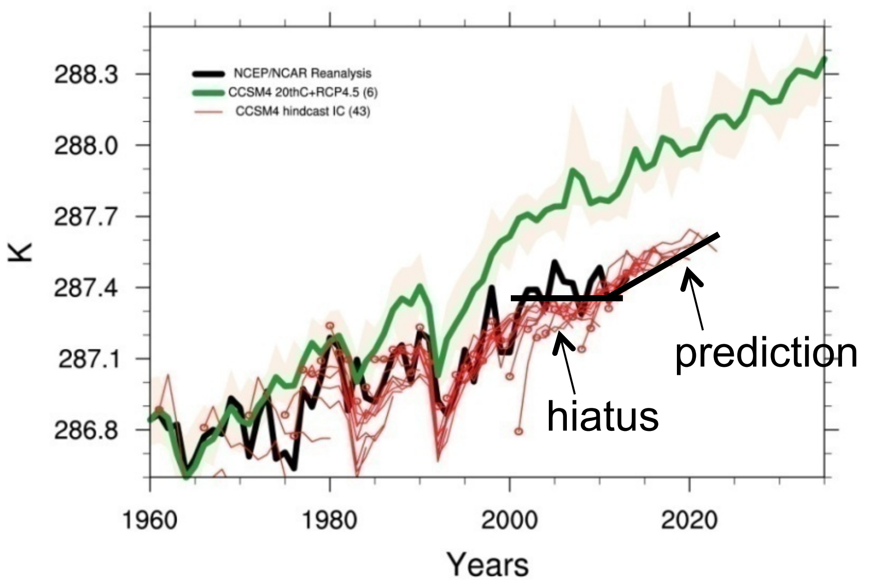
We have the monthly data from CCSM4 to see how it performed in predicting interannual ENSO variability for mid-1970s shift and early-2000s hiatus





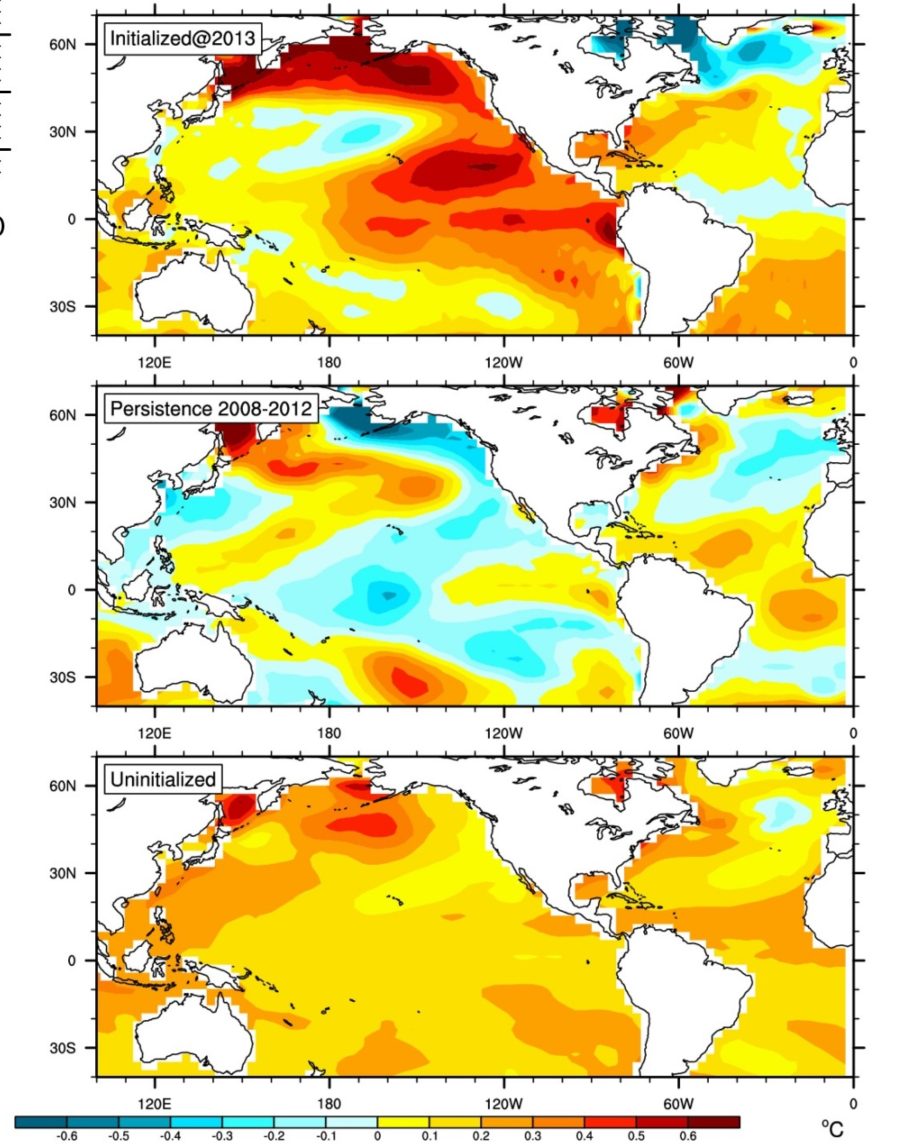
A climate model (CCSM4) initialized with observations in 2013 predicts a weak El Niño in 2014 and transition to the positive phase of the IPO with greater global warming

Global Annual Mean Surface Air Temperature



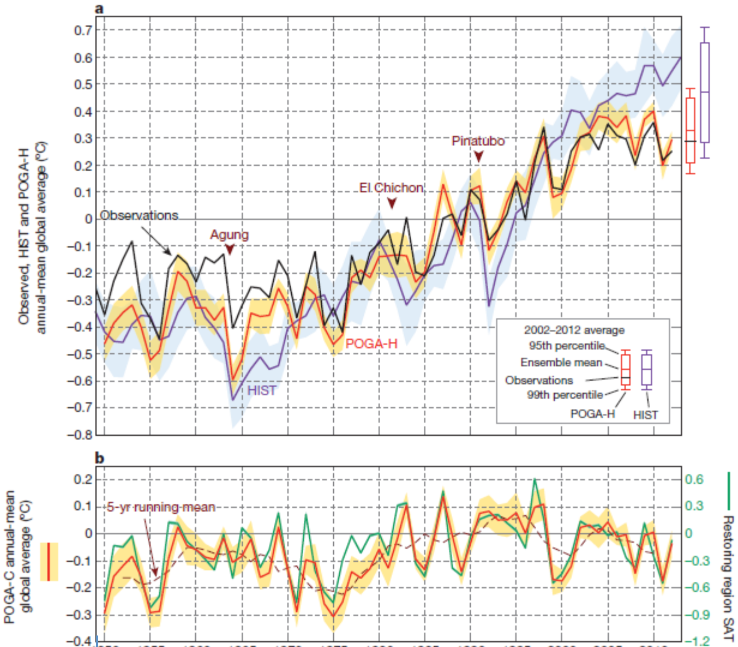
Sea surface temperature prediction

2015-2019 minus 1998-2012



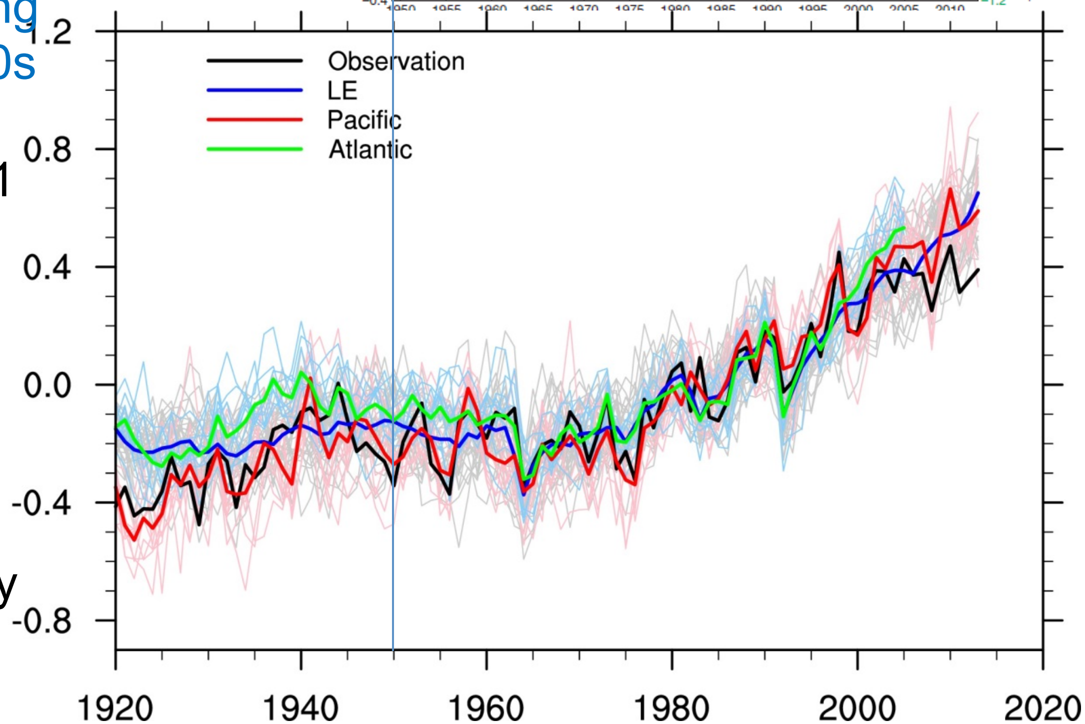
But maybe the IPO could be driven by the tropical Atlantic—use pacemaker runs to explore this possibility?

Kosaka and Xie (Nature, 2013): pacemaker run with GFDL fully coupled model specifying observed tropical eastern Pacific SSTs produces better agreement with observations than free-running forced run, especially in 2000s



Pacemaker runs with CESM1 show similar result, but not quite as good agreement for latter part of recent hiatus…role of volcanoes?

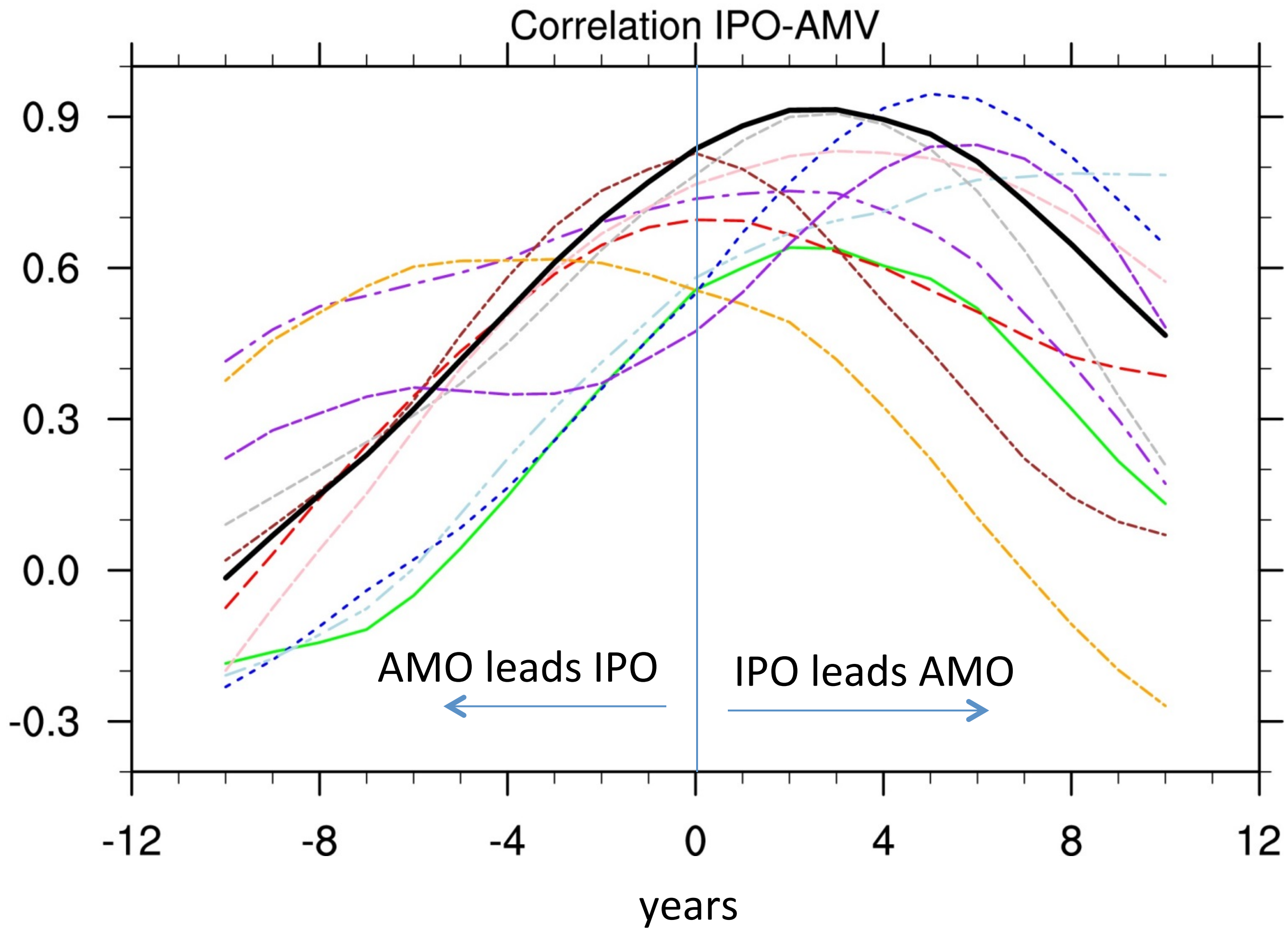
Better agreement with observations for early century warming…not as good for Atlantic pacemaker runs

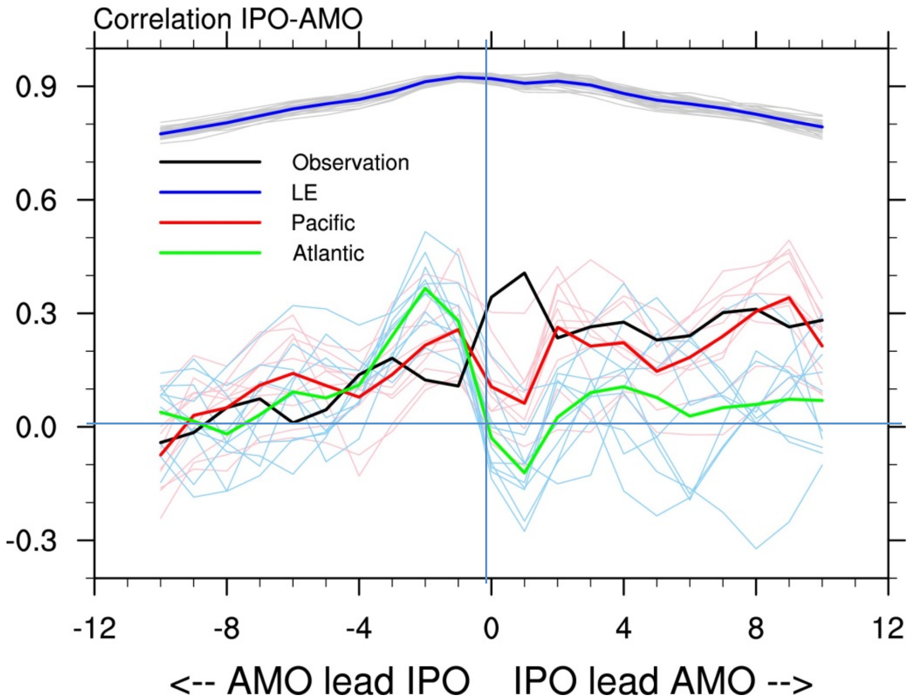


Does the Pacific drive the Atlantic or vice versa?

GFDL result suggests eastern tropical Pacific leads Atlantic on decadal timescales on average

Kosaka and Xie Pacific pacemaker runs

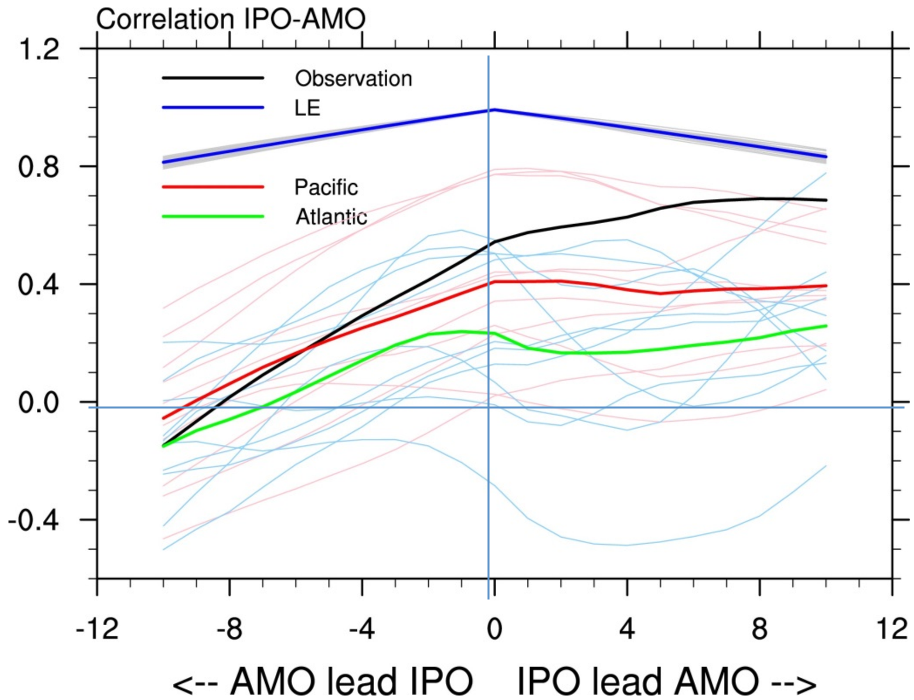




More of an ambiguous result from CESM1 pacemaker runs (1920-2013):

On decadal timescales (bottom) Pacific pacemaker runs suggest Pacific leads Atlantic as observed; Atlantic pacemaker runs suggest a slight edge for Atlantic leading Pacific but **big ensemble spread**

On interannual timescales (top) more or less the same story, but neither show observed one year lead of Pacific

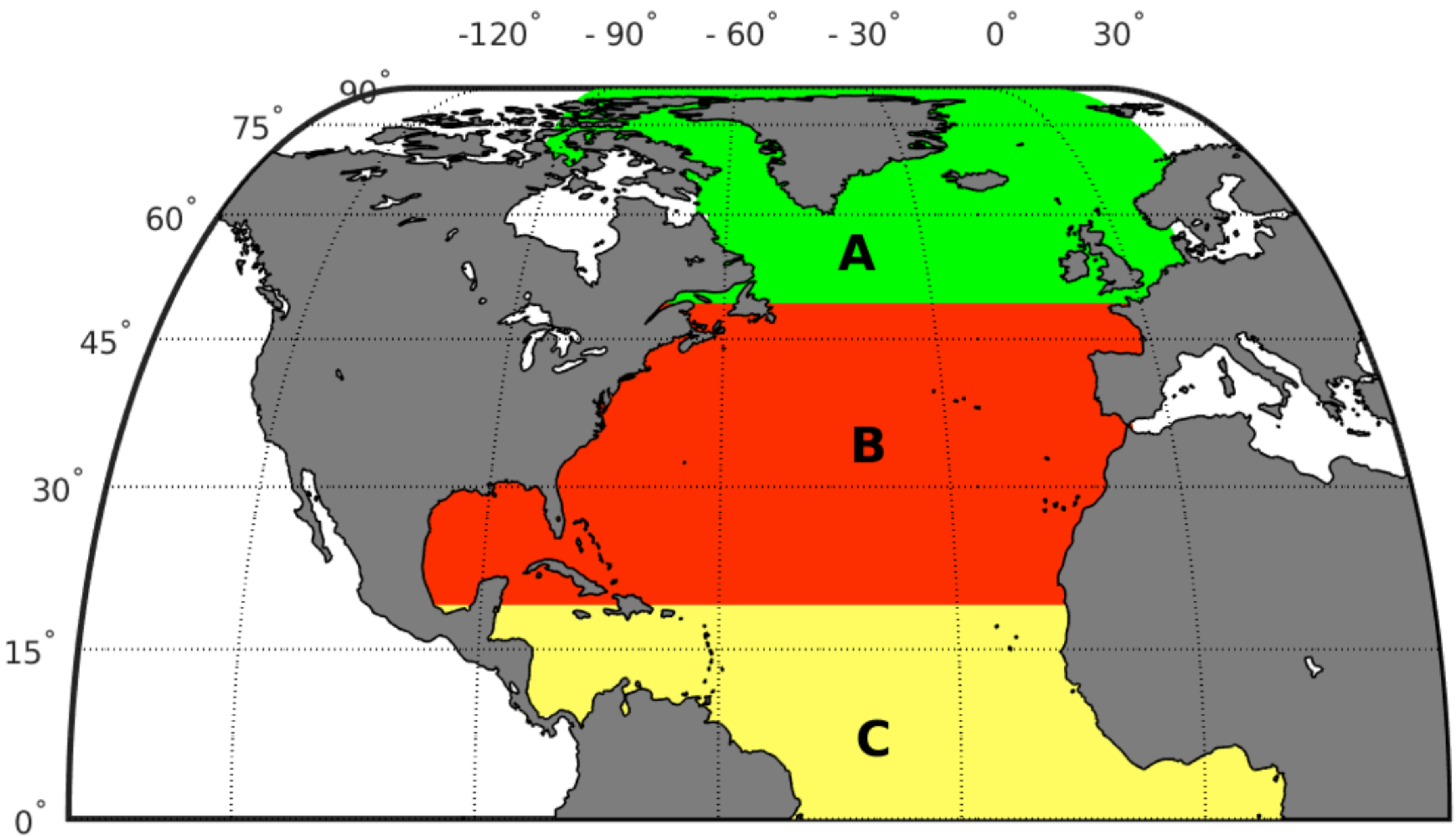


A restoring flux is calculated:

1/restoring time * depth of first model layer * (model temperature - obs temperature) * mask

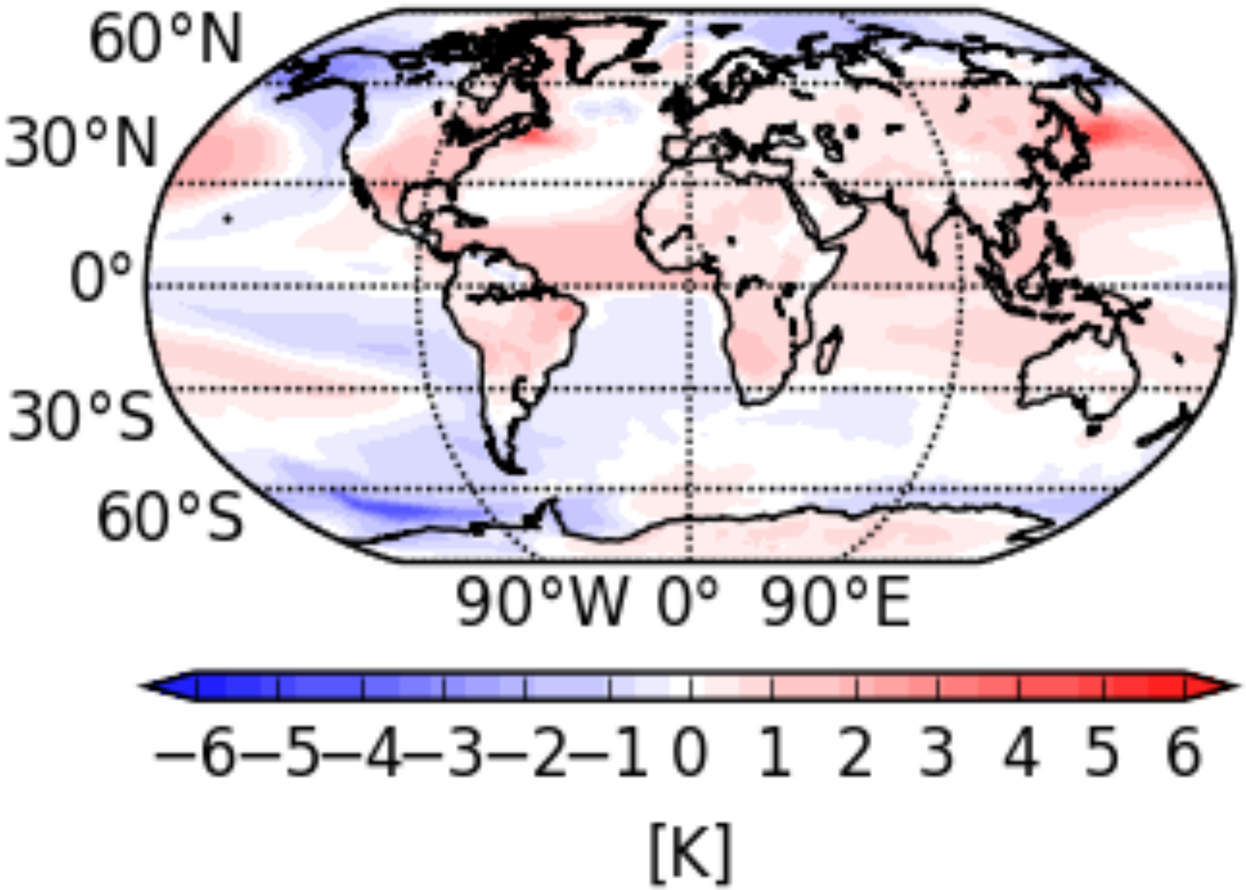
the restoring time is 2 days; depth of the first model layer is 10m. This is a temperature flux and is then converted to a heat flux. This heat flux is then added to the heat flux calculated by the fully coupled model.

Climatology +2K Atlantic forcing



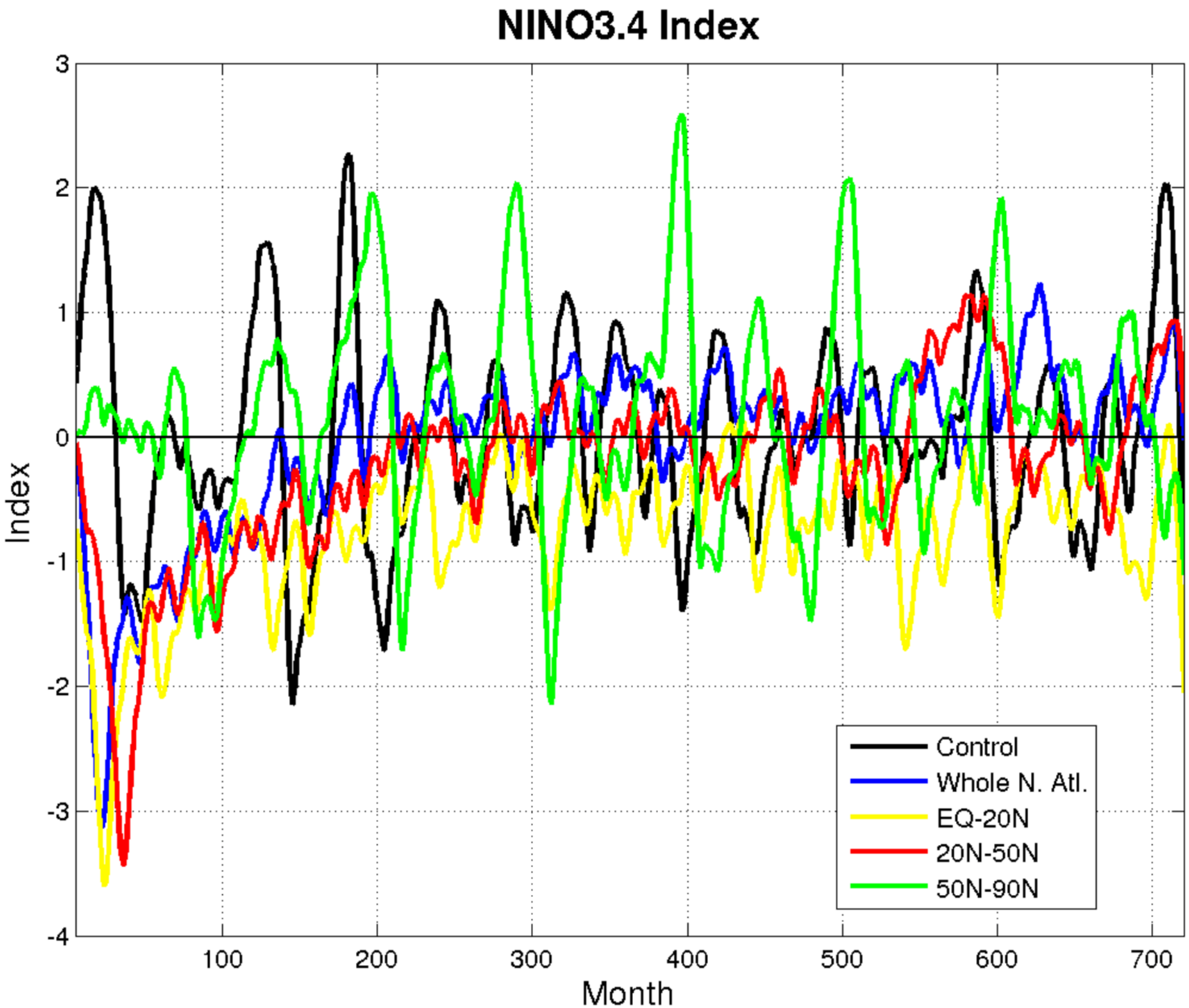
Herger, Sanderson & Knutti (in preparation)

Equatorial Forcing



- La Nina like response
- High latitude cooling
- Weak MOC slowdown

ENSO response (provisional runs)



- Equatorial and ML Atlantic forcing cause changes in both amplitude and frequency

Do pacemaker runs teach us anything about mechanisms or how physical processes work in the climate system?

Restoring a certain region to observed SSTs doesn’t solve all model systematic errors (e.g. precipitation and teleconnections) (Deser)

If part of the system is specified to observations, the rest of the system will “respond” by definition—it may not give us a very good idea of how coupled interactions work

It is likely the Pacific sometimes forces the Atlantic, and sometimes the Atlantic forces the Pacific (but there may be timescale differences)

Is there scientific justification for running a *coordinated multi-model set* of pacemaker experiments in terms of a defined science question or questions that pacemaker experiments can answer?

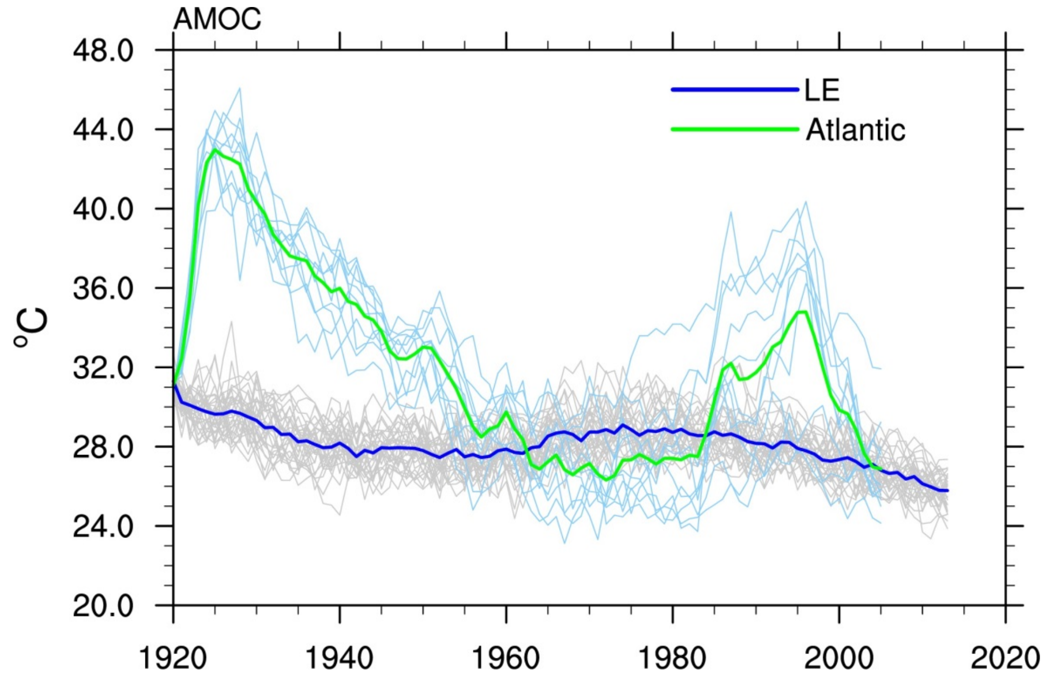
Summary

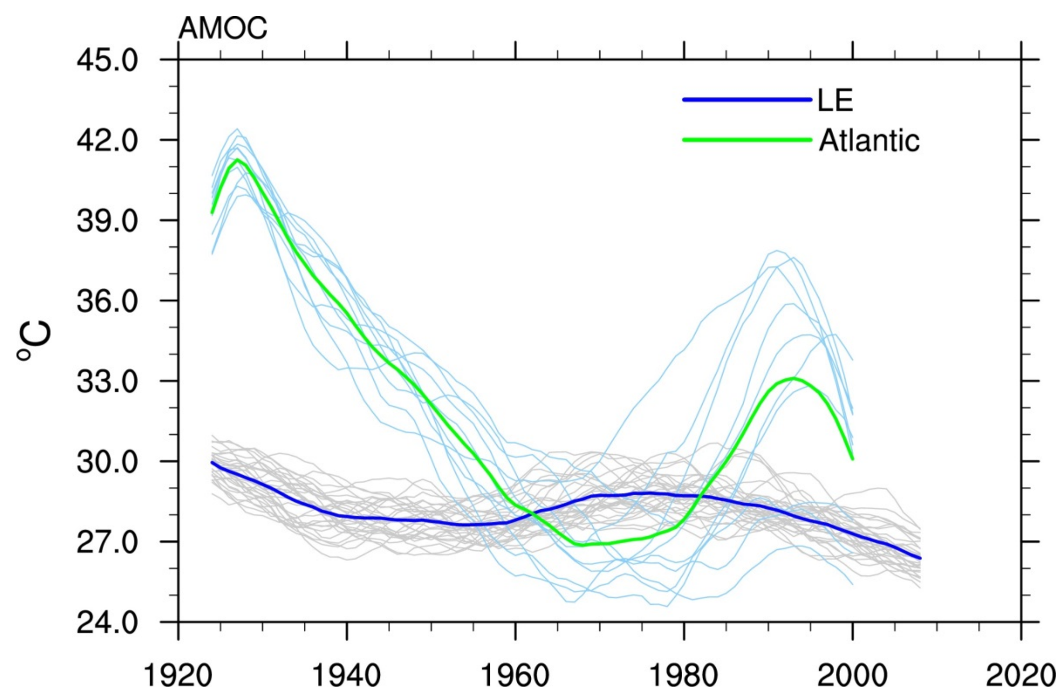
IPO is internally generated in long control runs; some uninitialized CMIP5 simulations capture the observed hiatus and negative IPO if internal variability in models happens to match that in observations

there appears to be some skill in simulation of IPO in initialized hindcasts, though there is loss of prediction skill of IPO from Pinatubo because models produce a forced response that does not resemble actual observations following Pinatubo eruption

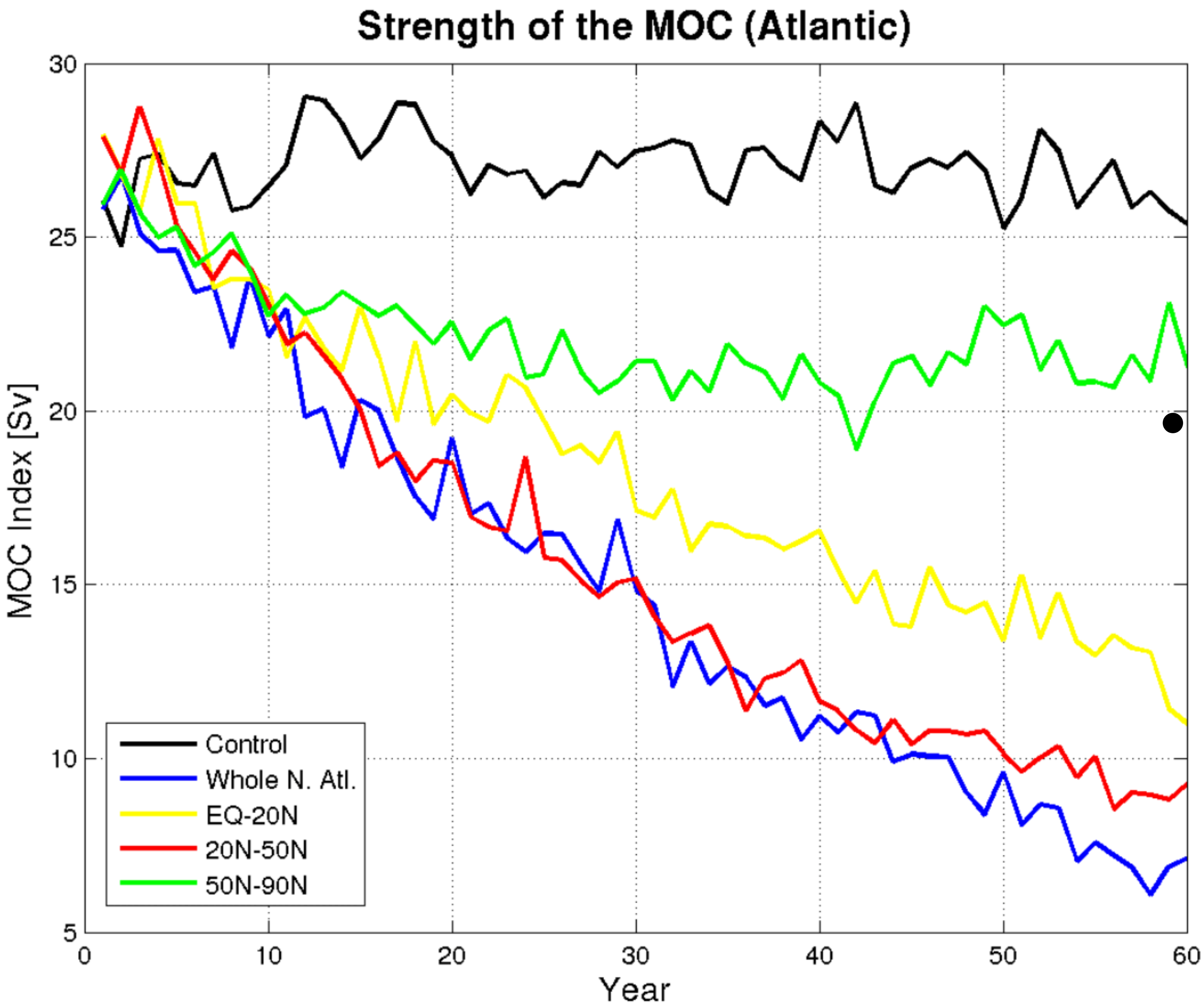
Mechanism of IPO: possibly within Pacific—off-equatorial W. Pac. heat content buildup and ENSO trigger for transitions, but maybe pacemaker experiments can be used to show role of Atlantic?

Pacemaker experiments—equivocal so far: It appears the Pacific sometimes forces the Atlantic, and sometimes the Atlantic forces the Pacific (but there may be timescale differences)


AMOC
LE
Atlantic
°C
48.0
44.0
40.0
36.0
32.0
28.0
24.0
20.0
1920
1940
1960
1980
2000
2020


AMOC
LE
Atlantic
°C
45.0
42.0
39.0
36.0
33.0
30.0
27.0
24.0
1920
1940
1960
1980
2000
2020

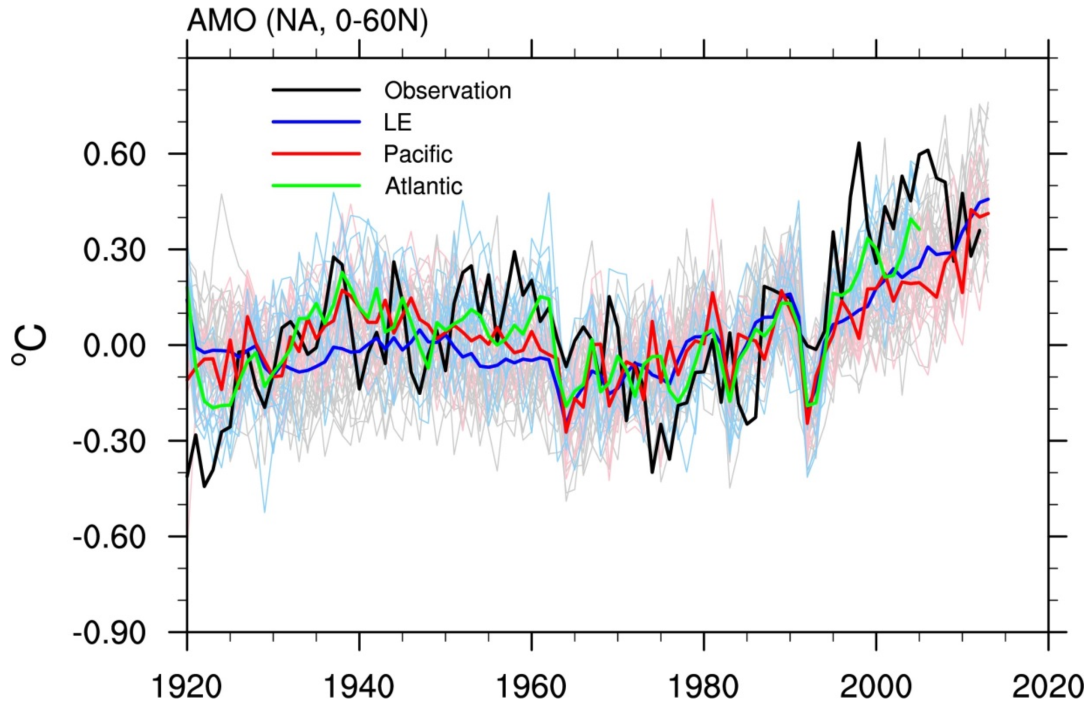
MOC response (provisional runs)



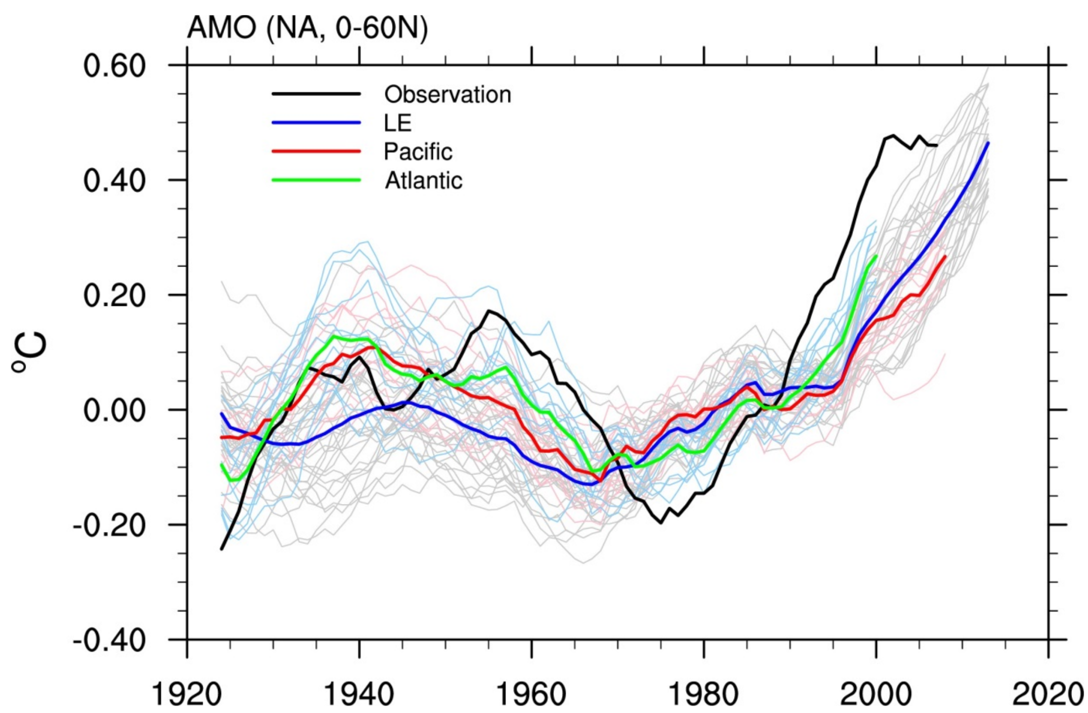
- Greatest response from midlatitude forcing

Simulating the AMO

On interannual timescales, Pacific and Atlantic pacemaker runs both follow observed AMO, (the Atlantic does better by design), as does the large ensemble all-forcings run (role of forcing in AMO?)



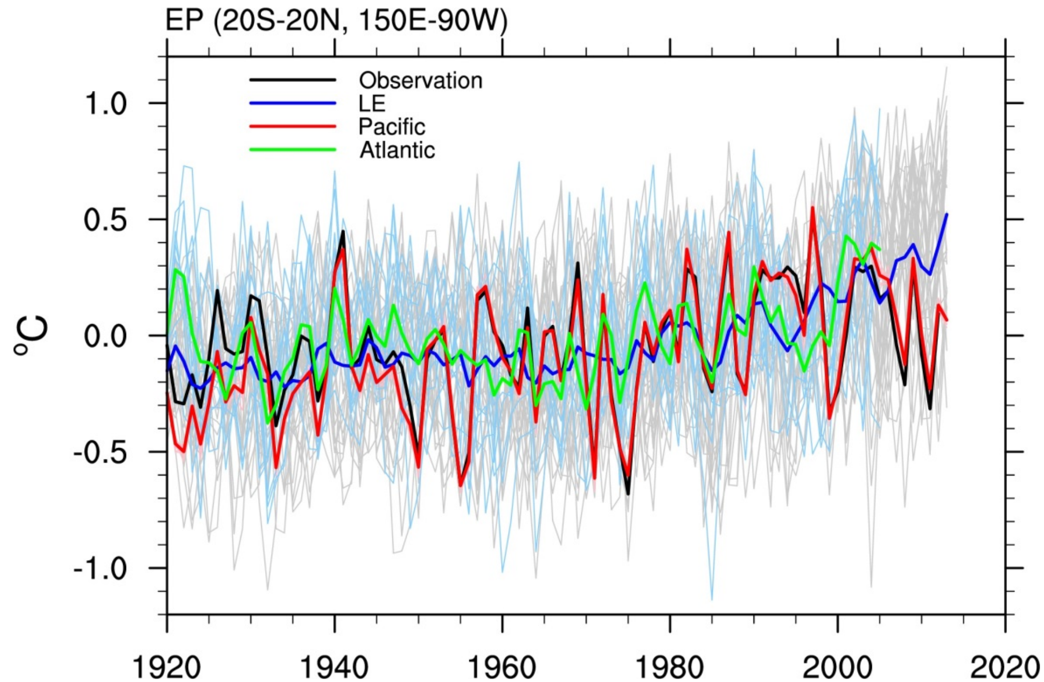
On decadal timescales, Pacific and Atlantic pacemaker runs follow each other (the Atlantic more close to the observations by design) and the large ensemble more closely than the observations

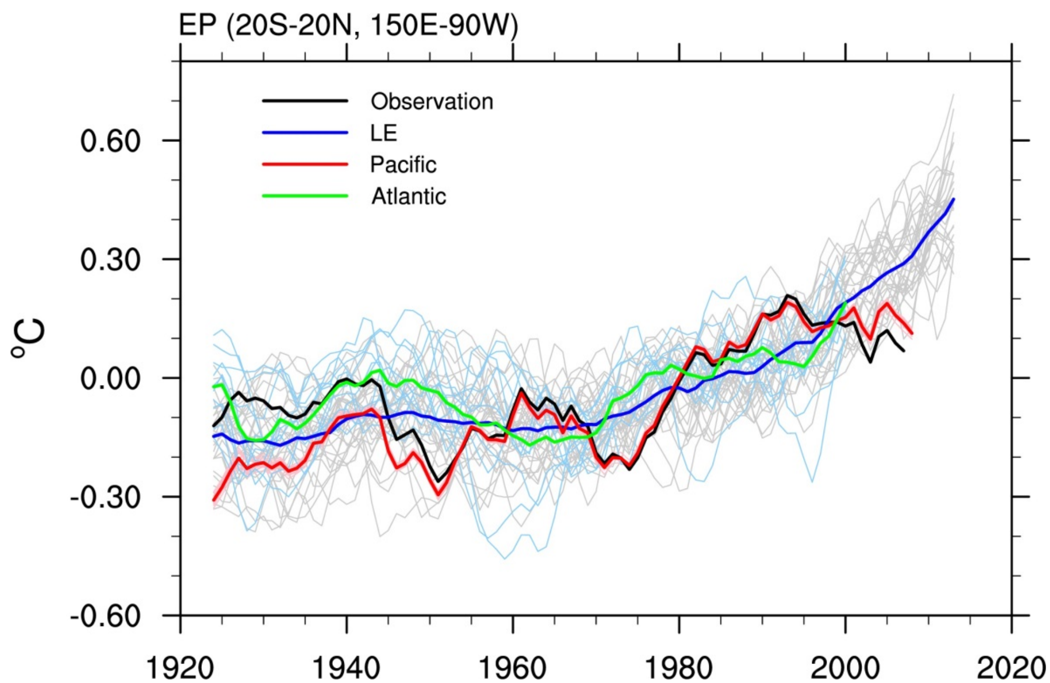


Simulating the IPO (EP SSTs)

On interannual timescales, Pacific pacemaker runs follow IPO (by design);

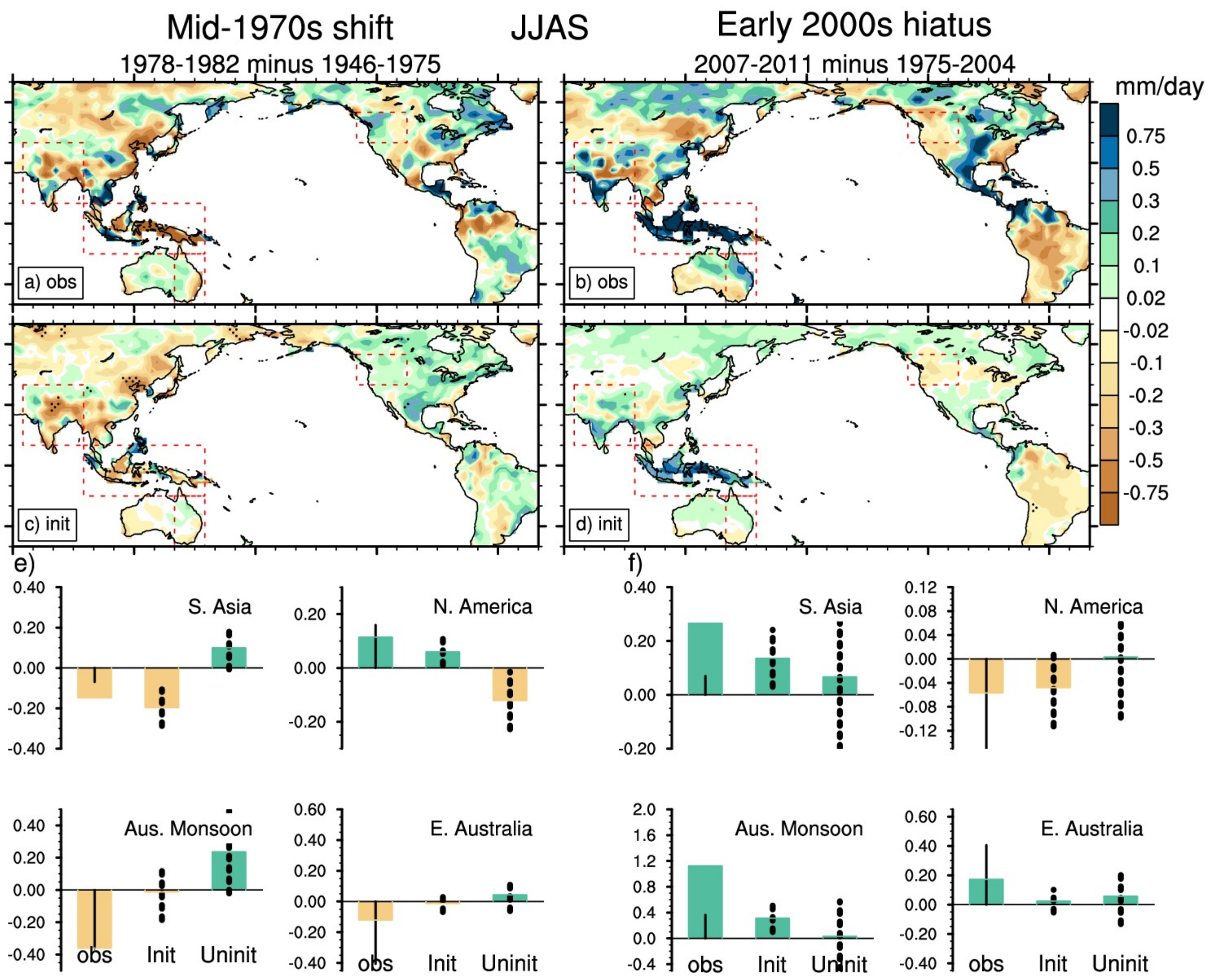
On decadal timescales, Pacific pacemaker and observations follow each other (by design) and lead the Atlantic pacemaker runs





What about decadal predictions for where people live?

An example of precipitation predictions over land areas for the CMIP5 decadal hindcasts



(Meehl and Teng, GRL, 2014)