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ITCP Workshop on Teleconnections in the Present and Future Climate, 24-28 October, 2016

Recent intensification of the Pacific trade wind: A possible linkage to Atlantic multidecadal variability

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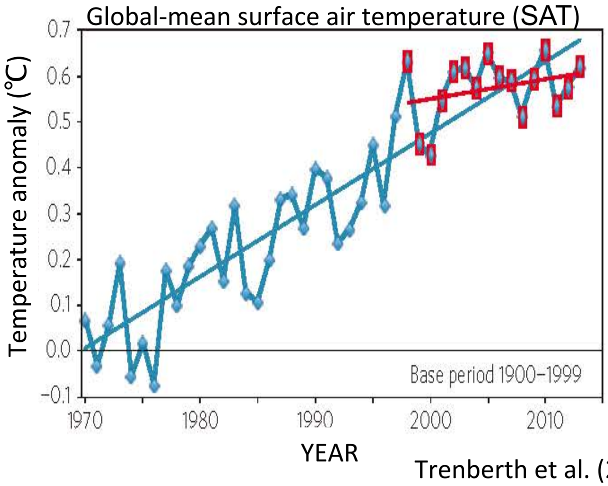
- ***Global warming hiatus***
- ***Trade wind intensification***
- ***Atlantic multidecadal variability (AMV)***
- ***Atlantic-Pacific co-variability***

Global warming hiatus



Industrial emissions continued to rise rapidly in the early 21st century, but temperatures did not increase as much as some expected.

Trenberth et al. (2014 Nature CC)

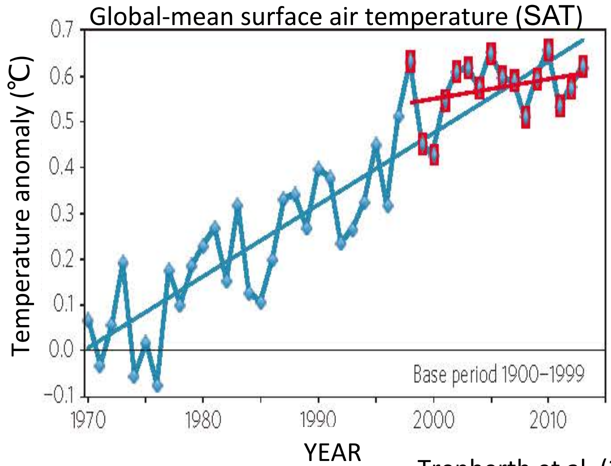
Externally forced?

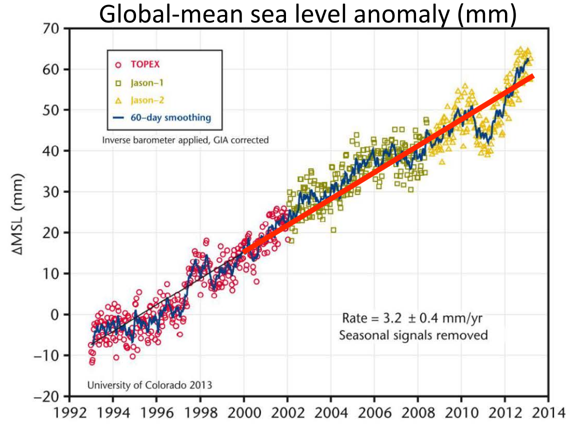
- ☐ *Stratospheric aerosols, Solar & minor volcanoes*

Internally generated?

- ☐ *Negative IPO*

Global warming hiatus





Trenberth et al. (2014 Nature CC)

UK Met Office (2013)

Externally forced?

- *Stratospheric aerosols, Solar & minor volcanoes*

Internally generated?

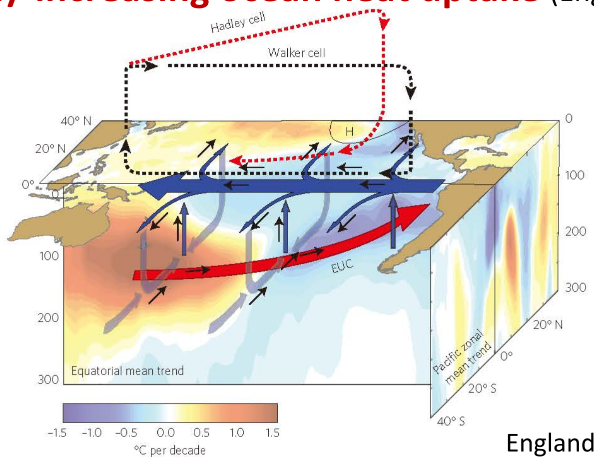
- *Negative IPO*

From energy budget perspective, Global warming has not been slowing down

Intensified Pacific trades and ocean heat uptake

- **Hiatus can be identified in CGCM piControl runs, with coherent strengthening of ocean heat uptake**
  (Meehl et al. 2011 Nature CC, Watanabe et al. 2013 GRL, Drijfhout et al. 2014 GRL)

- **Intensified Pacific trades in the 2000s**
  → hiatus w/ increasing ocean heat uptake (England et al. 2014 Nature CC)

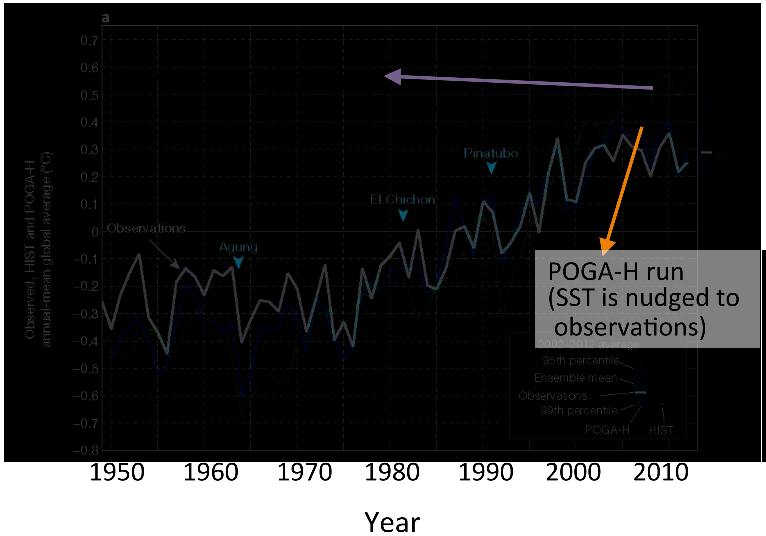


England et al. (2014 Nature CC)

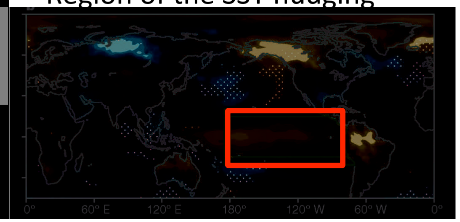
First successful simulation of the warming hiatus

'Pacemaker' experiment using GFDL CM2.1

Model can reproduce the hiatus if equatorial Pacific cooling were given



Region of the SST nudging



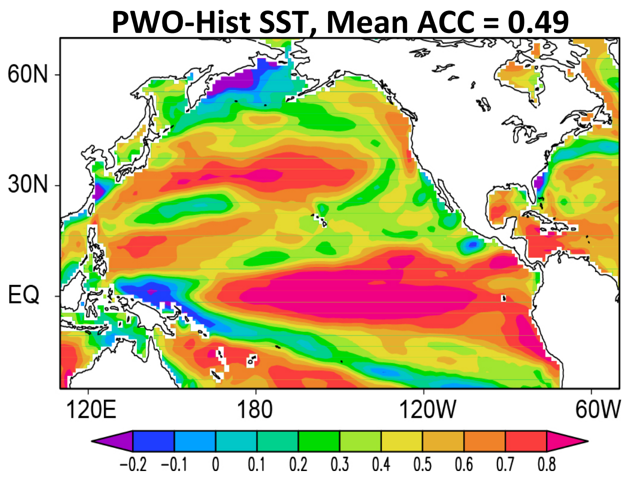
Kosaka and Xie (2013, Nature)

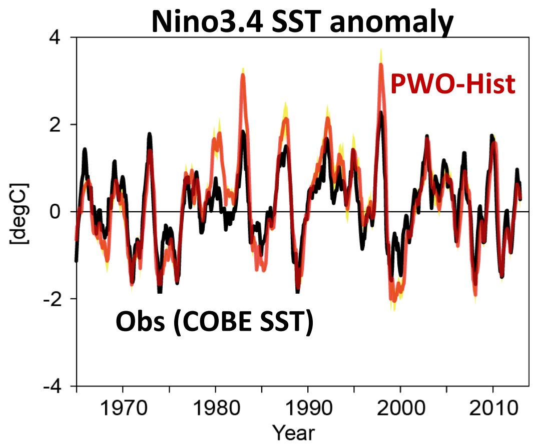
SST driven or wind driven? Does not matter

'Pacemaker' experiment using MIROC5.2

PWO-Hist: Tropical (30S-30N) τ anomaly replaced with JRA55

Reproducibility of the Pacific SST variability in PWO-Hist





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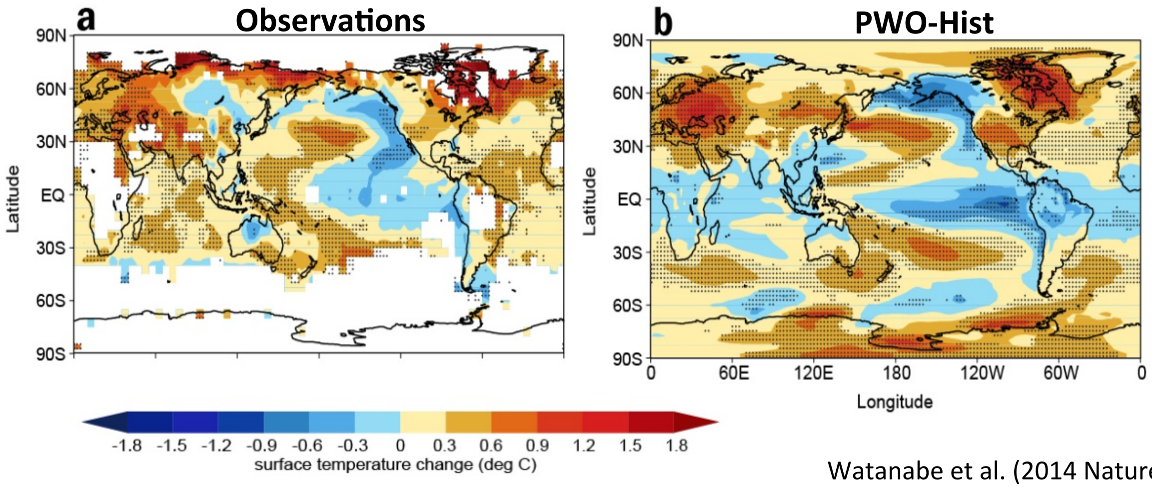
Hiatus pattern reproduced in MIROC5.2

Tropical ocean wind stress anomalies are sufficient to reproduce surface temperature anomaly pattern in the hiatus

SAT change from 1990-1999 to 2001-2012



Watanabe et al. (2014 Nature CC)

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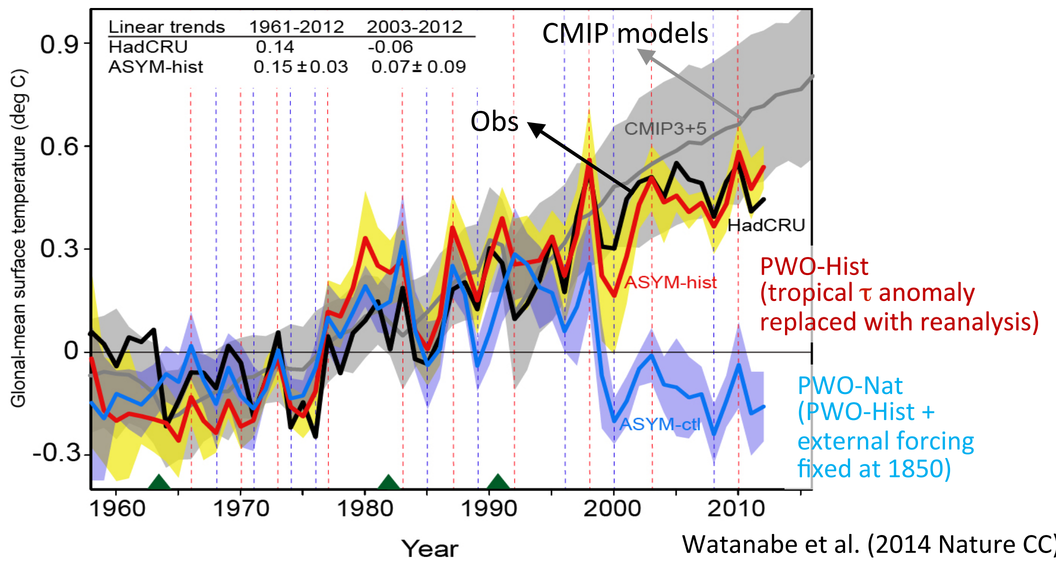
Global mean SAT time series in MIROC5.2

PWO-Hist vs PWO-Nat (no change in external forcing)

Decadal wind stress variability substantially contributes to the warming acceleration in the 1980-90s and hiatus in the 2000s



Watanabe et al. (2014 Nature CC)

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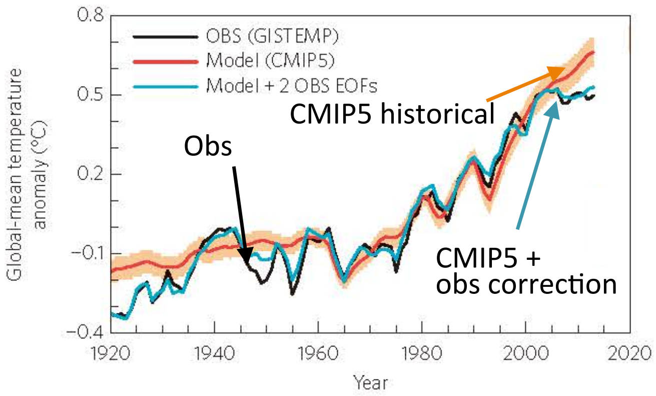
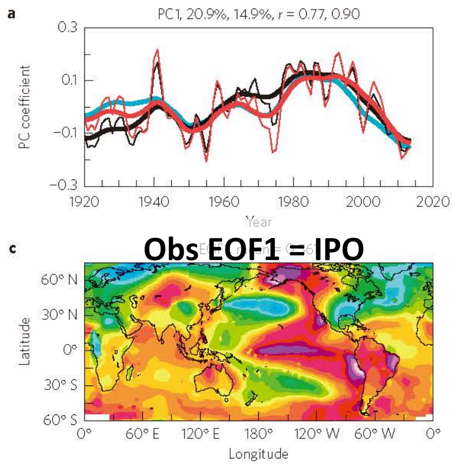
Global mean SAT time series (reconstruction)

Statistical combination of the CMIP5 historical runs and obs

Adding observed IPO is sufficient for CMIP5 models to reproduce the warming slowdown



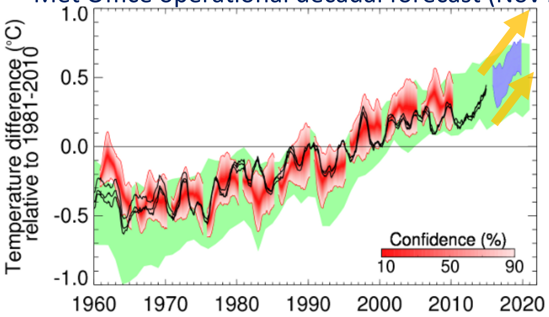


Dai et al. (2014 Nature CC)

What have we learned?

- Coupled models can reproduce the hiatus well if the tropical Pacific is constrained by observations (either SST or winds)
- Natural decadal variability associated with the IPO seems to explain a significant fraction of the global warming hiatus as well as acceleration in the 1980-90s
- A part of the decadal climate change responsible for the warming hiatus may be predictable (Doblas-Reyes et al. 2013 Nature Comm, Meehl et al. 2014 Nature CC, etc)

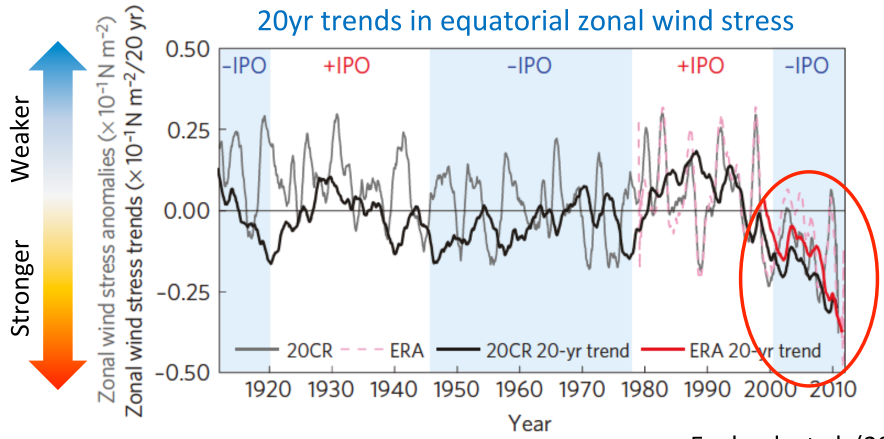
Met Office operational decadal forecast (Nov 2015-)



"10yr global average warming rates are likely to return to late 20th century levels within the next two years"

Met Office (2016)

Intensification of Pacific trade winds is still puzzling



England et al. (2014 Nature CC)

Record intensification over the past two decades → may not be due to the IPO *alone*

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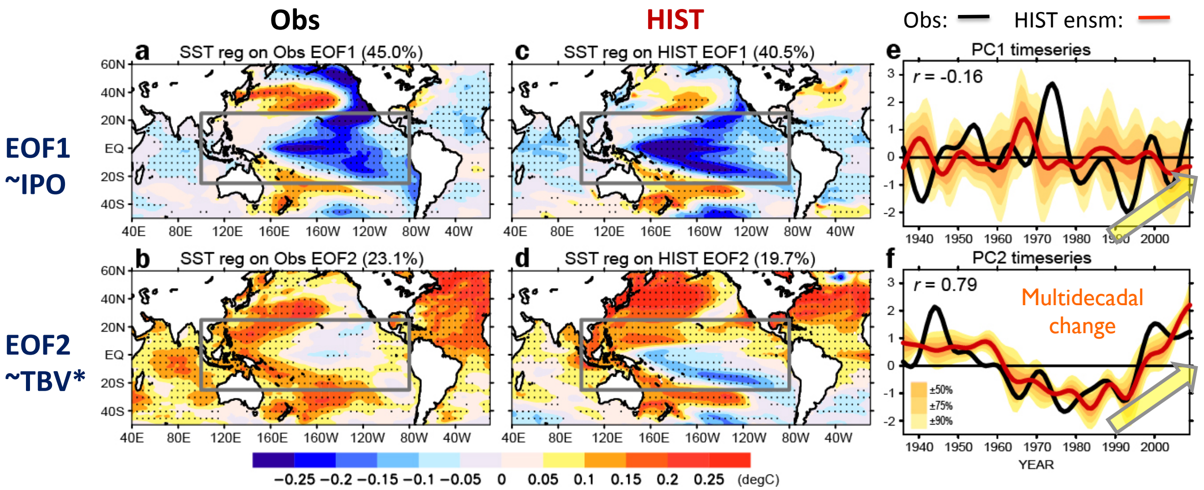
Two dominant decadal SST patterns and time series

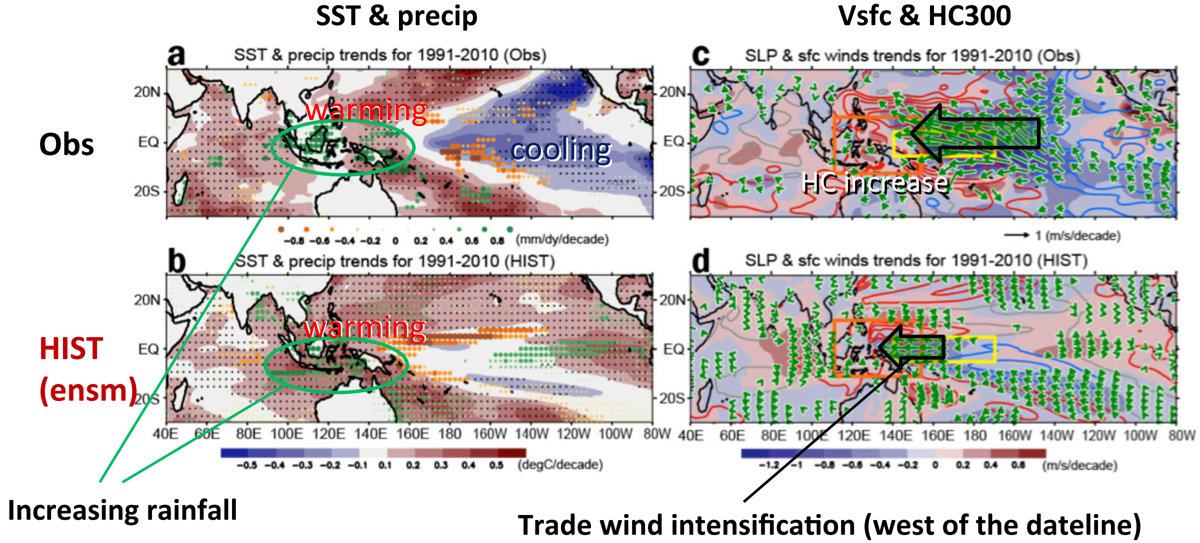
- MIROC5.2 CGCM (Atmosphere： T85L40, Ocean： 1x1°L63)
- 5-member historical simulations for 1921-2014 (HIST)

Analysis to the 10yr lowpass filtered SST anomalies (de-trended)



* Trans-Basin Variability (McGregor et al. 2014 Nature CC, Chikamoto et al. 2015 Nature Comm)

Linear trends for 1991-2010



Trade wind intensified by enhanced zonal SST gradient associated with:

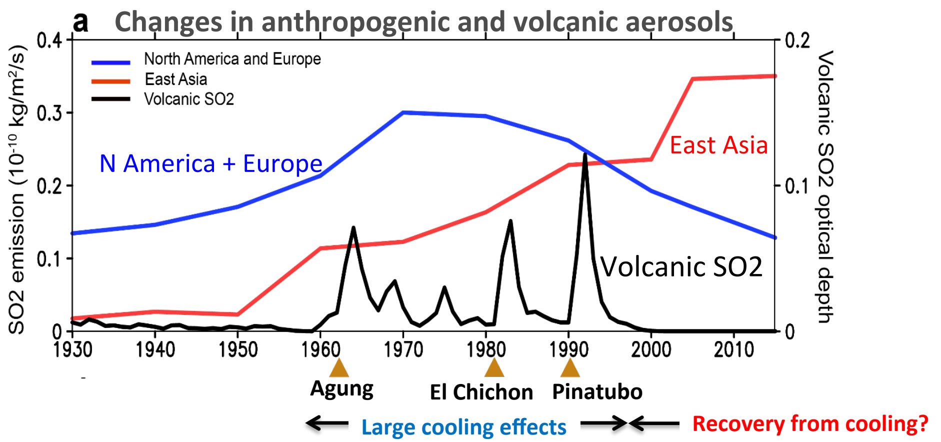
- ☐ Eastern Pacific cooling ← negative IPO (likely to be internal variability)
- ☐ Western Pacific warming ← positive TBV (forced by sulphate aerosols)

Possible cause of the forced multidecadal variability

- ☐ GHGs → unlikely
- ☐ Aerosols → may be

Which is guilty?

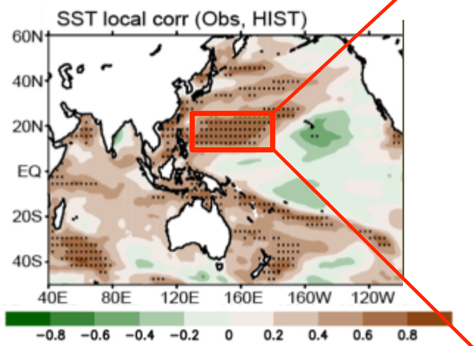
- ☐ MIROC5.2 CGCM (Atmosphere： T85L40, Ocean： 1x1°L63)
- ☐ 5-member historical simulations for 1921-2014 (HIST)
- ☐ 5-member fixed sulphate aerosol simulations for 1921-2014 (SO2CONST)
- ☐ 5-member fixed volcanic sulphate aerosol for 1921-2014 (VOLSO2CONST)

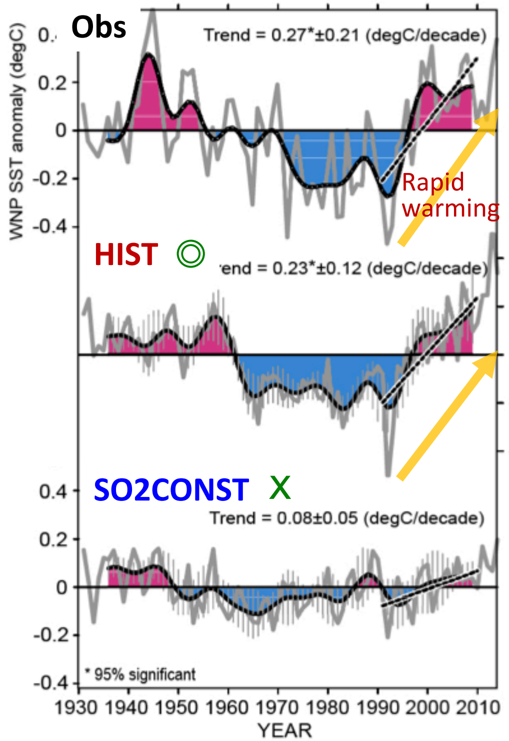


Western Pacific SST variability (1931-2014)

Reproducibility of decadal SST variability

Local correlation for decadal SST anomalies between Obs and HIST ensemble mean

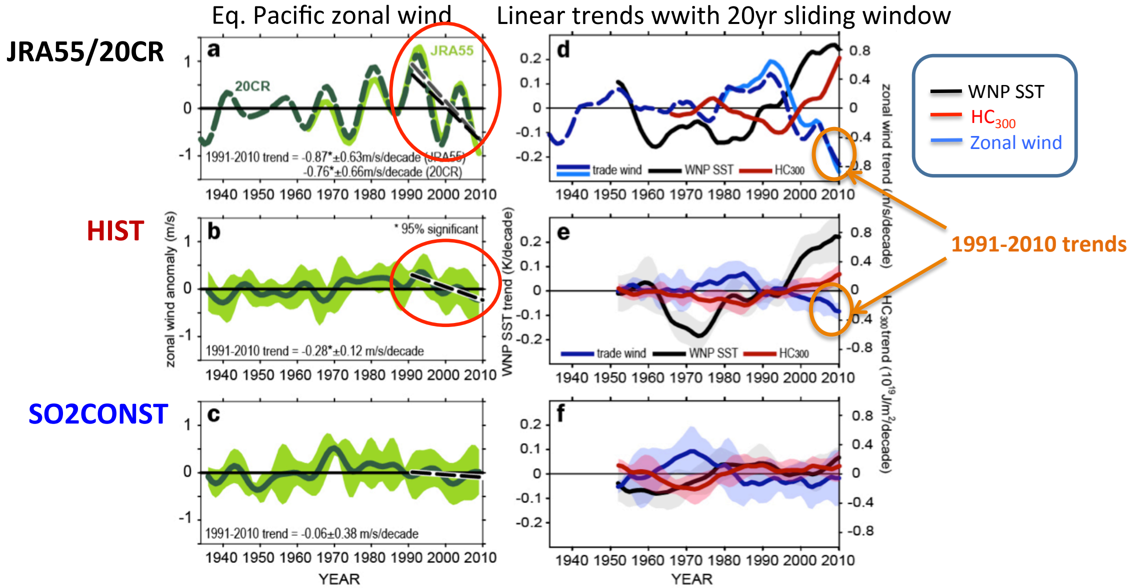




Takahashi and Watanabe (2016 Nature CC)

Western Pacific multidecadal SST variability has been driven by the past changes in sulphate aerosols (volcanic forcing > anthropogenic forcing)

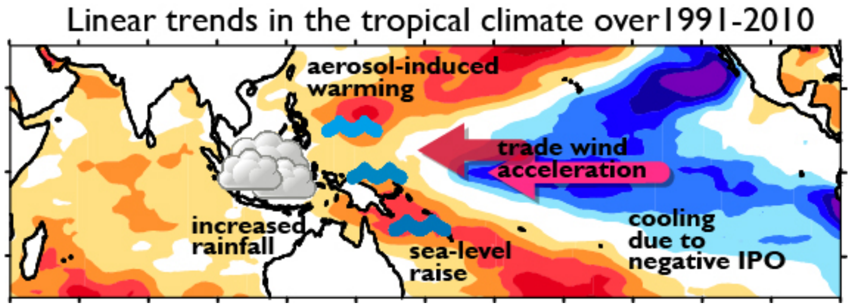
20yr linear trends in trade wind



Takahashi and Watanabe (2016 Nature CC)

Aerosol-induced acceleration of the equatorial trade wind, as well as the WNP warming and HC_{300} increase, explains 34% of the observed trends

Schematic

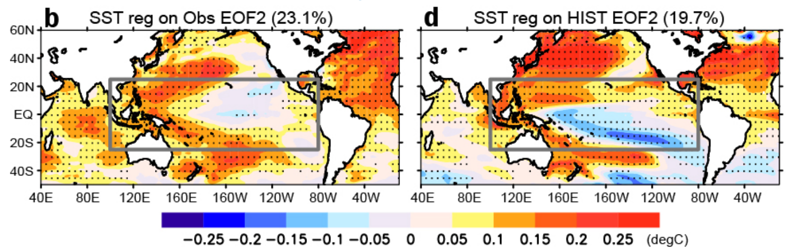


- Dominant Pacific decadal SST pattern (TBV), responsible for the western Pacific warming trends for 1991-2010, was forced by sulphate aerosols
- The western Pacific warming causes the Pacific trade wind to intensify
  → explain about 1/3 of the observed trends
- These trends are independent of the negative IPO and have not contributed much to the global warming hiatus, but impacted the western Pacific sea level and precipitation changes

Is TBV a forced pattern, or an intrinsic mode?

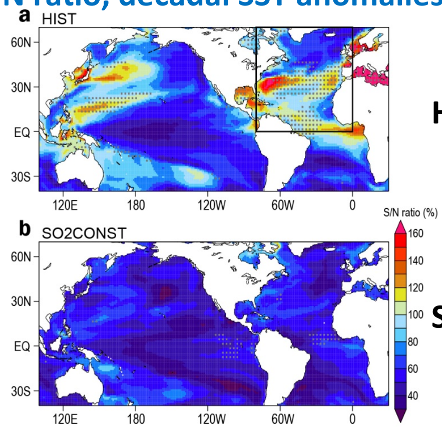
TBV patterns

Obs



MIROC HIST

S/N ratio, decadal SST anomalies



HIST

SO2CONST

- ☐ **TBV does not emerge in other MIROC runs (piControl, SO2CONST)**
- ☐ **Coincidence between TBV anomalies & large S/N ratio**

→ **Both suggesting TBV is *not* a mode of natural variability**

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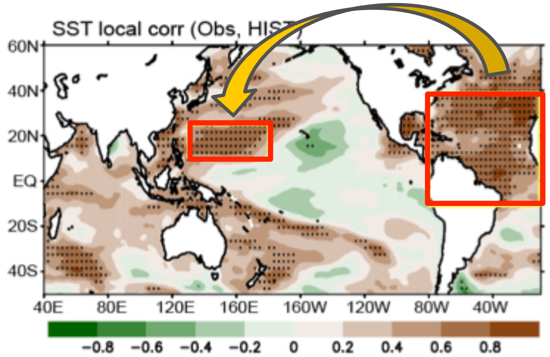
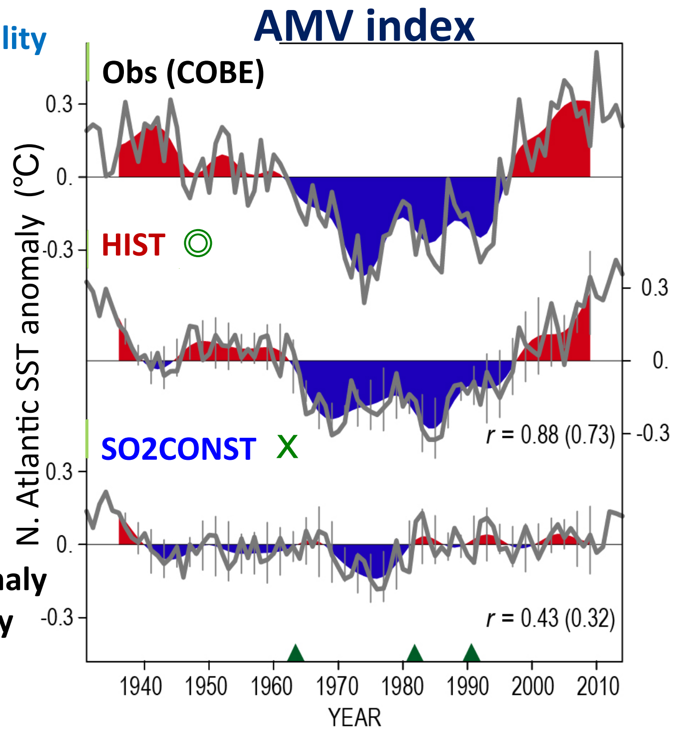
Covariation between WNP & N. Atlantic

Reproducibility of decadal SST variability

Significant correlation found in the Atlantic as well





* SW radiative forcing -> Atl SST anomaly
* Latent heat flux -> NWP SST anomaly

Suggest remote influence from the Atlantic is the key

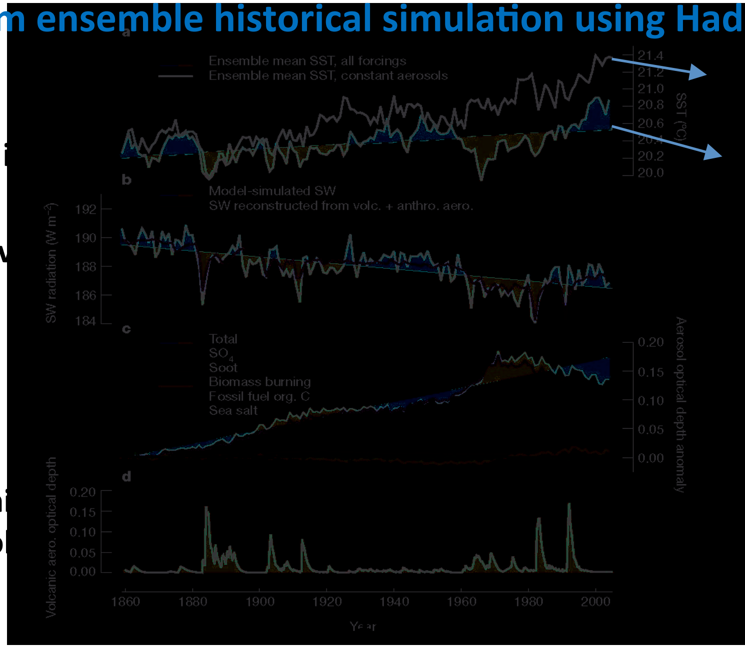
Aerosol driving of the AMV

4-mem m ensemble historical simulation using HadGEM2

Atl SST
(=AMV i

SW radiativ
forcing

Volcani
aerosol



onstant aerosols

All forcing

ntribution of
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rosols
ominated by
lphur aerosols)

et al. (2012 Nature)

First report showing that the observed AMV has been driven by the past history of sulphate aerosol emission

Aerosol driving of the AMV

Controversy

- Conventional view: AMV is an oscillatory mode of low-frequency climate variability coupled with changes in AMOC (Delworth et al. 1993, Zhang et al. 2013, and many others)
- But, external radiative drivers (e.g. solar activity and aerosols) might act to determine the phase of AMV (Booth et al. 2012, Otterå et al. 2010)
- Observed AMV may be a combination of the above two (Terray 2012, Ting et al. 2014)

Indeed, there is an internally generated variability!

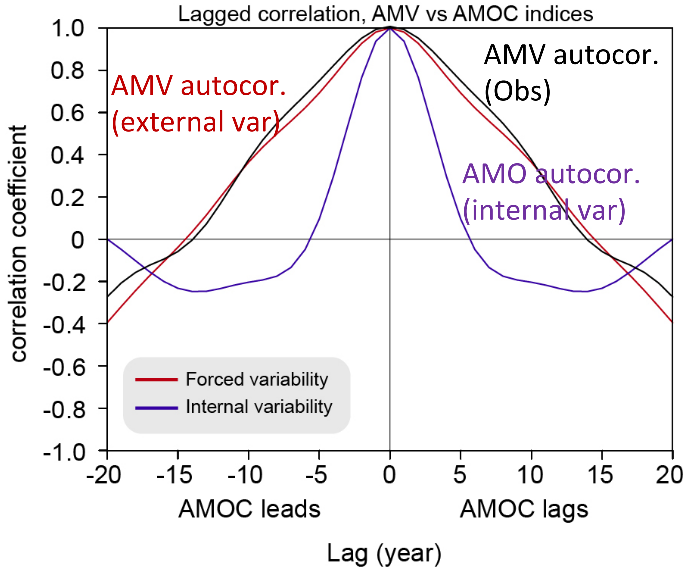
$$T = \langle T \rangle + T'$$

Ensemble mean (=forced component) — $\langle T \rangle$

Ensemble deviations (=internal variability) — T'

AMV, AMO and AMOC

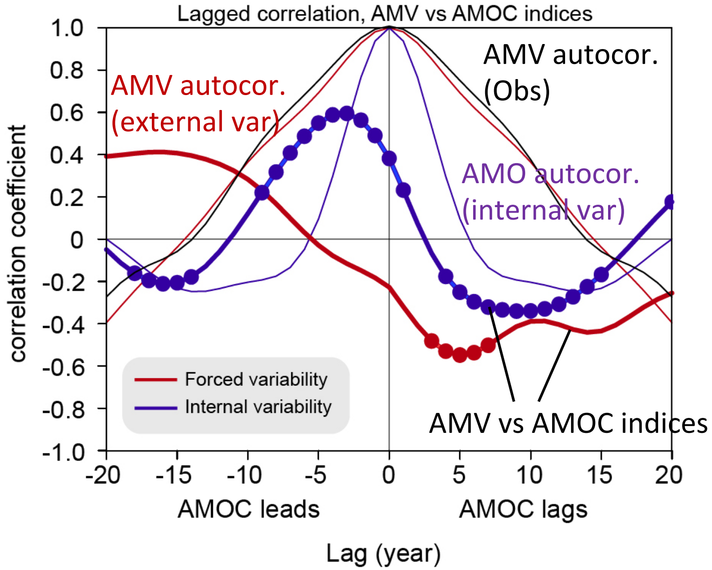
Atlantic Multidecadal *Oscillation* (AMO) = internally generated variability



＊AMO has a shorter timescale than AMV

AMV, AMO and AMOC

Atlantic Multidecadal *Oscillation* (AMO) = internally generated variability



＊AMO has a shorter timescale than AMV, and is coherent with AMOC at 3-4yrs leads

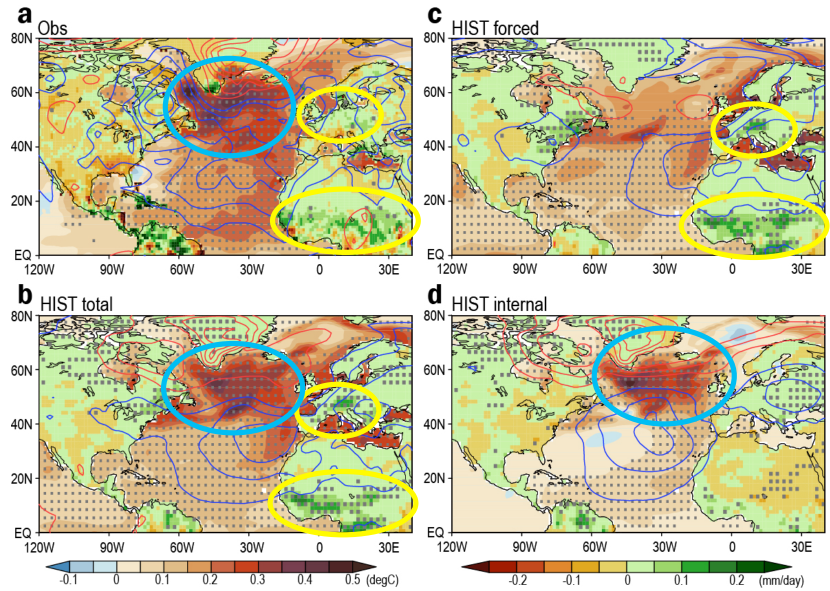
＊Time evolution of the AMO suggests a delayed oscillation mechanism as in literature

Attribution of AMV

Regression (SST, SLP, precip, 10y lowpass) on the AMV index

Obs T

HIST T (all)



HIST $\langle T \rangle$ (forced)

HIST T' (internal)
⇒ **coherent w/ AMOC**

* Large SST anomaly in the high latitudes from AMO
* Forced response has larger impacts on precip variability over Europe & Sahel

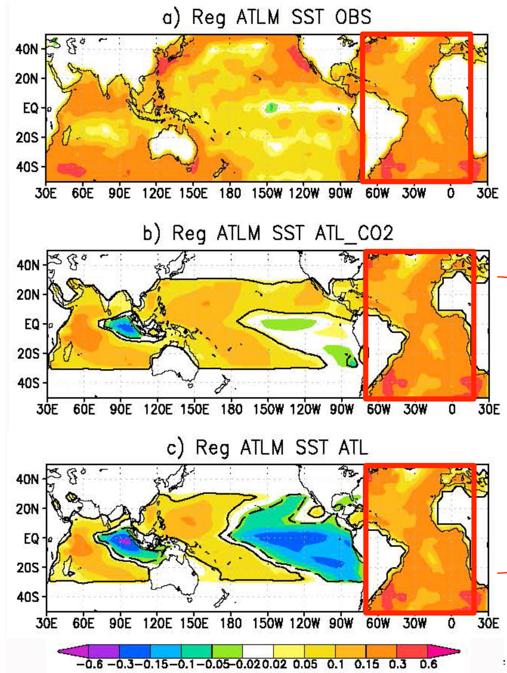
Atlantic impact on the Pacific

Partial coupling experiments

Reg with Atl SST index (Obs)

Reg with Atl SST index (ICTP GCM)

Reg with Atl SST index (same but fixed CO2)



Atlantic SSTA prescribed with HadISST data

WNP warming + La Nina-like cooling responses

Kucharski et al. (2011 GRL)

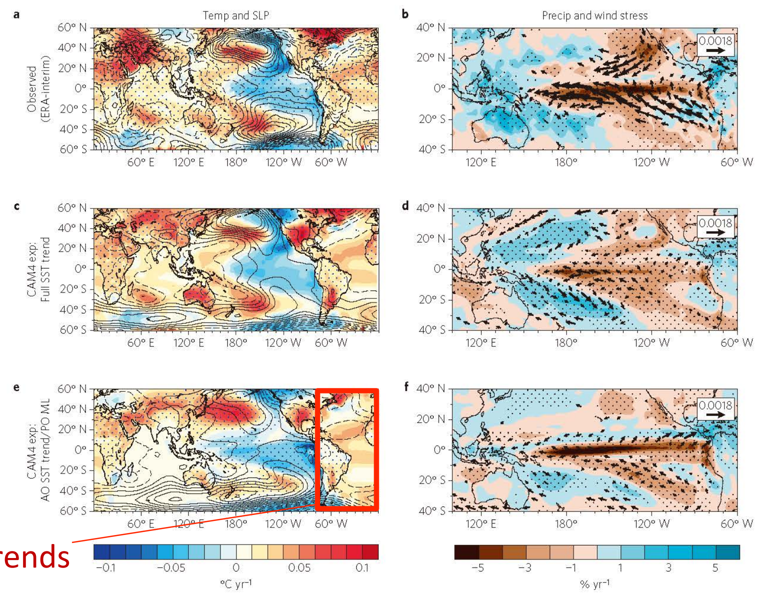
Atlantic impact on the Pacific

Linear trends in SST & winds for 1992-2011

Observations

CAM4 AGCM
(global SST trend)

CAM4 AGCM+ML
(Atlantic SST trend)



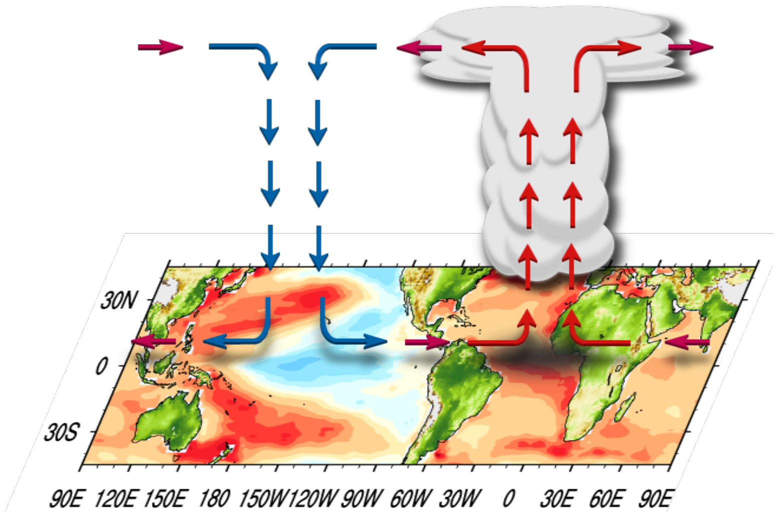
Prescribed SST trends

Much weaker than obs, but trade wind is intensified

McGregor et al. (2014 Nature CC)

Mechanisms of the Atlantic impact on the Pacific

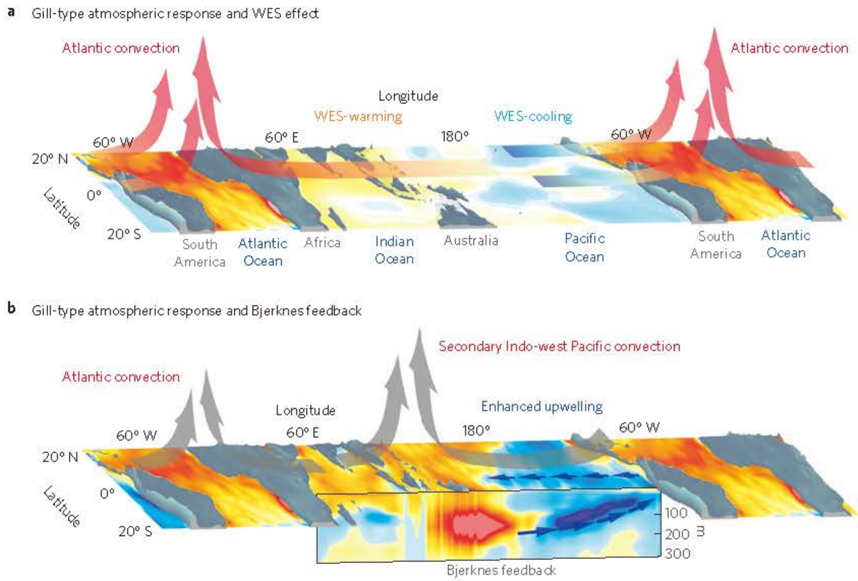
Westward remote influence



Chikamoto et al. (2015 Nature COMM)

Mechanisms of the Atlantic impact on the Pacific

Eastward remote influence



Li et al. (2015 Nature CC)

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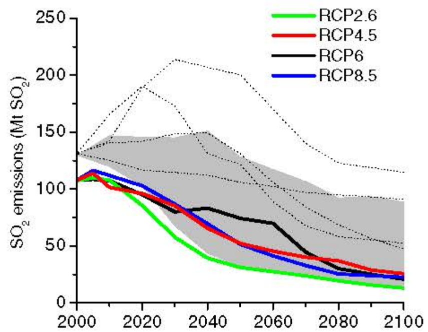
Implication to the AMV in future climate

Given that the past AMV has primarily been driven by sulphate aerosols, what will the future AMV be ?

- Anthropogenic SO2 emissions are assumed to decline in all RCP scenarios
- To the extent of future climate consistent with RCPs, internal processes will increasingly be the major driving mechanism of the AMV

Global SO2 emissions in RCPs



van Vuuren et al. (2012)

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Implication to the AMV in future climate

Given that the past AMV has primarily been driven by sulphate aerosols, what will the future AMV be ?

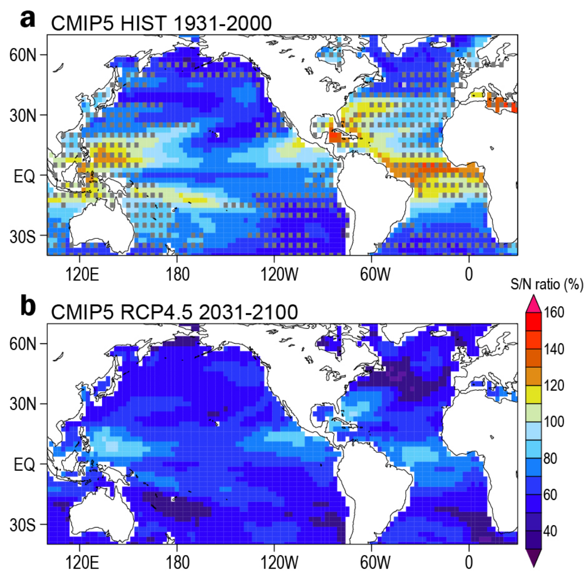
S/N ratio, decadal SST anomalies in CMIP5

1931-2000 (historical)

Forced decadal variability will dominate less in future climate as declining of the SO2 emissions

2031-2100 (RCP4.5)

Models:
CSIRO, CanESM2,
CCSM4, GISS-E2R,
MIROC5 (5mem each)



10y low-pass SST anomaly

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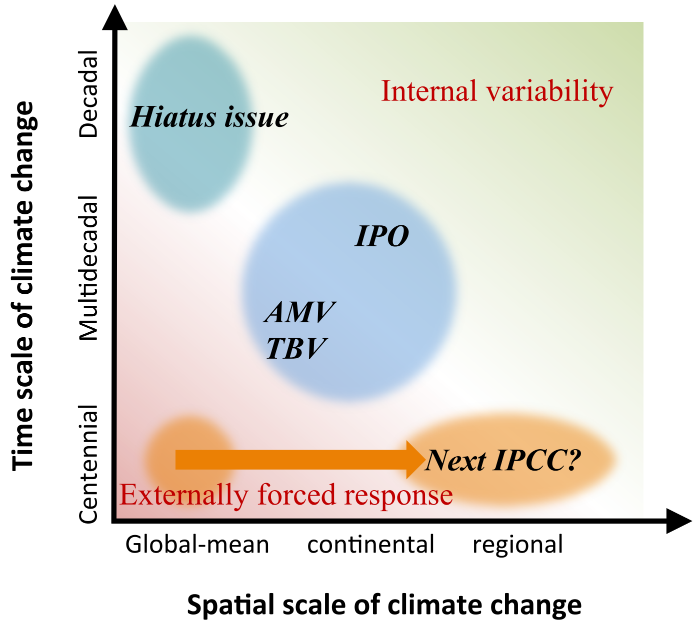
Controversy tends to reside between external and internal processes



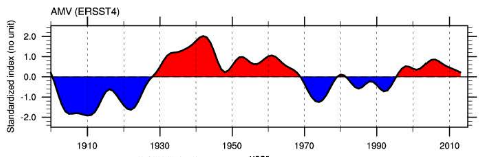
Opportunity for coordinated GCM experiments

An example: *Decadal Climate Prediction Project (DCPP)* (∈ CMIP6)

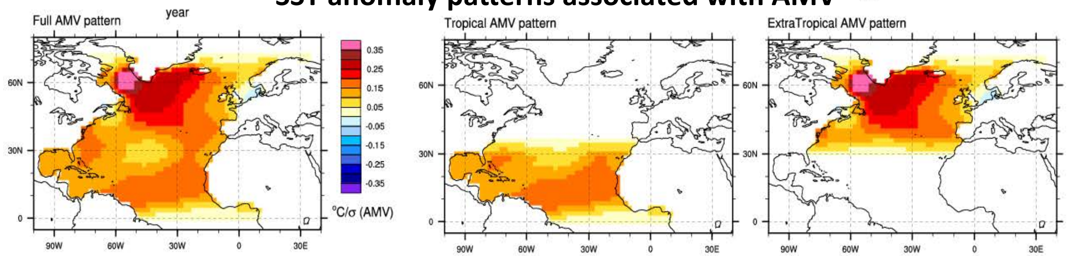
CGCM exps with restoring Atlantic SST to

- **Model climatology**
- **Model clim + Obs AMV+ pattern**
- **Model clim + Obs AMV- pattern**

AMV index



SST anomaly patterns associated with AMV



Boer et al. (2016 GMD in revision)

Understanding remote impacts of AMV (or a part of it) to other basins and GMT

Summary & remarks

- Dominant Pacific decadal SST pattern (TBV), representing a linkage with the Atlantic multidecadal variability, appears a forced response of the climate system. However, we need further evidence.

- Attribution of the AMV may still be controversial, and the path of remote teleconnection from the (tropical?) Atlantic to the western Pacific has to be clarified.

- Lessons from the debate on the warming hiatus include importance of attribution of decadal-scale climate change (even the global mean) to natural variability and externally forced response.

- Coordinated CGCM experiments (e.g. pacemaker experiments) will be useful for understanding the mechanism of the decadal climate change/variability, as well as for increasing the robustness.

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Thank you

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Chikamoto, Y., A. Timmermann, J.-J. Luo, T. Mochizuki, M. Kimoto, M. Watanabe, M. Ishii, S.-P. Xie, and F.-F. Jin, 2015: Skillful multi-year predictions of tropical trans-basin climate variability. *Nature Comm*., 6, doi: 10.1038/ncomms7869.

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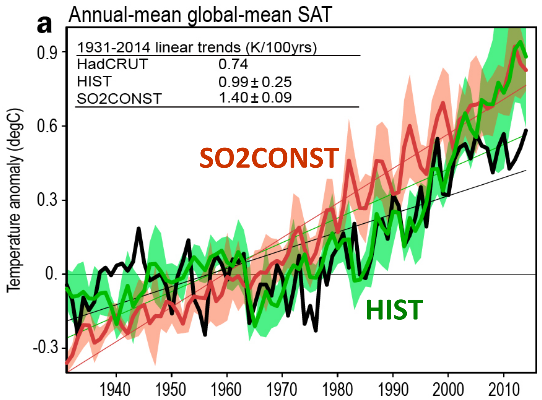
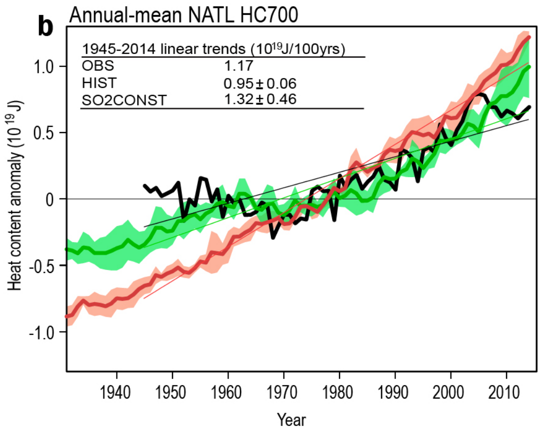
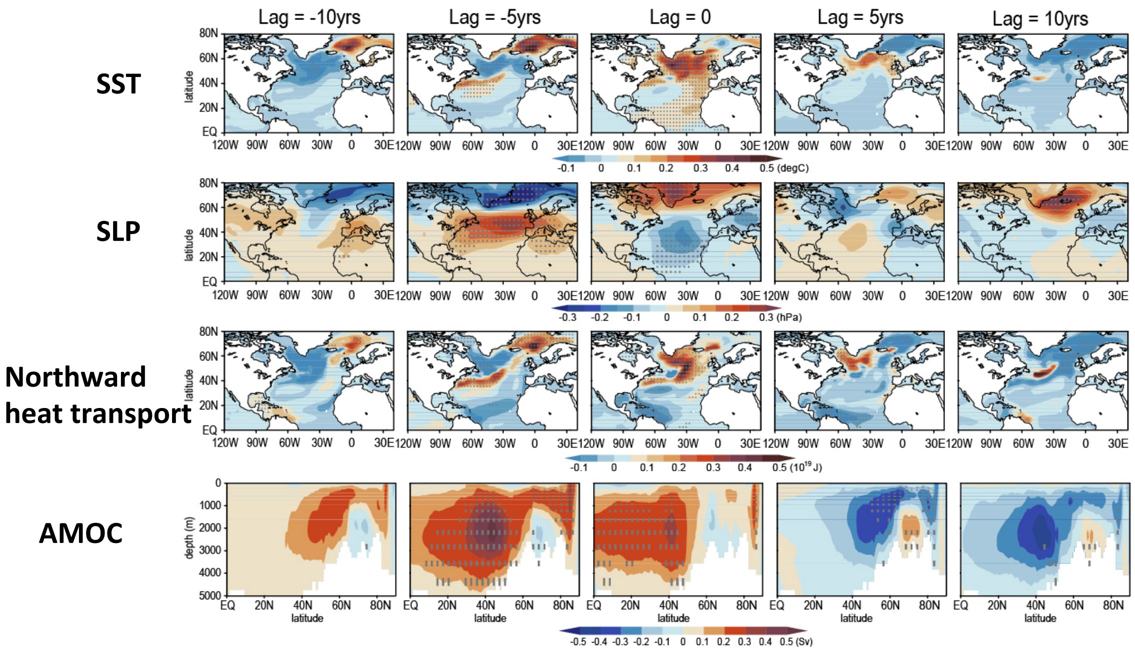
Global mean SAT & N.Atl heat content

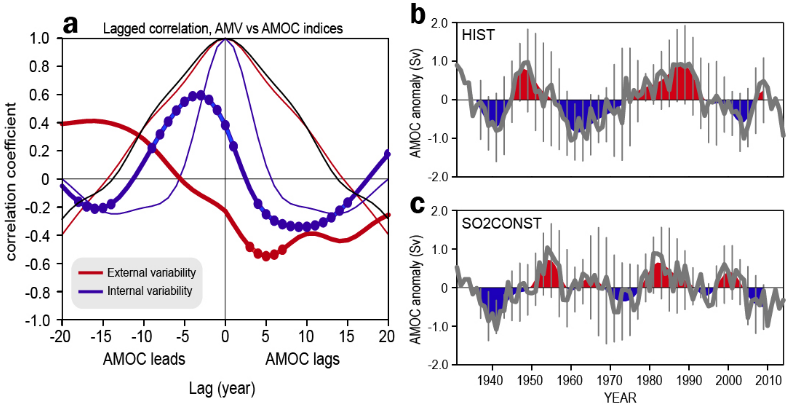




Time evolution of the AMO



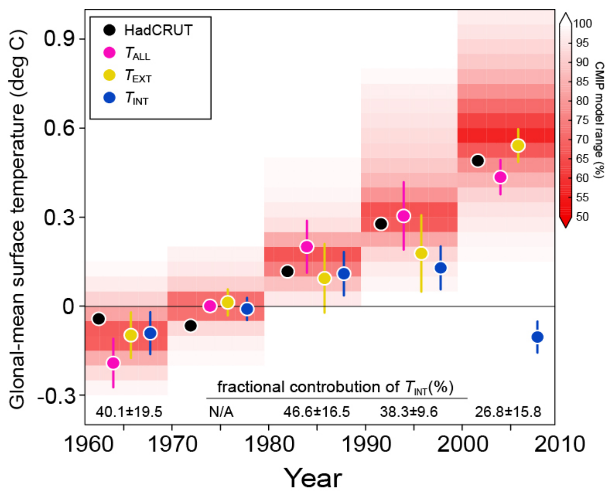
AMV


a
Lagged correlation, AMV vs AMOC indices
correlation coefficient
External variability
Internal variability
AMOC leads
AMOC lags
Lag (year)
b
HIST
AMOC anomaly (Sv)
c
SO2CONST
AMOC anomaly (Sv)
YEAR

Attribution of hiatus

Contribution of natural internal variability & external forced component to the global warming acceleration & hiatus

Substantial contribution of the internal decadal variations
Fractional contribution decreases as rising signal of anthropogenic warming



Decomposition of decadal-mean SAT changes

$$\Delta T_{ALL} = \Delta T_{INT} + \Delta T_{EXT}$$

PWO-Hist PWO-Nat diff.

Decade	ΔT_{INT}	$\Delta T_{INT}/\Delta T_{ALL}$
1980s	+0.11K	47%
1990s	+0.13K	38%
2000s	-0.11K	27%

Watanabe et al. (2014 Nature CC)

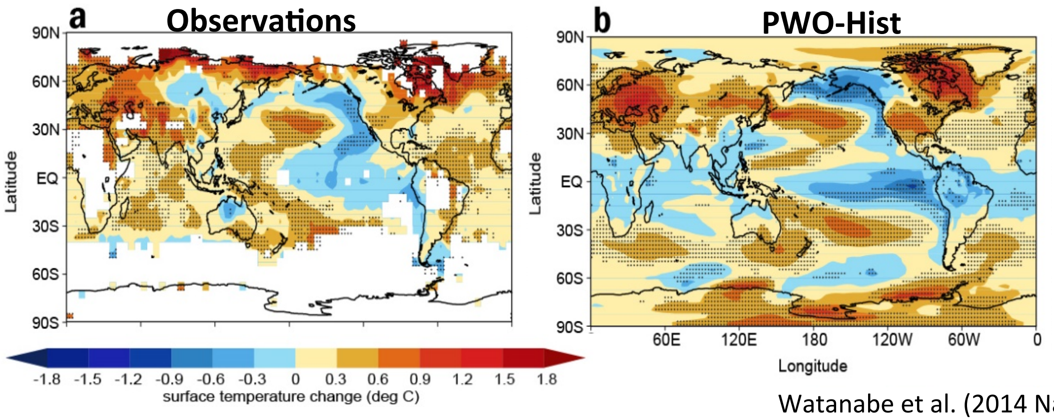
Hiatus reproduced in MIROC5.2

Partial wind overriding experiments (5-mem ensemble) for 1958-2012

*** PWO-Hist: Tropical (30S-30N) τ anomaly replaced w/ JRA reanalysis**

*** PWO-Nat: As in PWO-hist but with external forcing fixed at 1850**

SAT change from 1990-1999 to 2001-2012



Watanabe et al. (2014 Nature CC)

Tropical ocean wind stress anomalies are sufficient to reproduce surface temperature anomaly pattern during the hiatus

THE UNIVERSITY OF TOKYO
SOUSEI Program for Risk Information on Climate Change
気候変動リスク情報創生プログラム

Partial Wind Overriding historical experiments

MIROC5.2 (T85L40) 5-member ensembles for 1958-2012

*** PWO-Hist: Tropical (30S-30N) τ anomaly replaced w/ JRA reanalysis**

*** PWO-Nat: As in PWO-hist but with external forcing fixed at 1850**

2001-2010 average:

PWO-Hist

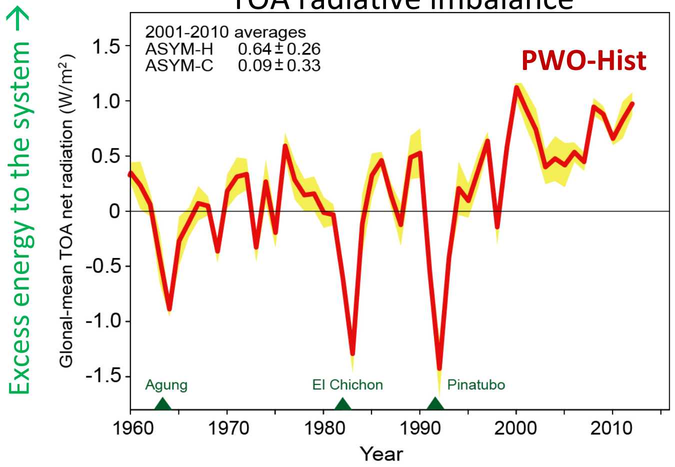
✓ 0.64±0.26 W/m^2

CERES

✓ 0.5±0.43 W/m^2
(Loeb et al. 2012 NGeo)

✓ 0.62±0.43 W/m^2
(Allan et al. 2014 GRL)

TOA radiative imbalance



Watanabe et al. (2014 Nature CC)

Fractional contributions of external radiative forcing to SST trend in WNP and Atlantic (1991-2010)

	SST Trend (K/decade)		Fractional Contribution (%)		
Region	**COBE-SST**	**HIST**	**Anthropogenic SO_2**	**Volcanic SO_2**	**Others (GHG etc.)**
WNP	0.27± 0.21	0.23 ± 0.12	-22	89	33
T. Atlantic	0.21± 0.15	0.21 ± 0.11	29	73	-2

- ☐ Anthropogenic aerosol = VOLCONST-SO2CONST
- ☐ Volcanic aerosol) = HIST- VOLCONST
- ☐ Other (GHG etc.) = SO2CONST

- Volcanic forcing : predominantly contribution to the warming

⇒ a recovery from the Pinatubo-induced cooling in the early 1990s

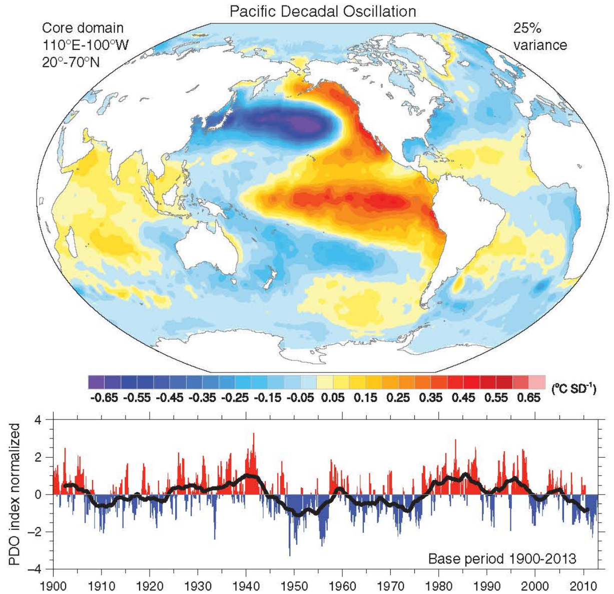
- Anthropogenic forcing : warming effect (Atlantic), cooling effect (WNP)

⇒ decrease in NA and EU (Atlantic)
increase in East Asia (WNP) of anthropogenic aerosols emission

Tropical Atlantic remote impact on Pacific with dominant volcanic aerosol forcing can explain significant SST warming trend in WNP for 1991-2010

Pacific Decadal Oscillation (PDO)

Dominant natural decadal variability in the Pacific atmosphere-ocean system



PDO tends to be in its negative phase during 2000-2012

Trenberth and Fasullo (2013)