Does the Atlantic force the Pacific or does the Pacific force the Atlantic?

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NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

U.S. DEPARTMENT OF ENERGY
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Biological and Environmental Research
Regional and Global Model Analysis

YES

YES

the Atlantic forces the Pacific and
the Pacific forces the Atlantic

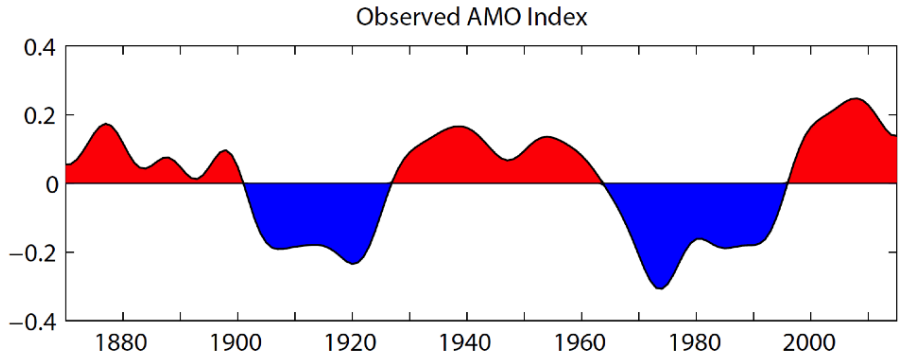
Decadal climate prediction presumes:

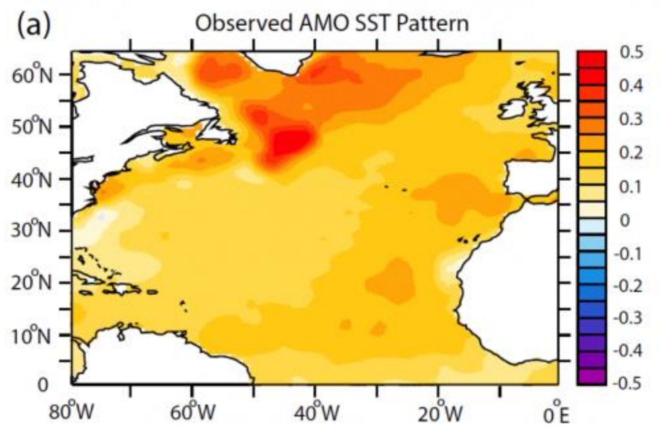
--there are relevant decadal timescale processes and mechanisms that arise from coupled processes with the ocean playing a major role

-- if initialized properly, these processes and mechanisms could provide predictive skill beyond the first year or two

Chief candidates for decadal timescales processes and mechanisms:

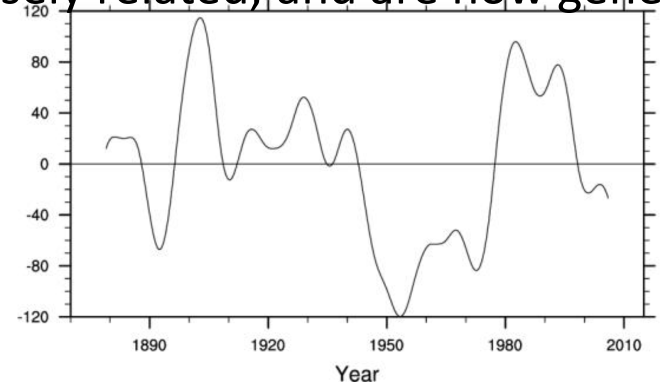
For the Atlantic: the Atlantic Multidecadal Oscillation (AMO) now generically referred to as Atlantic Multidecadal Variability (AMV)

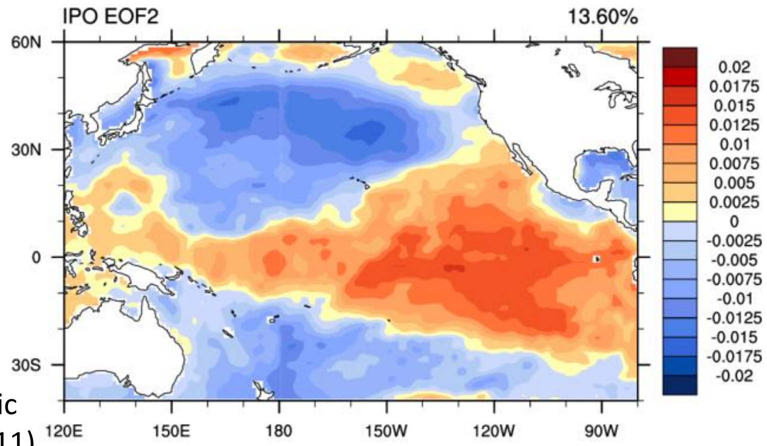




detrended 10-year low-pass filtered annual mean area-averaged SST anomalies over the North Atlantic basin (0N-65N, 80W-0E), using HadISST 1870-2015 (e.g. Trenberth and Shea, 2006)

For the Pacific: the Interdecadal Pacific Oscillation (IPO) and Pacific Decadal Oscillation (PDO); both are very closely related, and are now generically referred to as Pacific Decadal Variability (PDV)





2nd EOF of low-pass filtered annual mean area-averaged SST anomalies over the Pacific basin (40S-60N, 120E-80W), using HadISST 1870-2015, (e.g. Meehl and Arblaster, 2011)

How are AMV and PDV related?

Perhaps if one was driving the other, then a skillful prediction of decadal variability in one basin would drive the other; the resulting predicted SST and teleconnections would then simplify the decadal climate prediction problem

e.g. if the Atlantic drives the Pacific, predicting AMOC would produce initialized prediction skill for not only the Atlantic, but for the Pacific, and on to much of the globe through teleconnections from those ocean basins

However, in the observed climate system, it is difficult to separate how the two ocean basins are connected

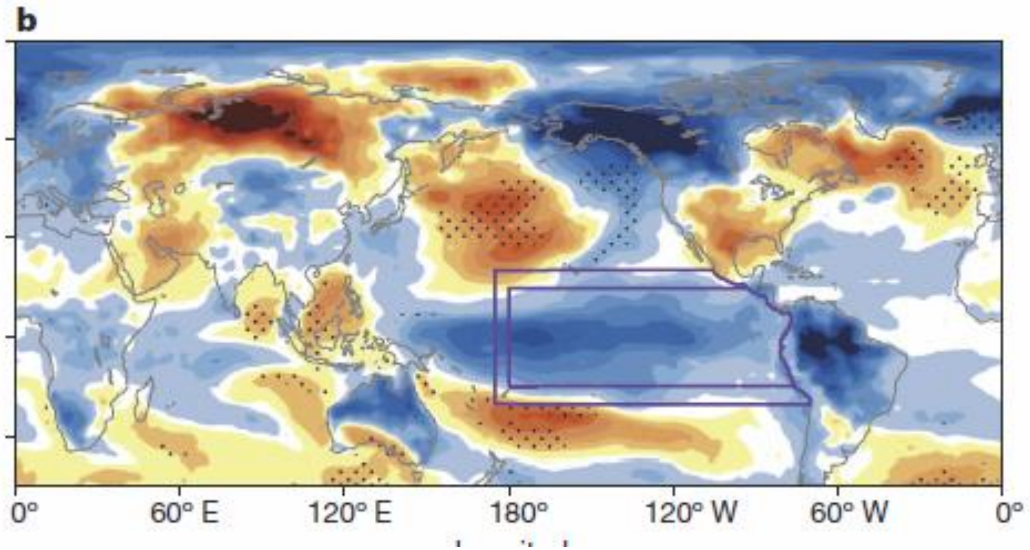
The **“pacemaker” methodology** (Kosaka and Xie, 2013) was devised to attempt to determine the effects of SST forcing from one ocean region on the global climate system

In a fully coupled climate model: specify SSTs in one region and the rest of the climate system is coupled

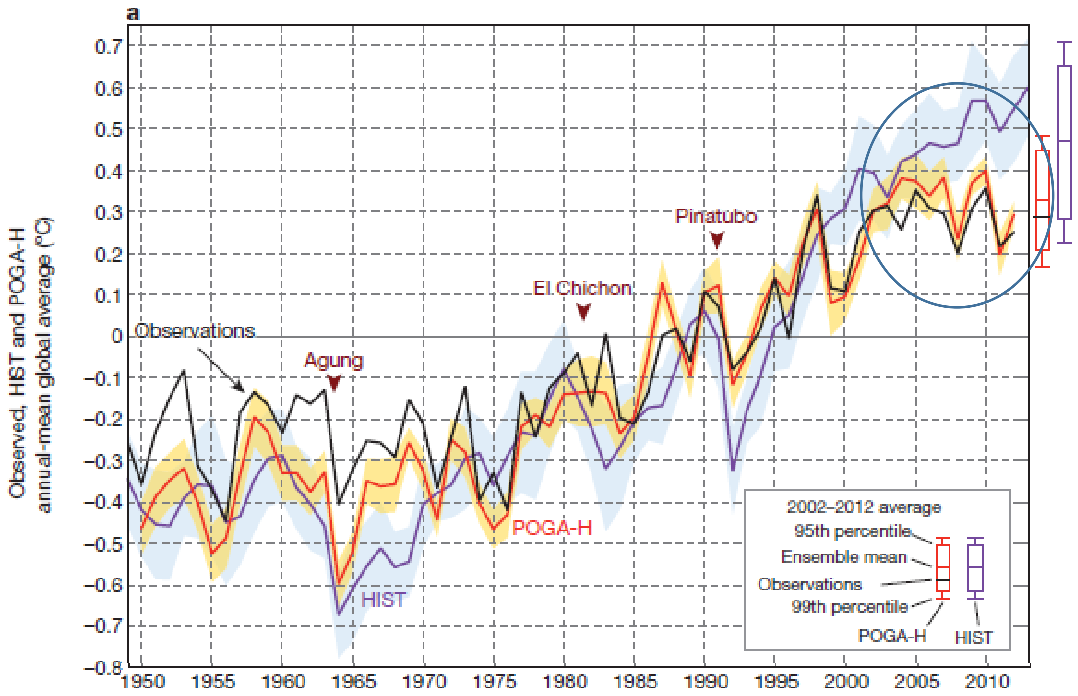
Quantifies the global climate system response to specified SSTs in one region

The “pacemaker” methodology

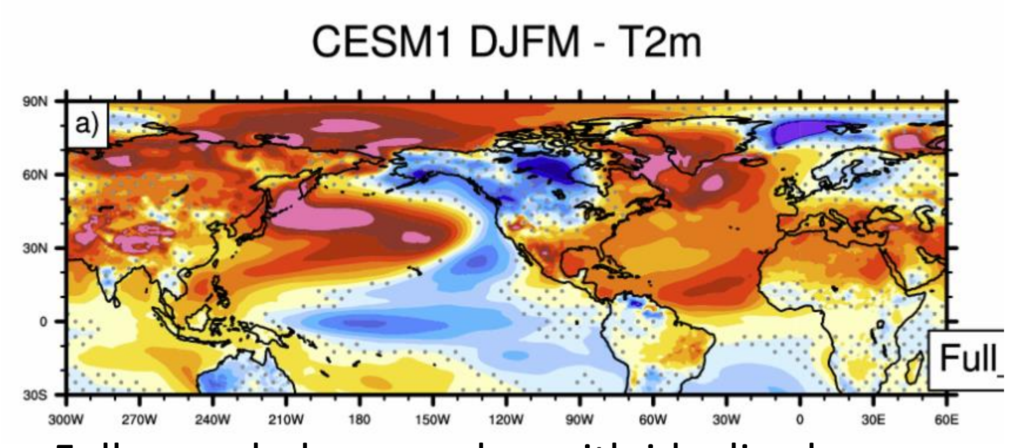
For example, by specifying the observed time evolution of tropical Pacific sea surface temperatures (“time series pacemaker”), the early-2000s slowdown is simulated, thus implicating the IPO’s role
(Kosaka and Xie, 2013, Nature)



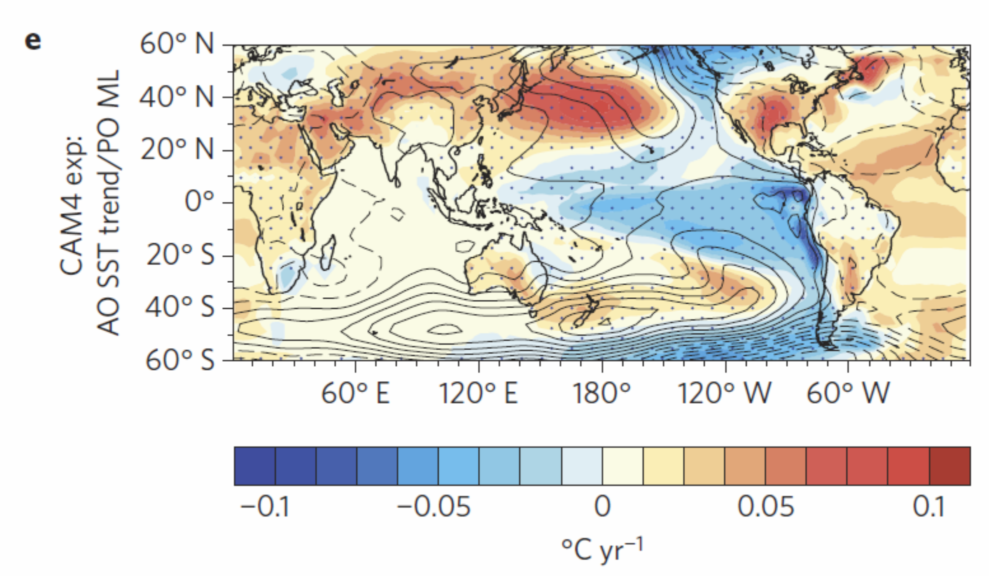
Pacific pacemaker trend 2002-2012
(Kosaka and Xie, 2013)



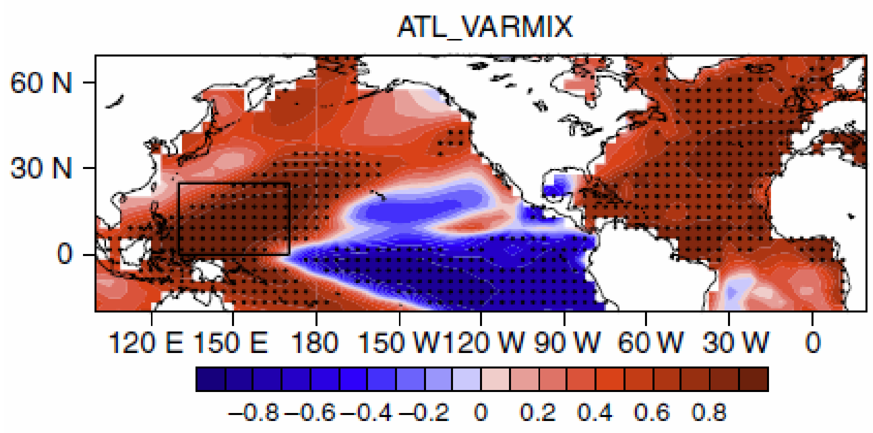
Results from Atlantic pacemaker experiments show that the Atlantic drives the Pacific with **opposite-sign** SST anomalies



Fully coupled pacemaker with idealized Atlantic AMV (Ruprich-Robert et al., 2017)

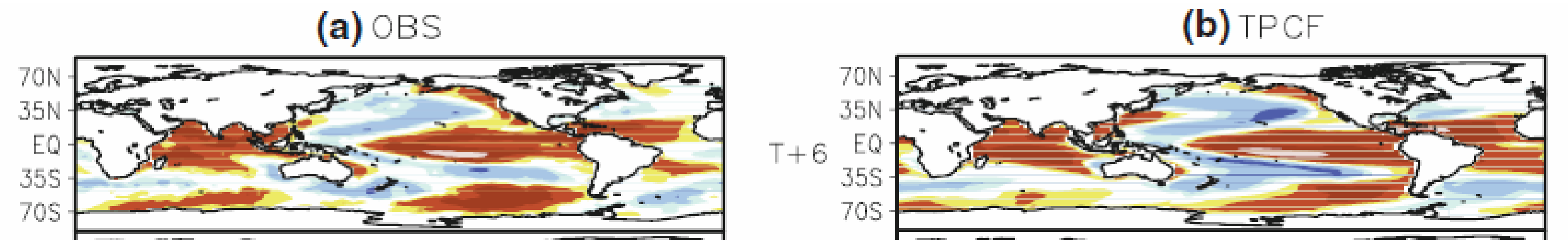


Observed Atlantic SST trend 1992-2011 and Pacific mixed layer (McGregor et al., 2014)

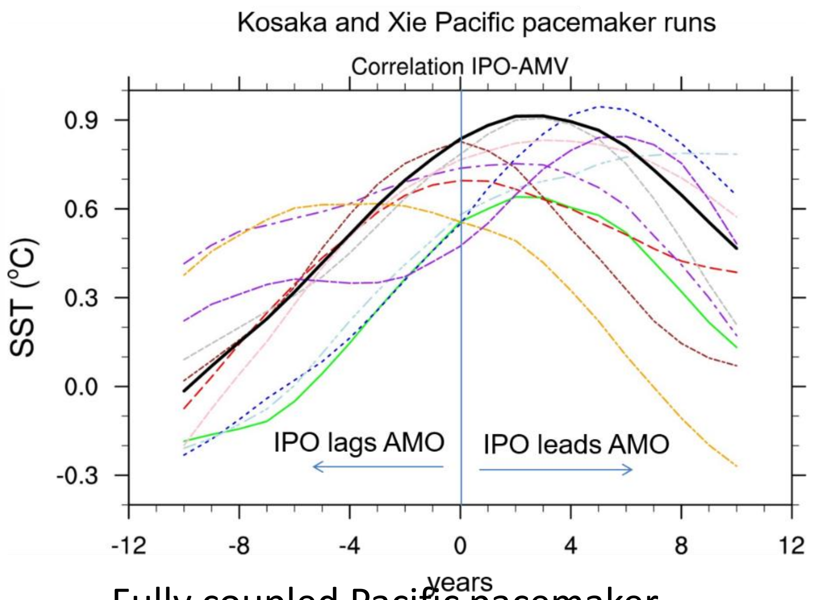


Observed Atlantic SST trend 1992-2011 and Pacific mixed layer (Sun et al., 2017)

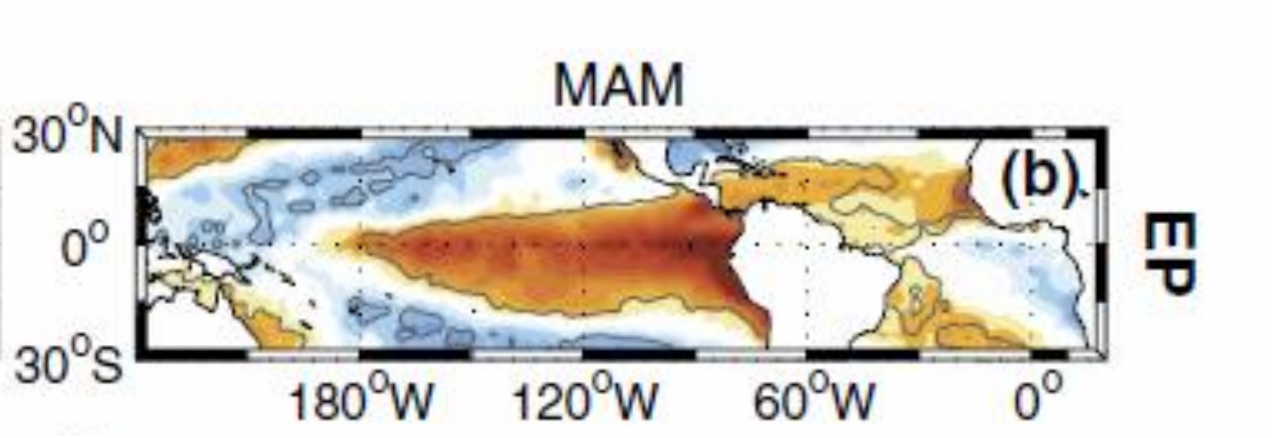
Results from Pacific pacemaker experiments show that the Pacific drives the Atlantic with **same-sign** SST anomalies



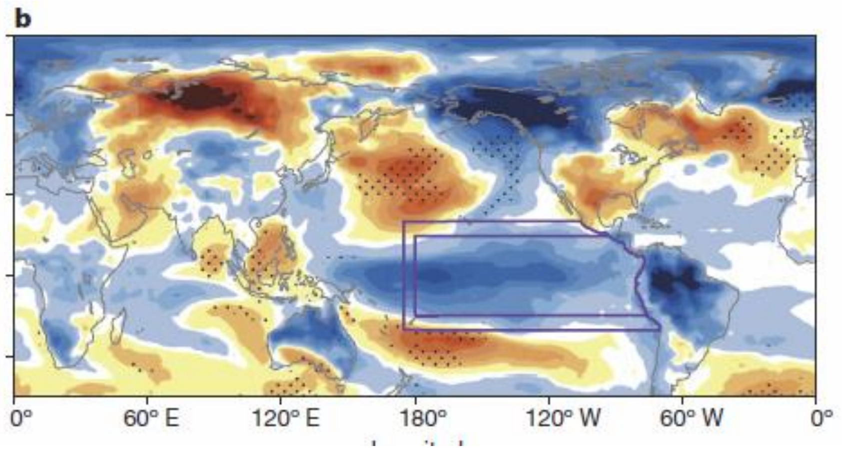
Nino3.4 index correlated with observed SSTs at 6 months lead, and fully coupled Pacific pacemaker (Kumar et al., 2014)



Fully coupled Pacific pacemaker (Meehl et al., 2016)



Composite Eastern Pacific El Nino events from observations (Taschetto et al., 2015)



Pacific pacemaker trend 2002-2012 (Kosaka and Xie, 2013)

Two types of pacemaker experiments:

--specify the observed time-evolution of SSTs (e.g. 1920-2013)

“time series pacemakers”

(e.g. Kosaka and Xie, 2013)

--devise an idealized pattern of SSTs over a region that represents internal variability (e.g. PDV or AMV) and do an ensemble of 10 yr simulations

“idealized pacemakers”

(e.g. Ruprich-Robert et al., 2017)

Formulate the idealized internally generated SST patterns for Atlantic and Pacific pacemaker experiments ("idealized pacemakers")

The externally-forced part:

1. apply signal-to-noise maximizing EOFs (Ting et al., 2009) to the CMIP5 multi-model ensemble using historical simulations and RCP8.5 simulations for the 1870-2005 and the 2006-2013 periods This produces the time series of the radiatively-forced component of SST as PC1 of the global signal-to-noise EOF
2. the spatial pattern is derived by regressing the observed global SST (ERSSTv3; Smith et al. 2008) onto the PC1 time series

The internally generated decadal timescale SST pattern for the Atlantic and Pacific (resembling the AMO and IPO):

1. The internally generated SST components are obtained as the residuals of the observed North Atlantic and Pacific average SSTs (resembling the AMV and PDV) for 40°S to 60°N and Equator to 60°N, 75°W to 7.5°W, respectively, after subtracting the externally-forced component
2. The AMV and PDV spatial patterns of SST are then calculated by regressing the annual-mean observed SST time series onto the respective AMV and PDV indices.

(The AMO and IPO time series and the SST fields are low-pass filtered for the period 1870-2013 prior to the regression using a Lanczos filter: 10-year cutoff with 21 weights)

CESM1.1 LENS version (1 degree)

Prescribed SST anomalies superimposed on model climatology

Two experiments are run for each of the idealized specified PDV (IPO) and AMV (AMO) configurations (AMV+, AMV-, PDV+, PDV-).

Results are shown as differences, AMV+ minus AMV-, and PDV+ minus PDV-

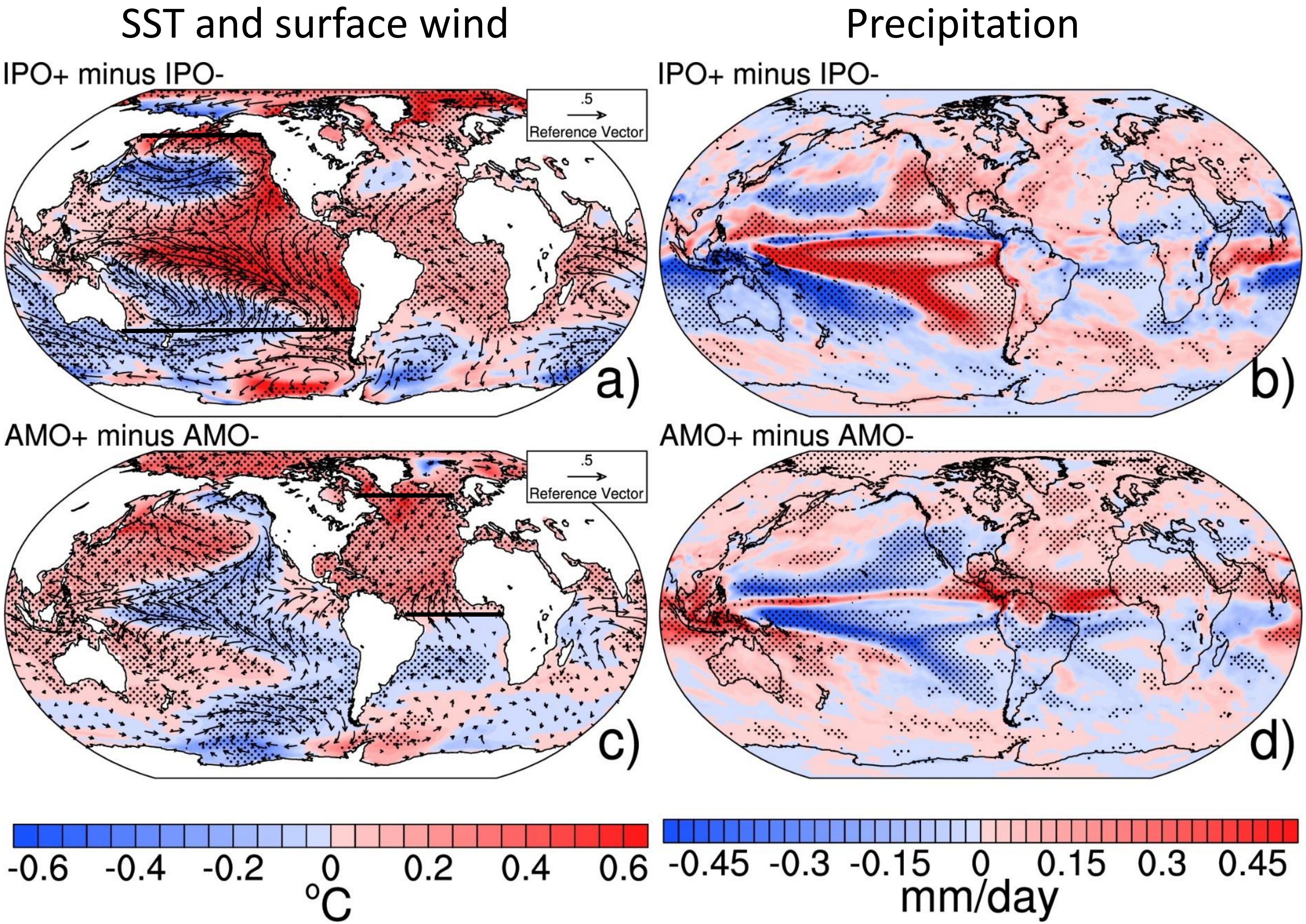
All external forcings are held constant at pre-industrial values.

The ten ensemble members for Pacific are formed from ten different ocean initial states, and the thirty for the Atlantic are formed from 3 different ocean initial states and 10 ensemble members are run from each of those initial states performing small perturbations in the atmospheric initial conditions.

Stippling indicates 95% confidence level

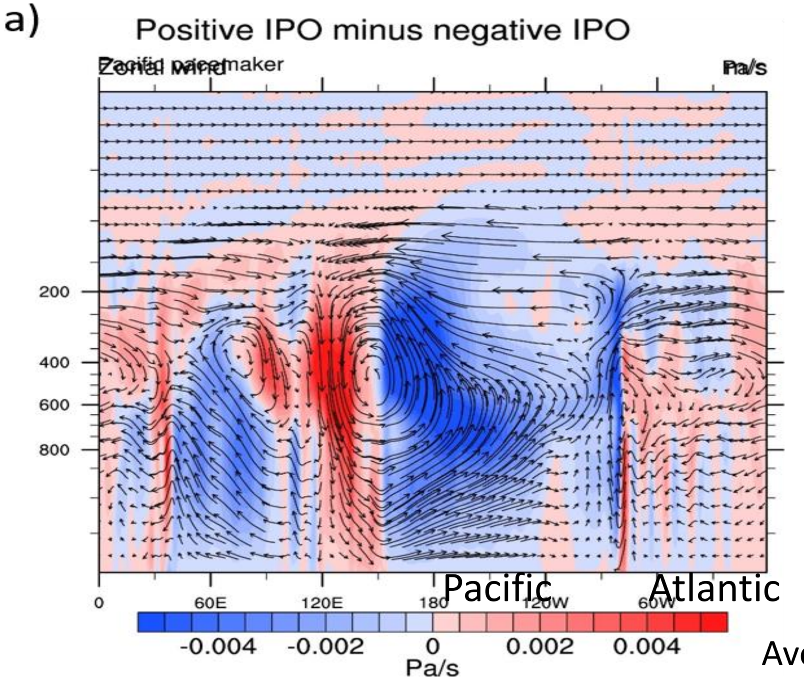
Pacific pacemaker: same sign response **in tropical Atlantic**

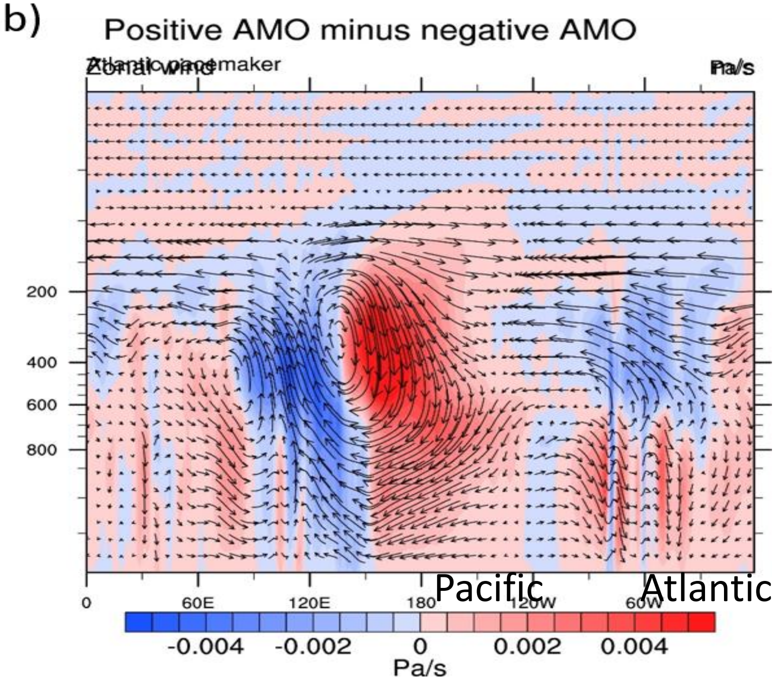
Atlantic pacemaker: opposite sign response **in tropical Pacific**



Pacific pacemaker

Atlantic pacemaker



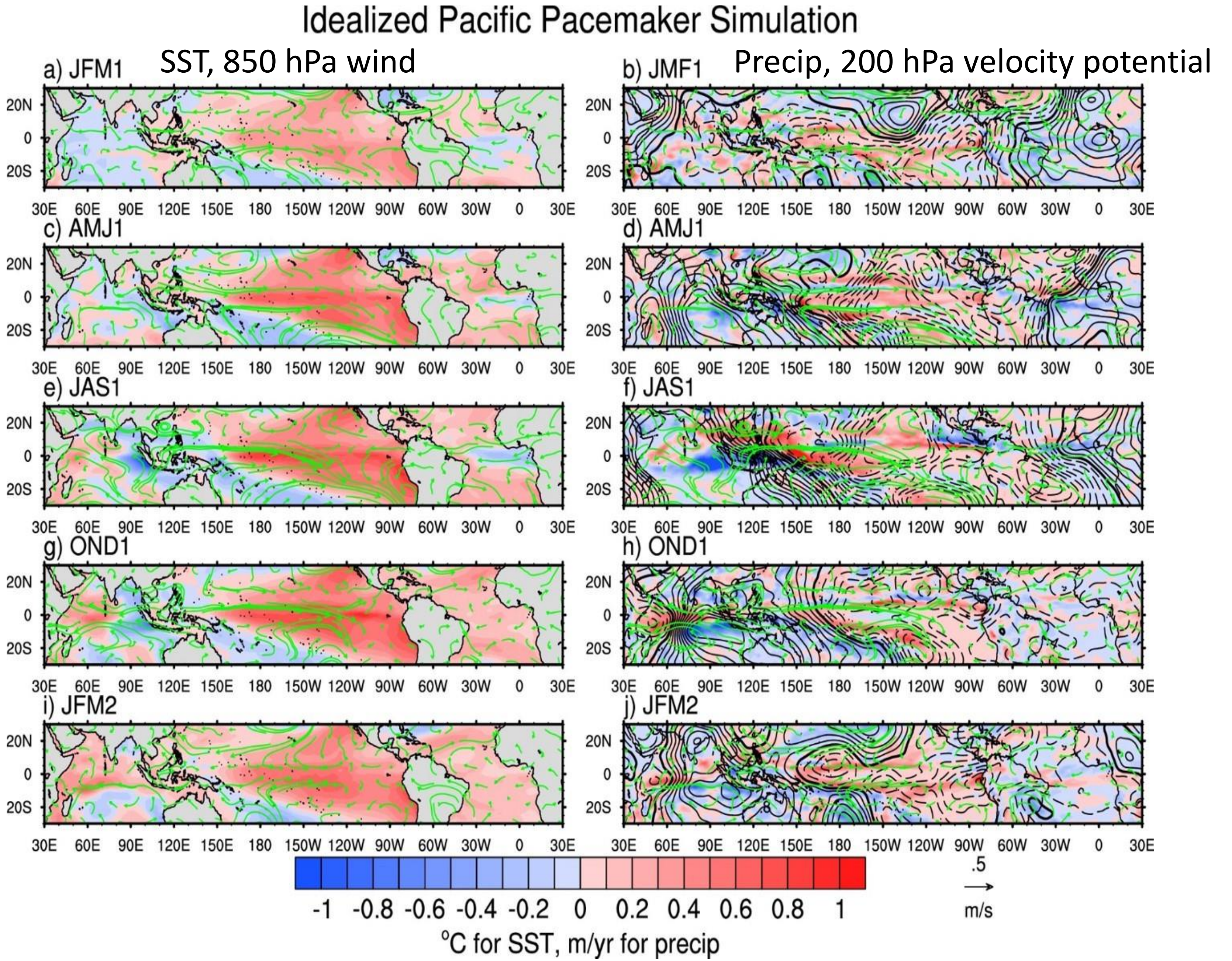


Average 5N-5S

As noted in previous studies, large-scale east-west circulations (Walker circulation) connect the Pacific and Atlantic basins

Why does the Atlantic pacemaker drive an opposite-sign response in the tropical Pacific, and the Pacific pacemaker drive a same-sign response in the tropical Atlantic?

Track the time evolution in the first year of the pacemaker simulations to see how anomalies develop



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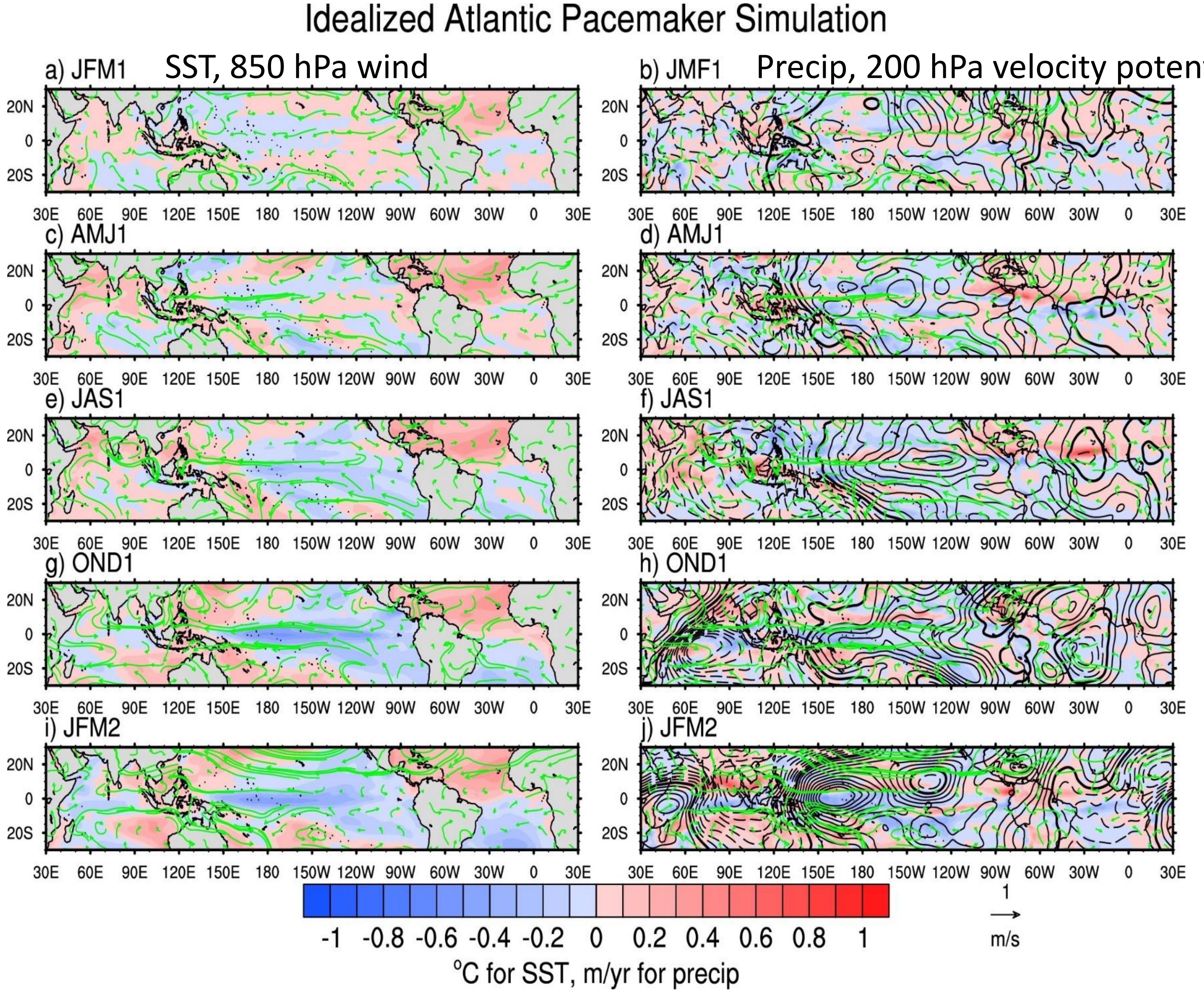


Heat budget for tropical Atlantic in Pacific pacemaker, and tropical Pacific in Atlantic pacemaker

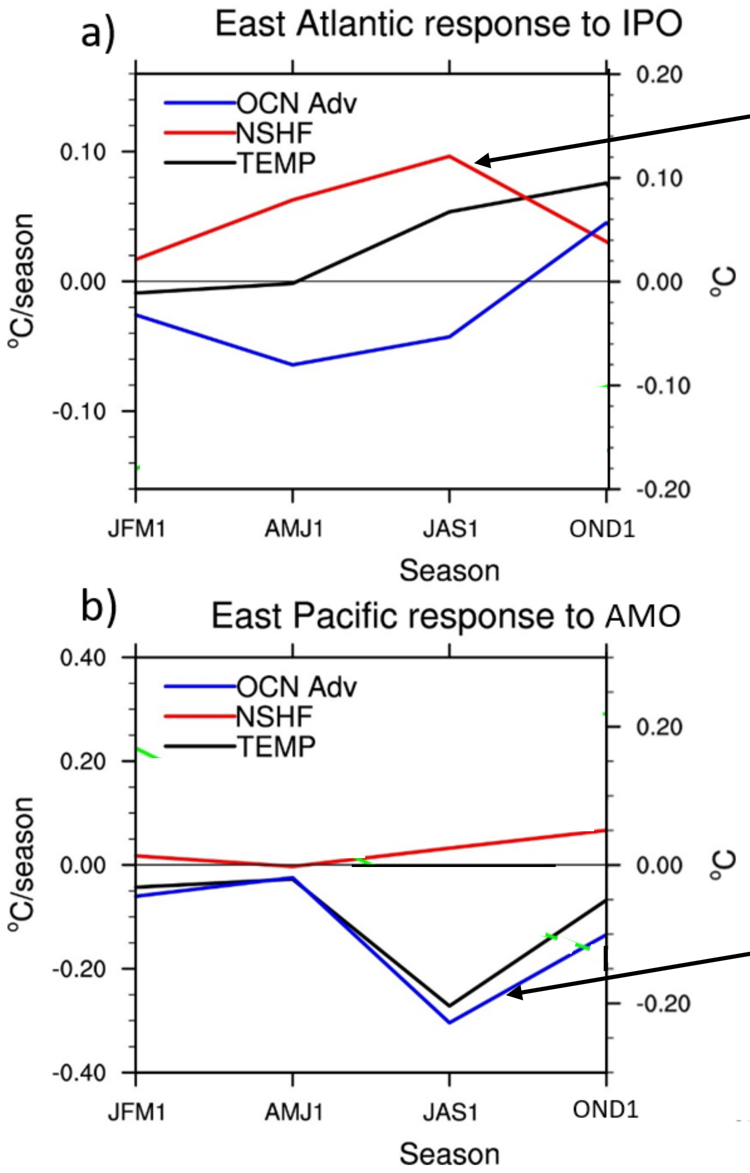
$$H_{tot} = \underbrace{H_{surface}}_{\text{surface heat flux}} + \underbrace{H_{o\_advection} + H_{diff} + H_{submeso} + H_{mixing}}_{\text{ocean advection term, diffusion, submeso- scale, and mixing due to KPP and diabatic processes over upper 100m}}$$

Atlantic eq-10S, 35W-10E

Pacific 120W-180, 5N-5S

Ocean heat budget, upper 100m

Heat budget terms are trends over each season;

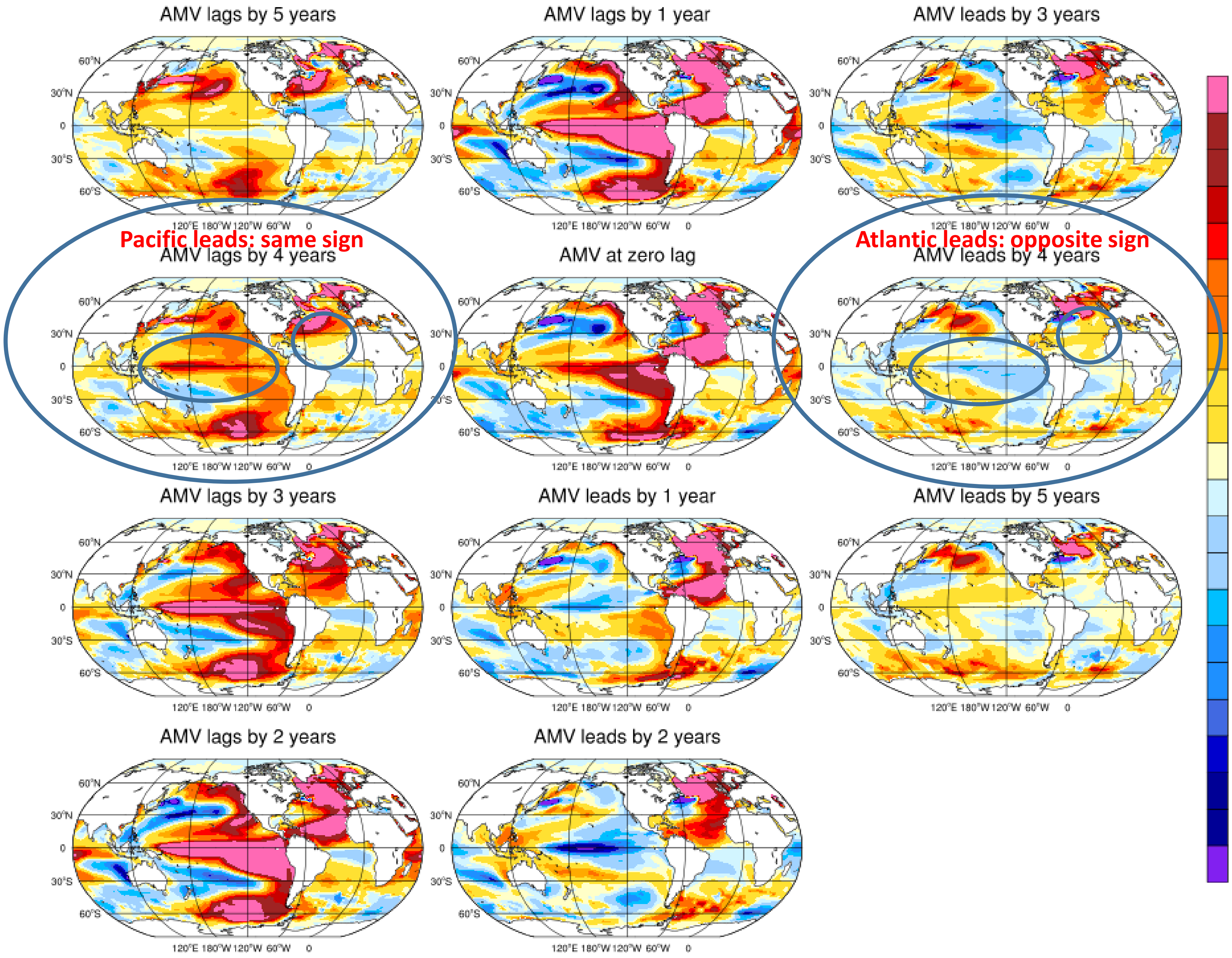


Net surface heat flux is more important in the positive temperature response in the tropical Atlantic

Ocean dynamics are more important in the negative temperature response in the tropical Pacific

Lagged regressions of winter time (DJFM) sea surface temperature on the simulated AMV index from 1800-year CESM1 large ensemble PI control

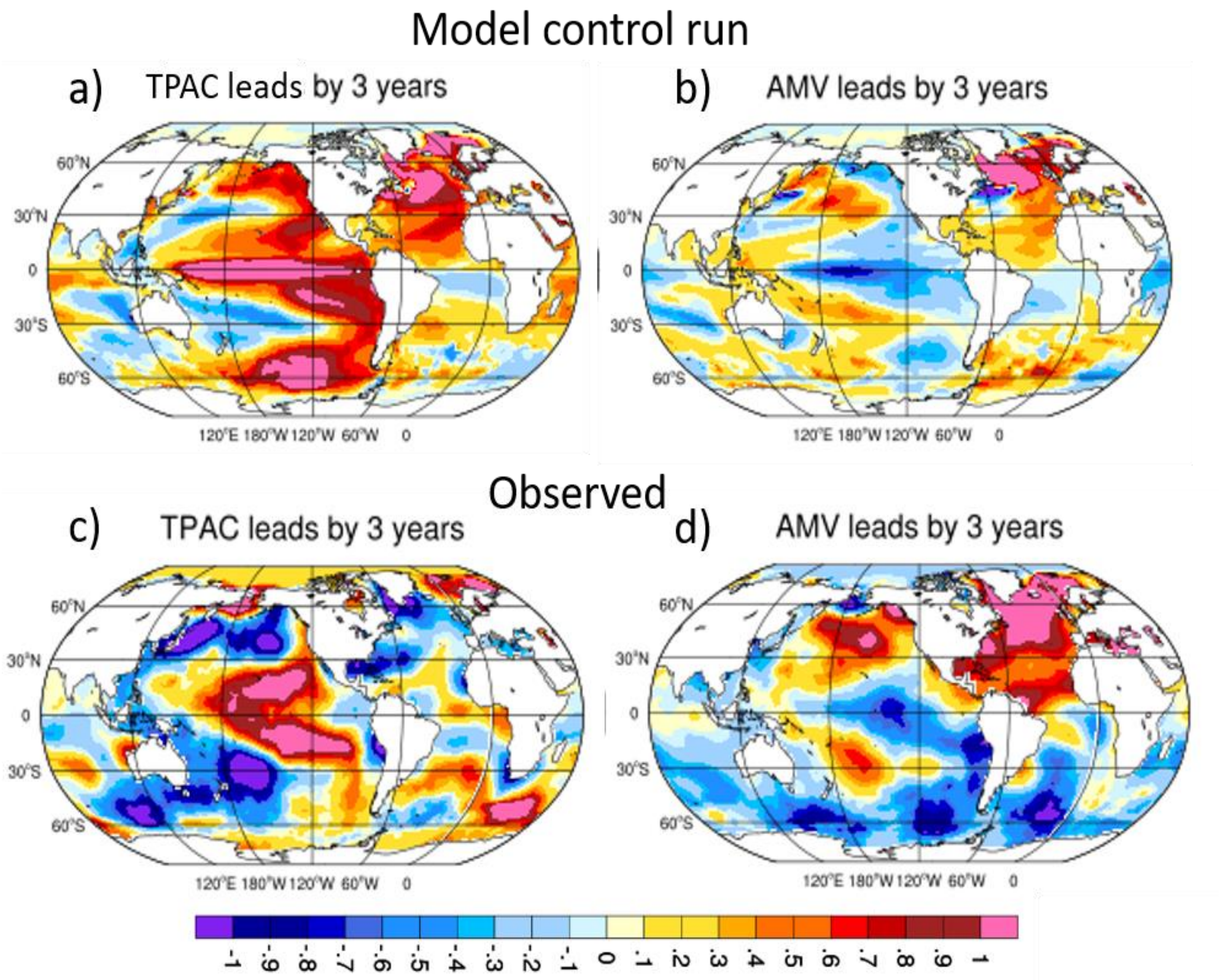
AMV index: deviation from climatological mean for the spatially averaged North-Atlantic SST, Eq - 60˚N, 7.5˚ to 75˚W. A low-pass Butterworth filter with a 10-yr cutoff is applied the time series



Similar lag regressions from observations provide evidence to support the model results

Model

Observations



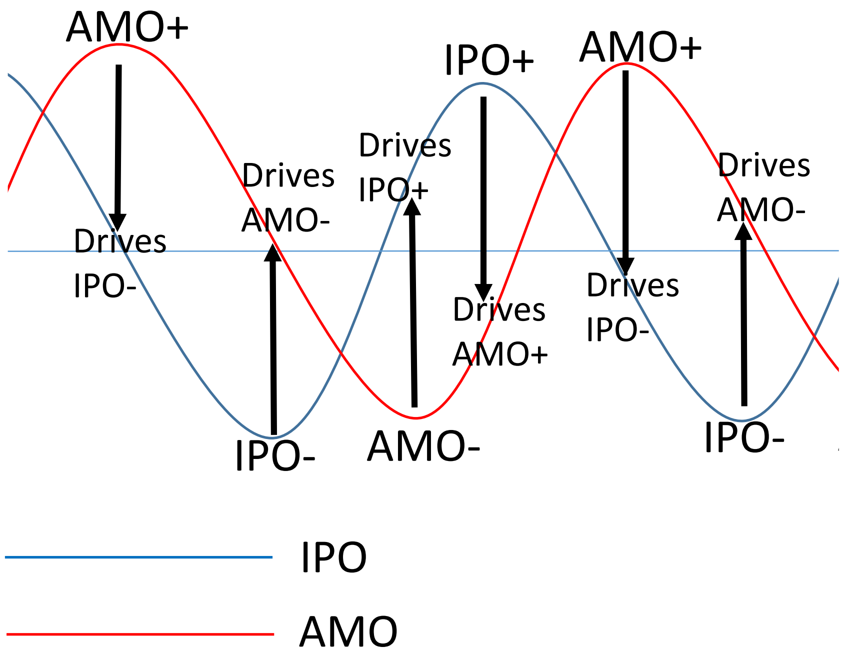
Could the two ocean basins be mutually interactive?
(i.e. each one can affect the other in turn)

Schematic of mutual interactions between Atlantic and Pacific

Pacific would tend to make Atlantic same sign;

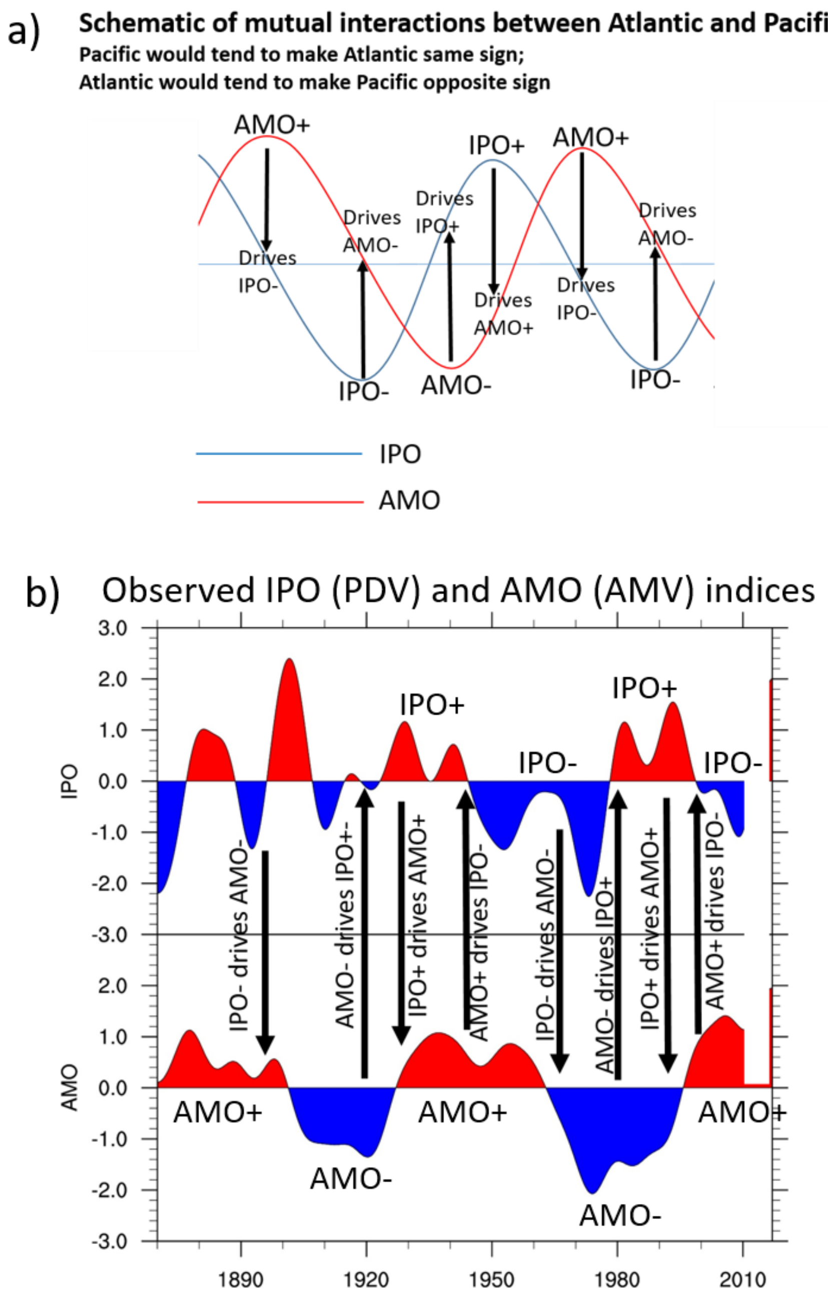
Atlantic would tend to make Pacific opposite sign

(AMO+ drives tendency to IPO-, and IPO- drives tendency to AMO-, AMO- drives tendency to IPO+, and IPO+ drives tendency to AMO+)



Can we see anything like this in the observations?

Issues: short record (only 2 cycles); time-varying forcing complicates the response

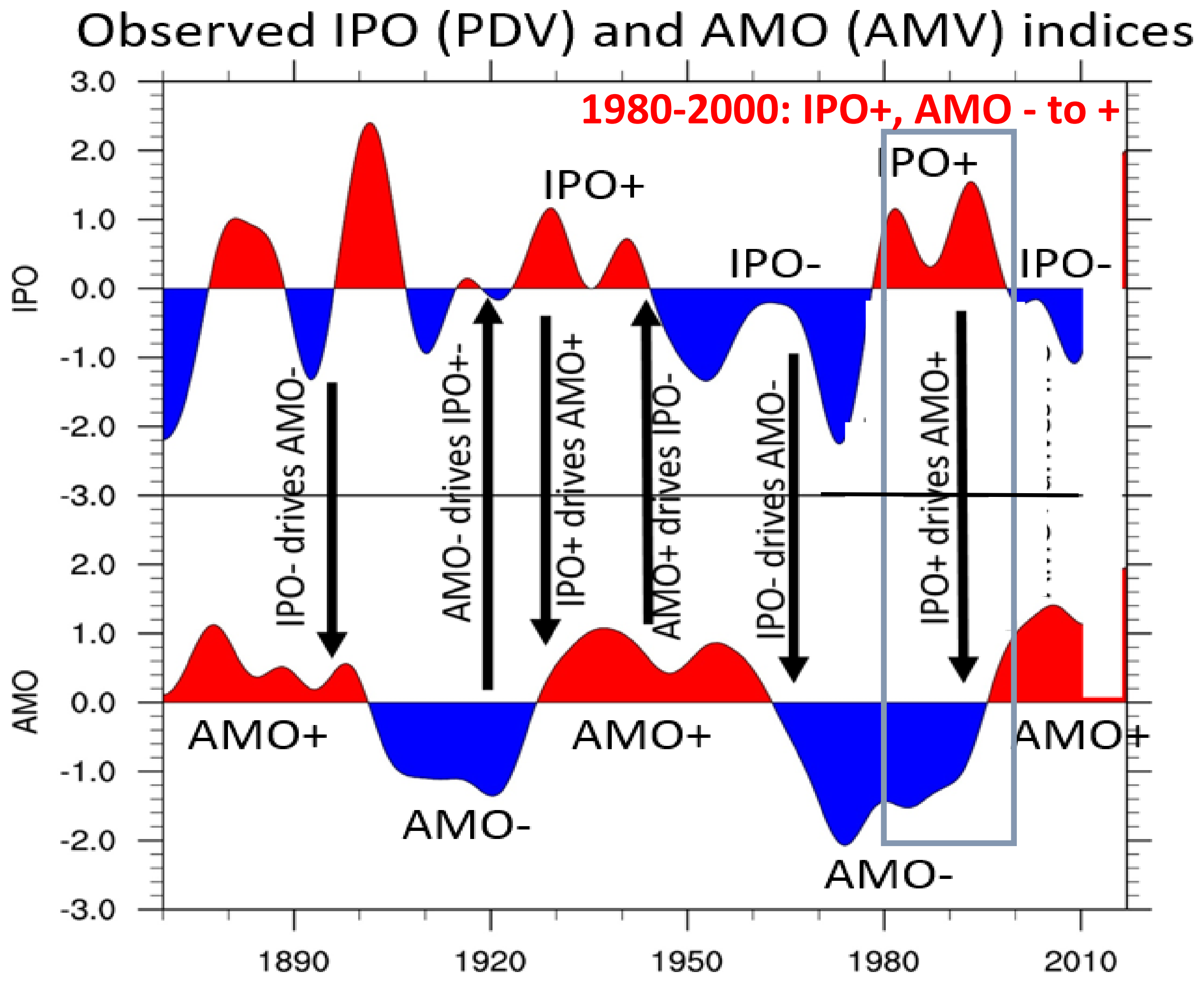


Use time-series pacemakers to address role of Atlantic-Pacific interactions

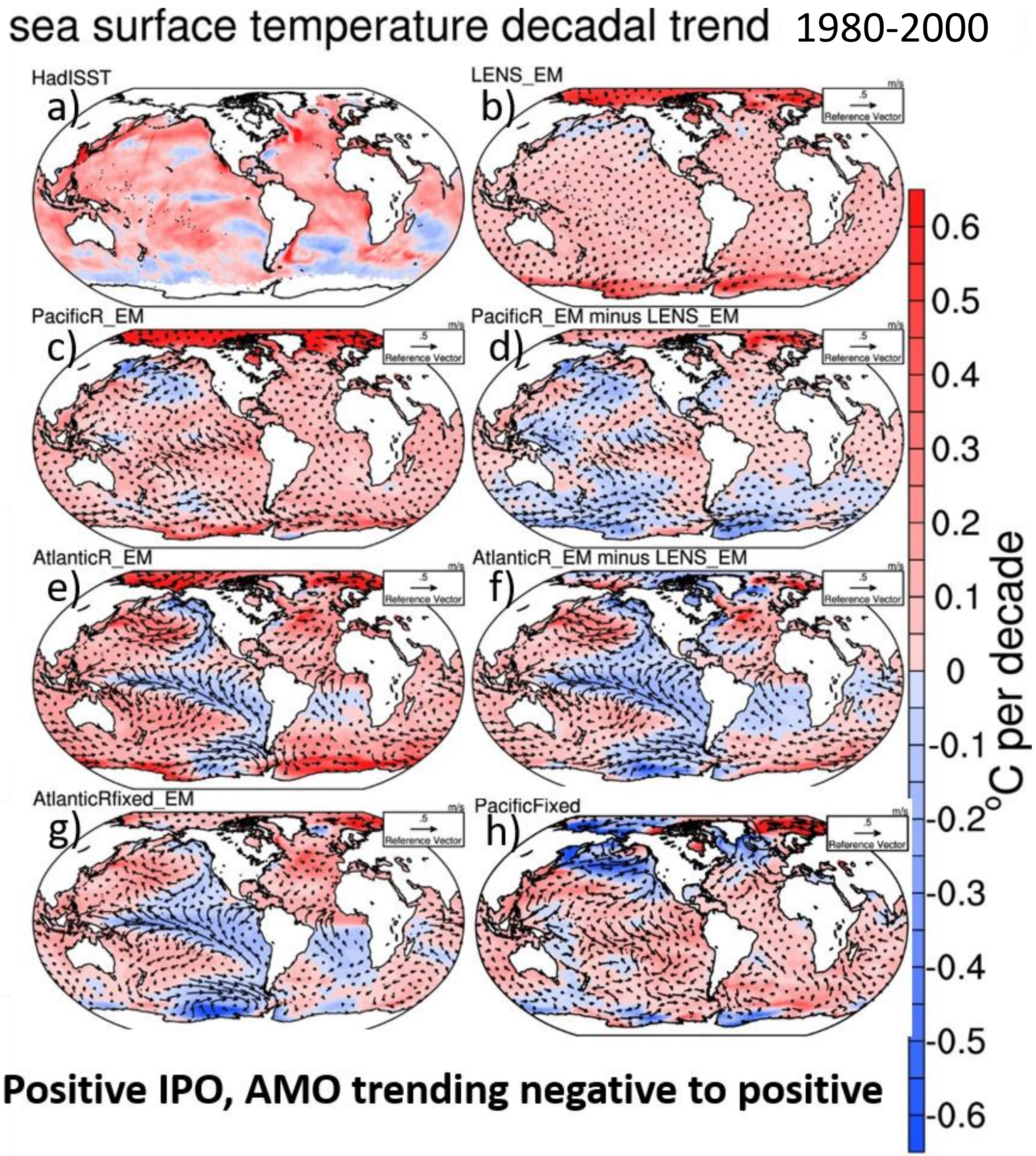
--Pacific: 20N-20S, 180-80W; restore to observed SSTs in that region, fully coupled everywhere else, 1920-2013 (Schneider and Deser, 2018)

--Atlantic: same as Pacific but for equator-60N across Atlantic basin

10 members for each



1980-2000:
Positive IPO
AMO trending negative to positive



Pacific pacemaker

Atlantic pacemaker

Atlantic and Pacific pacemakers (fixed aerosols)

Positive IPO, AMO trending negative to positive

Use time-series pacemakers to address role of Atlantic-Pacific interactions

--Pacific: 20N-20S, 180-80W; restore to observed SSTs in that region, fully coupled everywhere else, 1920-2013 (Schneider and Deser, 2018)

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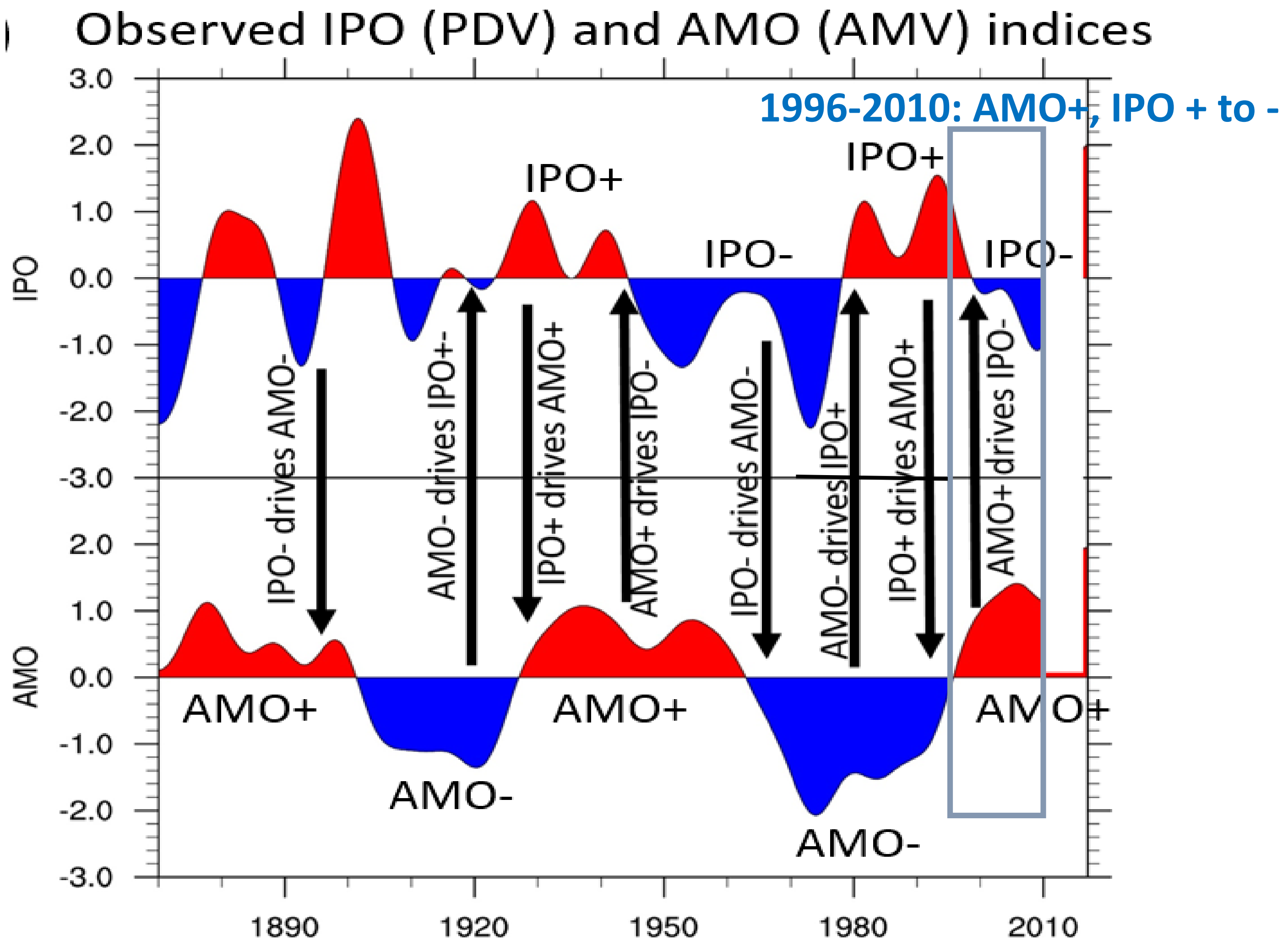
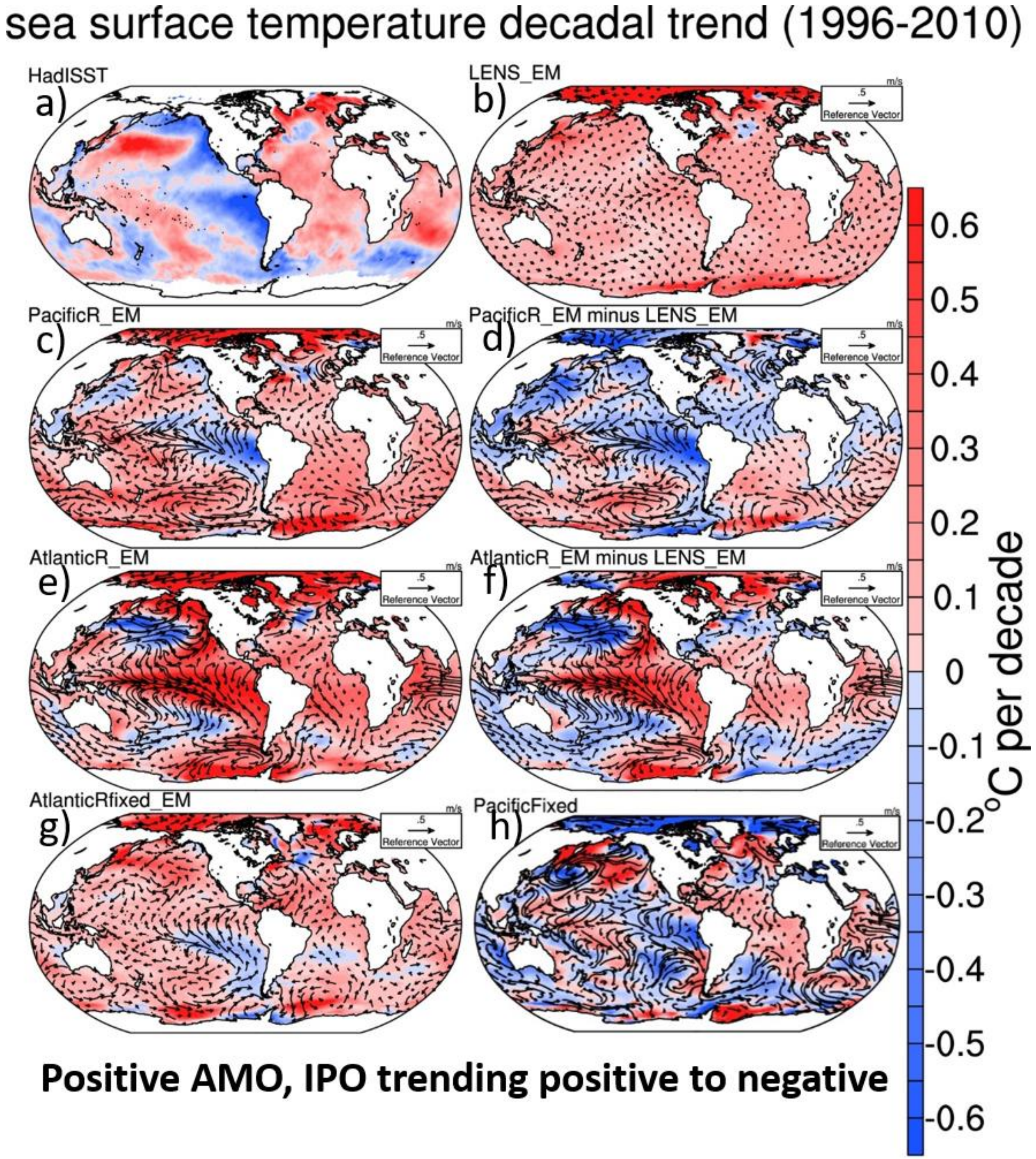


1996-2010:
Positive AMO
IPO trending positive to negative

Pacific pacemaker

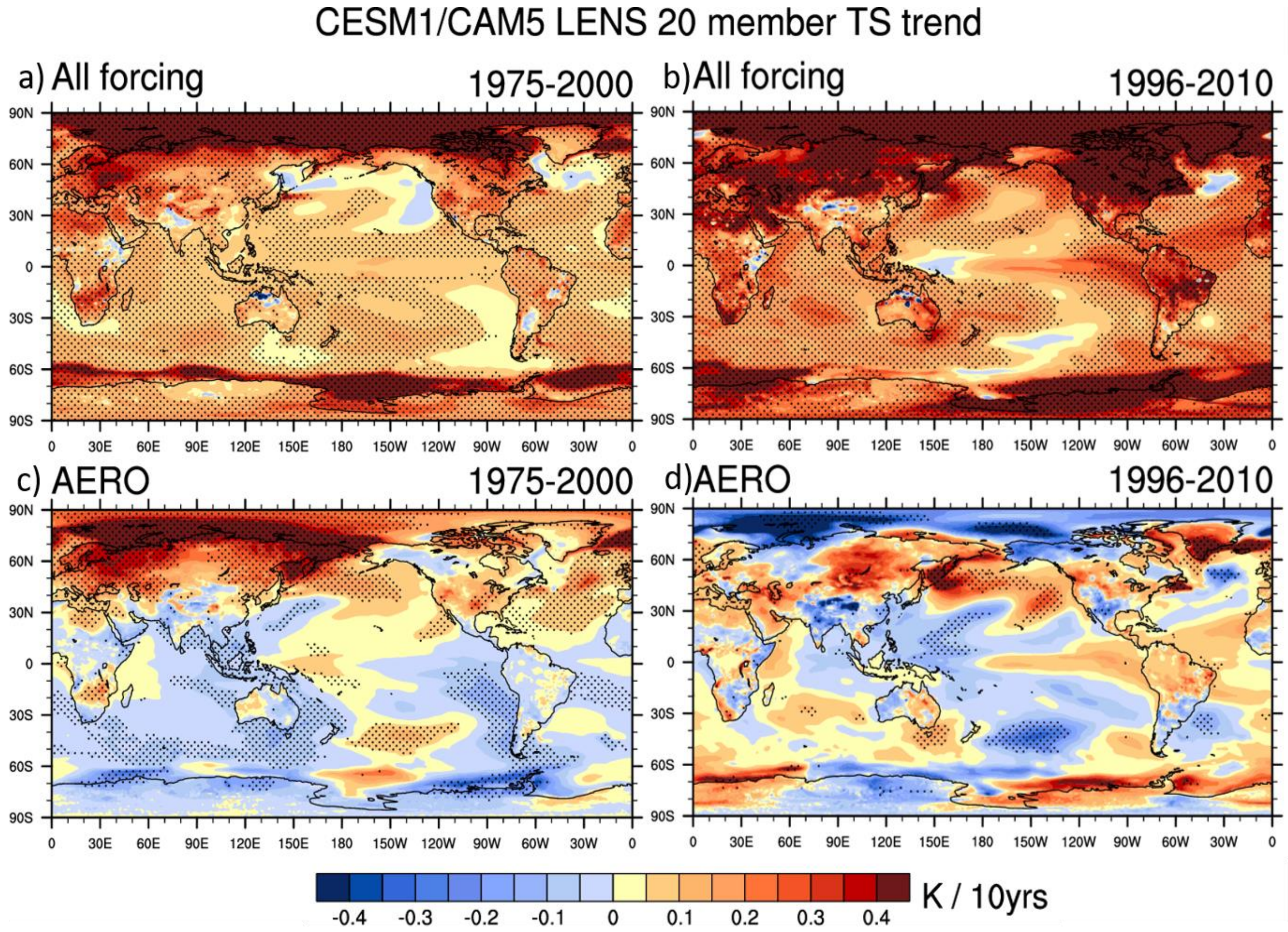
Atlantic pacemaker

Atlantic and Pacific pacemakers (fixed aerosols)



The role of aerosols in decadal variability in the observed system is still unclear

Model simulations with single forcings suggest different responses in different time periods as aerosol emissions from different regions change



Conclusions:

--by applying idealized pacemaker configurations of CESM1: **Pacific and Atlantic are mutually interactive ocean basins through the atmospheric Walker Circulation**

--**time-varying forcings complicate interpretations of short observational record** (use time series pacemakers and single forcing runs to help interpret role of aerosols in decadal variability)

--**Processes and mechanisms in both basins and their interactions must be simulated to produce credible decadal climate predictions**


1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010