



Tropical basin interactions and climate variability: A review

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Trieste, Italy
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Looking Back: Ocean-Atmosphere Interactions

- **Sir Gilbert Walker in the 1920s/30s found that notable climate anomalies occur every few years, associated with what he called the Southern Oscillation.**
- **Bjerknes (1969) published his seminal paper hypothesized that a ocean-atmosphere feedback involving the Walker circulation is a cause of ENSO.**
- **The scientific community ignored Bjerknes' seminal work until the 1980s because of the intense 1982-83 El Niño.**
- **The scientific community built an international Tropical Ocean-Global Atmosphere (TOGA) program (1985-1994) to study ENSO; then TOGA COARE program (1992-1993).**
- **Different programs were also developed by focusing on climate variability in particular regions or individual ocean basins.**
- **In recent years, the focuses were on CP-type El Niño, the Indian Ocean (by countries in Asia) and the Atlantic Ocean (by countries in NA and Europe).**
- **As a climate community, what should we do next?**

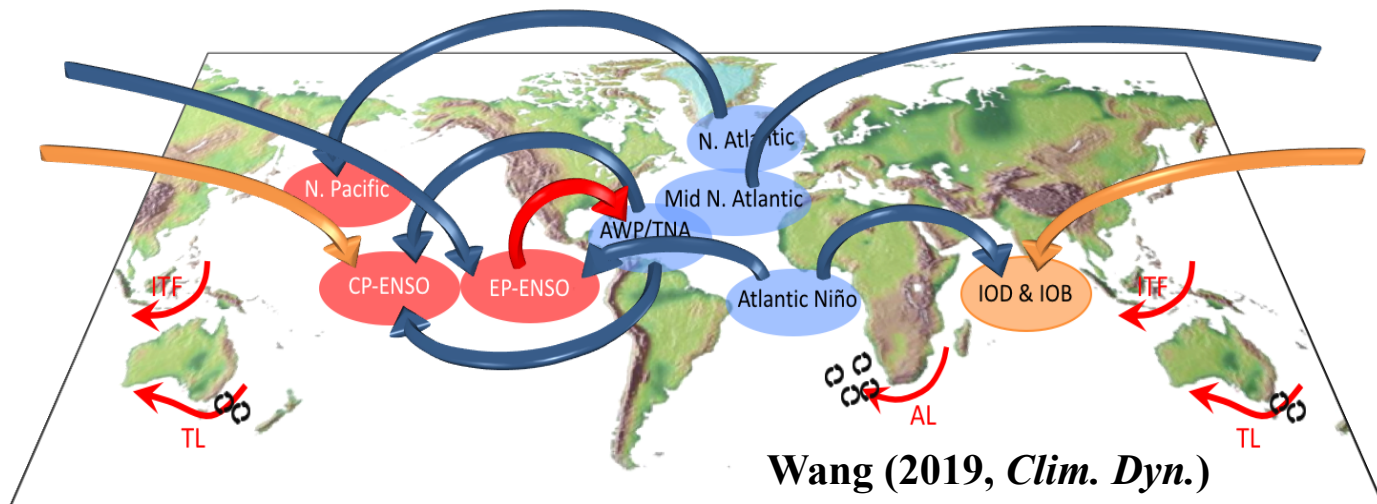
Ocean-Atmosphere Interactions and Climate

The past climate studies have reached a consensus that ocean-atmosphere interactions can form and/or modulate various climate phenomena. Several **positive** ocean-atmosphere feedback processes have been proposed:

- Bjerknes' positive feedback (1969).
- Positive wind-evaporation-SST (WES) feedback (Xie and Philander 1994; Chang et al. 1997).
- Positive SST-cloud-shortwave radiation feedback (Philander et al. 1996).
- Positive SST-cloud-longwave radiation feedback (Wang and Enfield 2003).
- ...

Looking Ahead: Three-Ocean Interactions

- The past 30+ year climate studies have reached a consensus that ocean–atmosphere interactions form various climate phenomena.
- The word “climate” is almost a synonym of ocean–atmosphere interactions.
- Global climate is beyond ocean-atmosphere interactions: **Three-ocean interactions.**



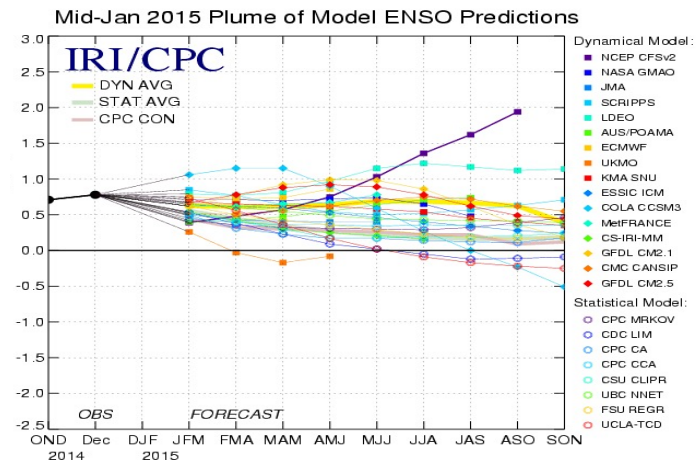
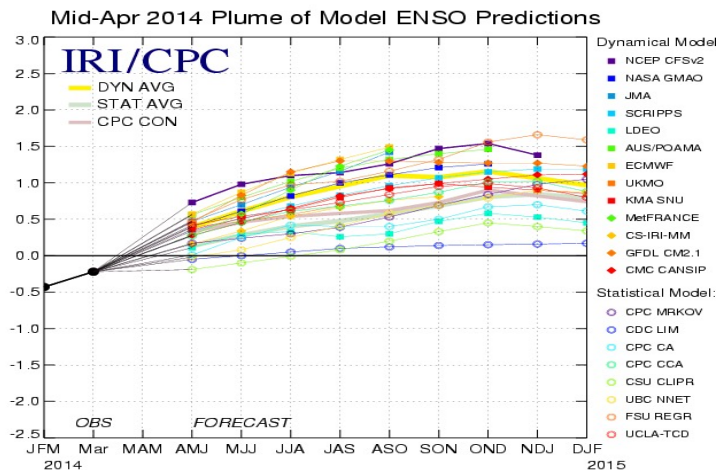
Outline

- **Why three-ocean interactions?**
- **Influence of the Pacific Ocean on other oceans**
- **Influence of the Indian Ocean on other oceans**
- **Influence of the Atlantic Ocean on other oceans**
- **Summary and future work**

Why Three-Ocean Interactions?

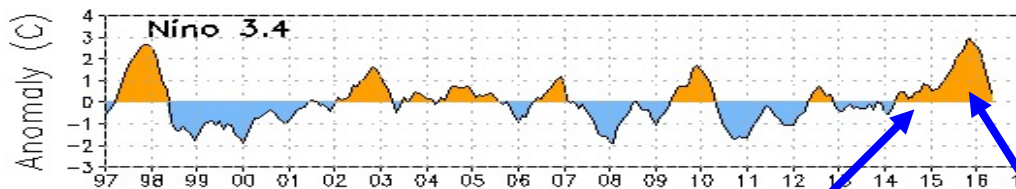
Studying the influences of three-ocean interactions on climate may help improve climate prediction and projection.

All ENSO Prediction Models (24 Models)



2014年

2015年



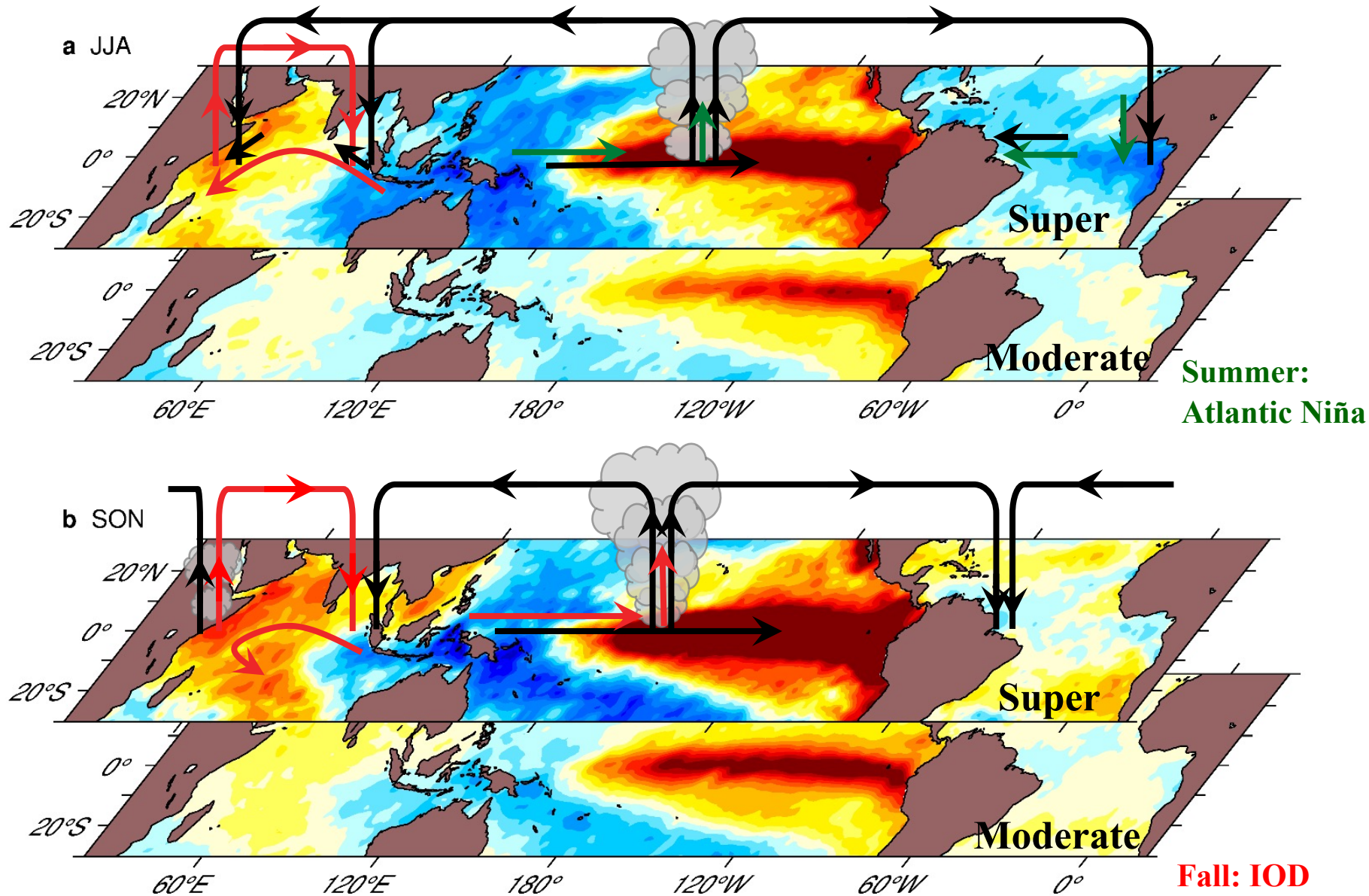
Observed Niño3.4 SST anomaly

El Niño did not occur

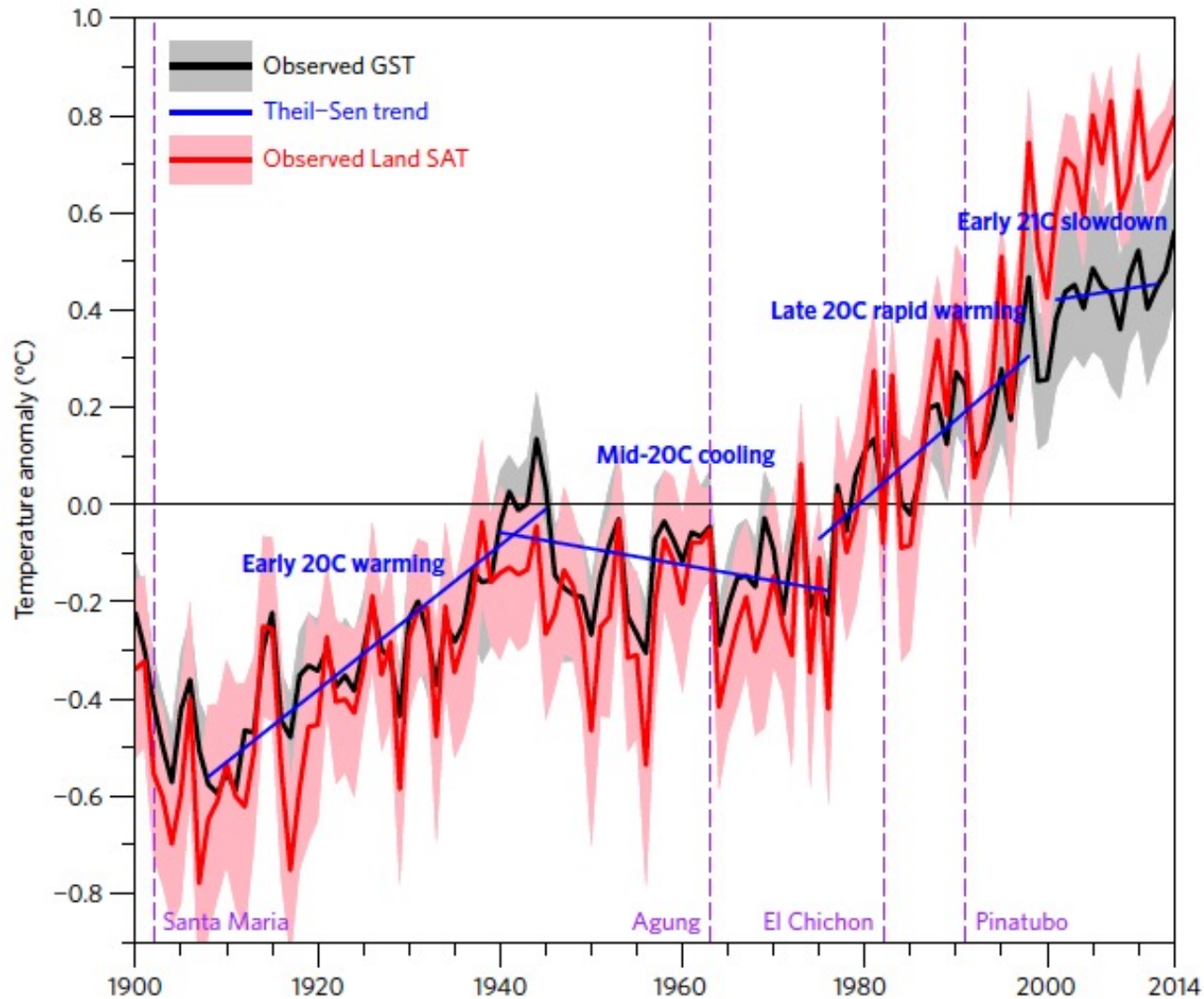
El Niño occurred

The lack of influences of three-ocean interactions on ENSO in climate models may be one of the reasons for causing prediction uncertainty.

Super El Niño is a product of three-ocean interactions



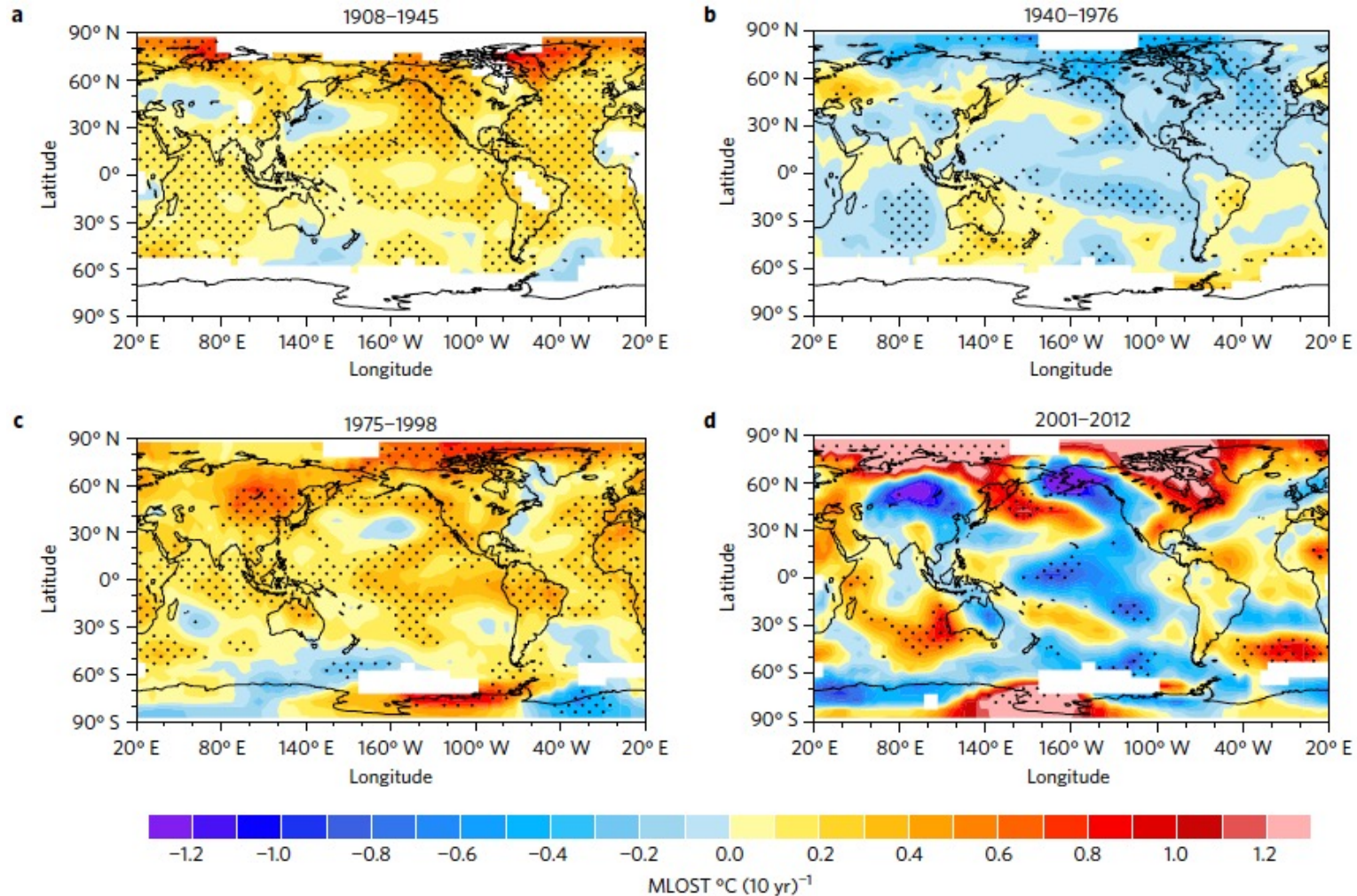
Global Change: A Problem of Global Oceans



Yao et al. (2017, *Nature CC*)

All of three oceans matter in global change

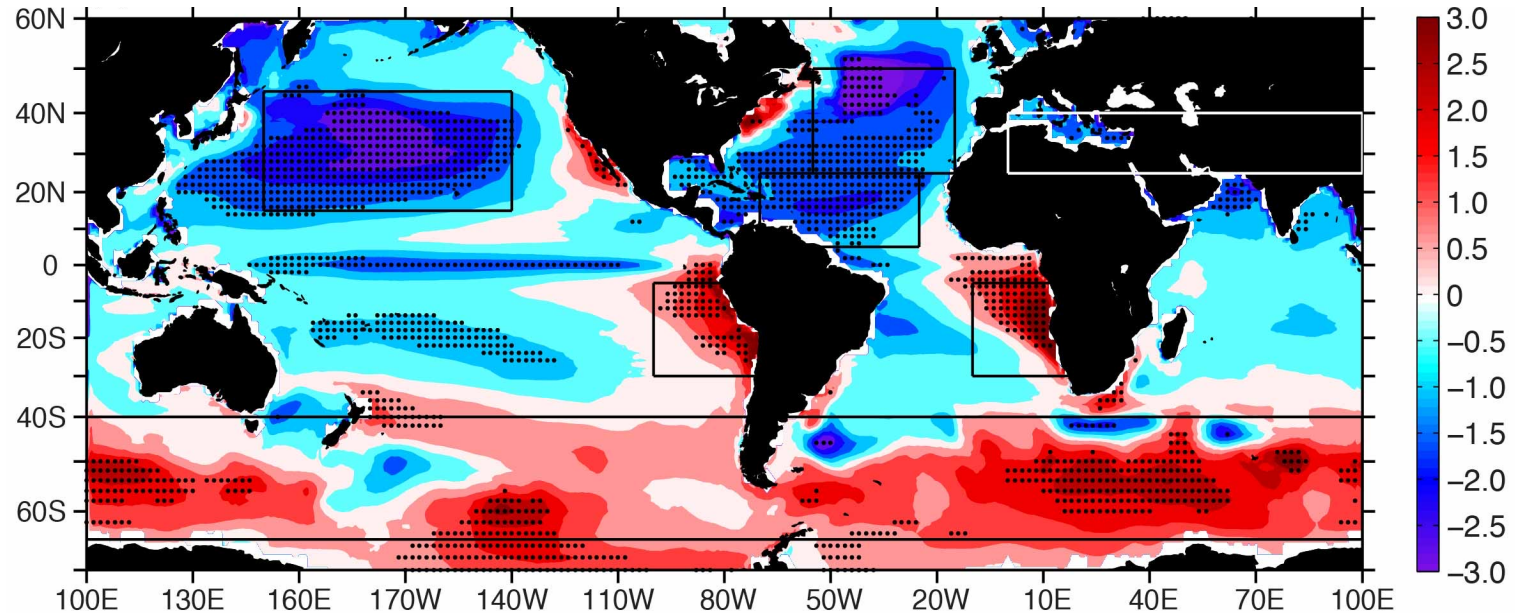
Temperature trends in different time periods corresponding to global warming



The roles can be warm or cool dependent on time!

Model Biases Caused by Inter-Ocean Processes

Global SST biases averaged in 22 CMIP5 models



Wang et al. (2014, *Nature CC*)

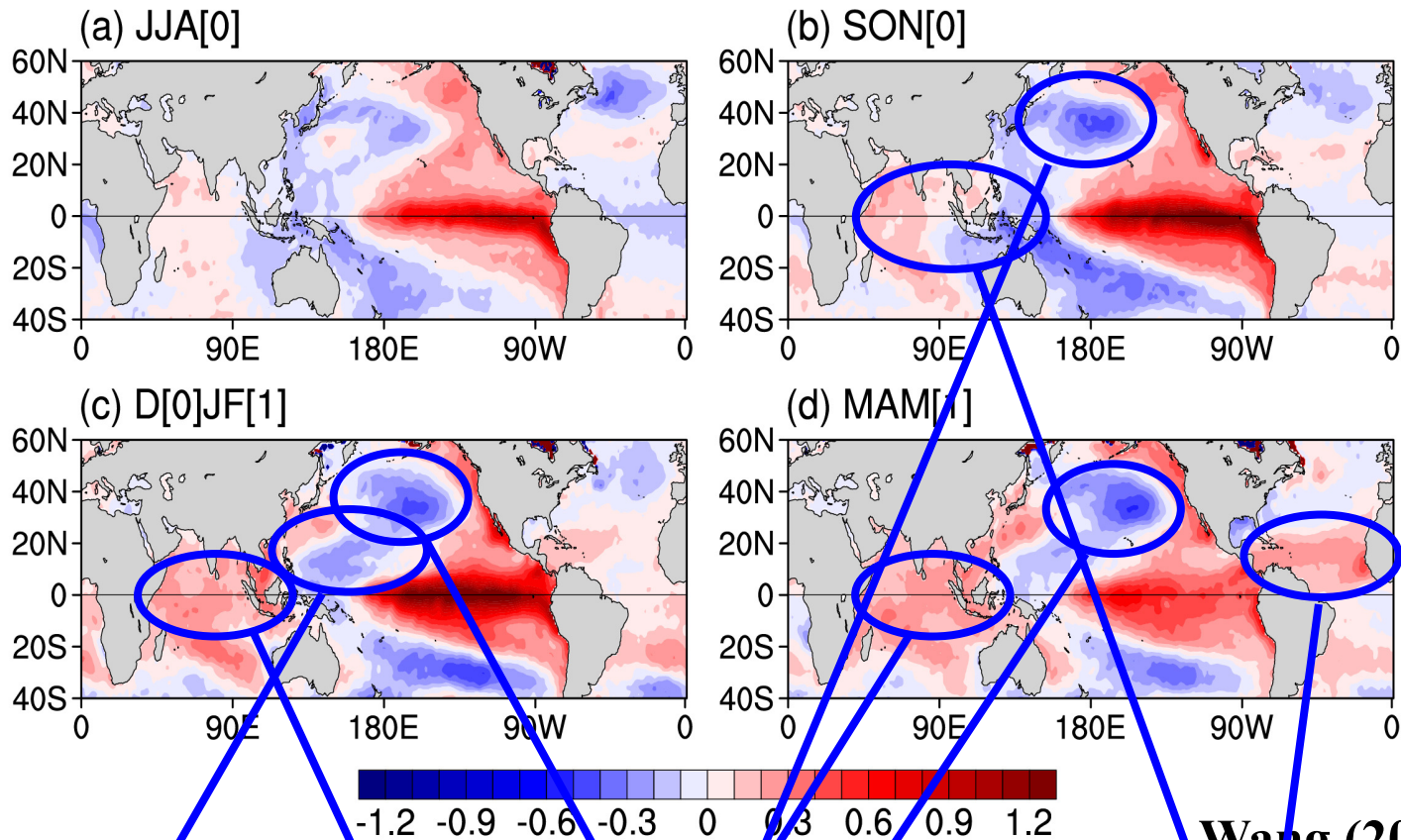
- All models show large biases, reaching $\pm 3^\circ\text{C}$.
- All models display a common bias pattern: cold in the N. H. and warm in the S. H. The AMOC is important for this pattern.
- In addition to local processes, inter-ocean processes play a key role in causing the model biases.

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Pacific ENSO's Impact on Global Oceans

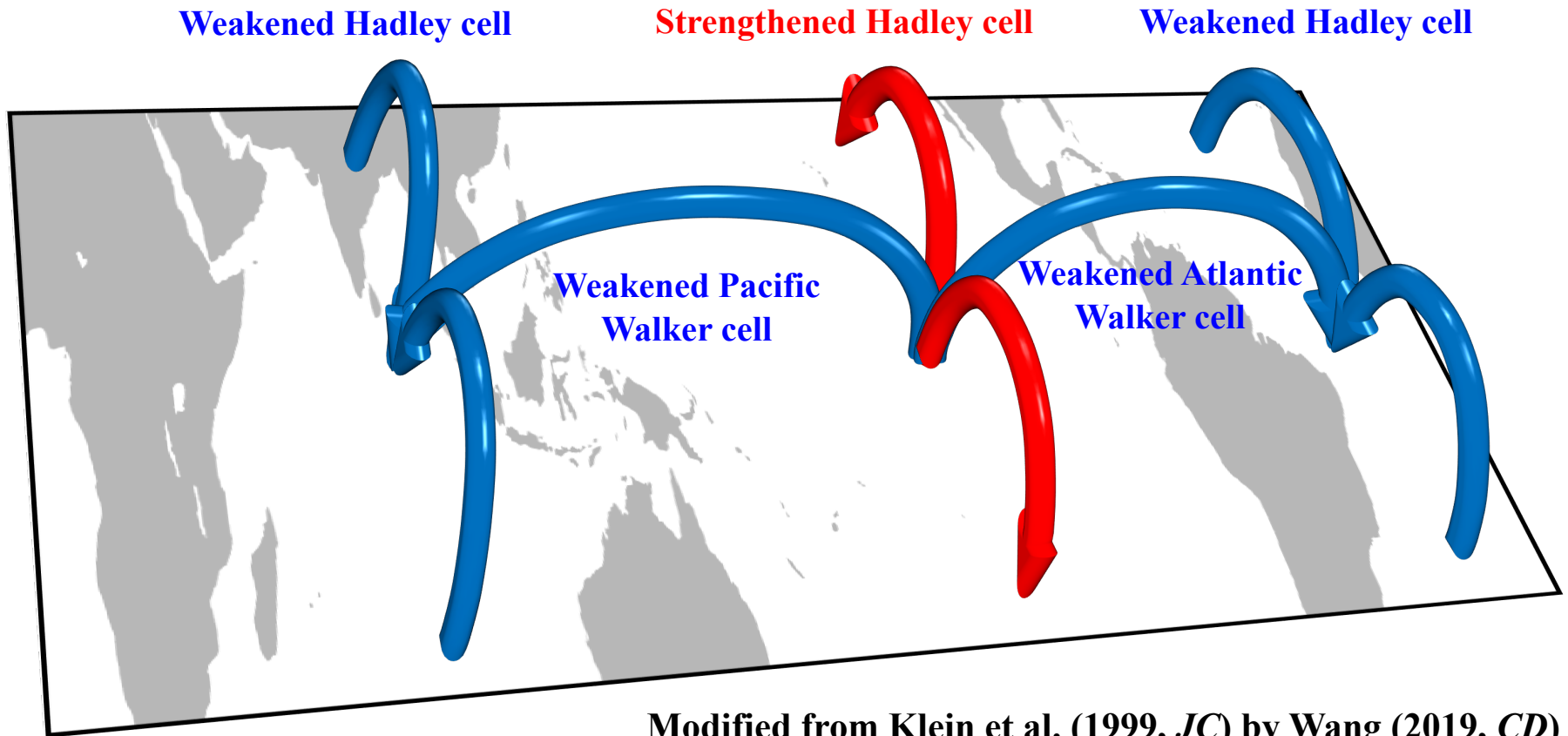
Regressions of DJF Nino3.4 onto global SST anomalies



Many papers were focused on these influences during past 30 years

Cold tropical NWP
IOB in winter and spring
Cold North Pacific
IOD in fall
Warm TNA in spring

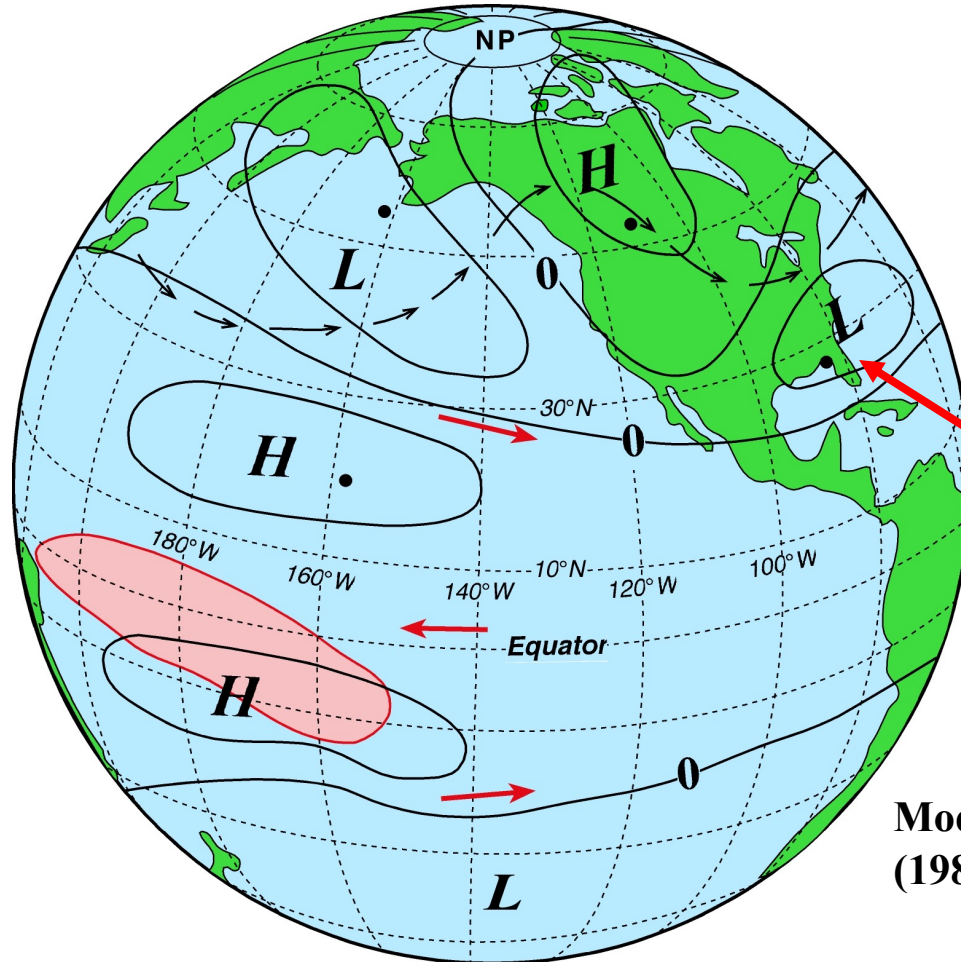
Atmospheric Bridges Linked Three Oceans



Nicely explain why ENSO affects global oceans!

Atmospheric Teleconnections

Pacific-North American (PNA) Pattern



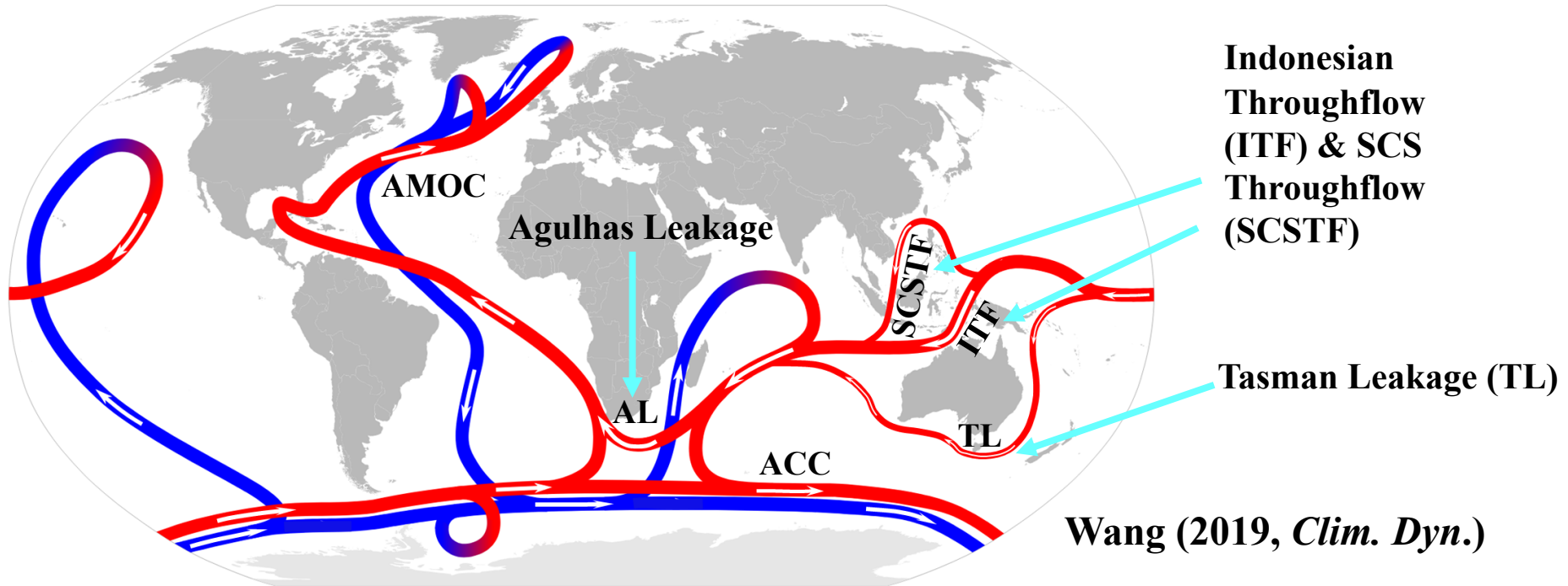
Changes in tropical Pacific SST/rainfall affect global atmospheric circulation via “teleconnections”

This is why Florida has more rainfall and fewer hurricanes during El Niño.

Modified from Horel and Wallace (1981, *MWR*) by Wang (2019, *CD*)

Global Oceans Linked by Ocean Circulation

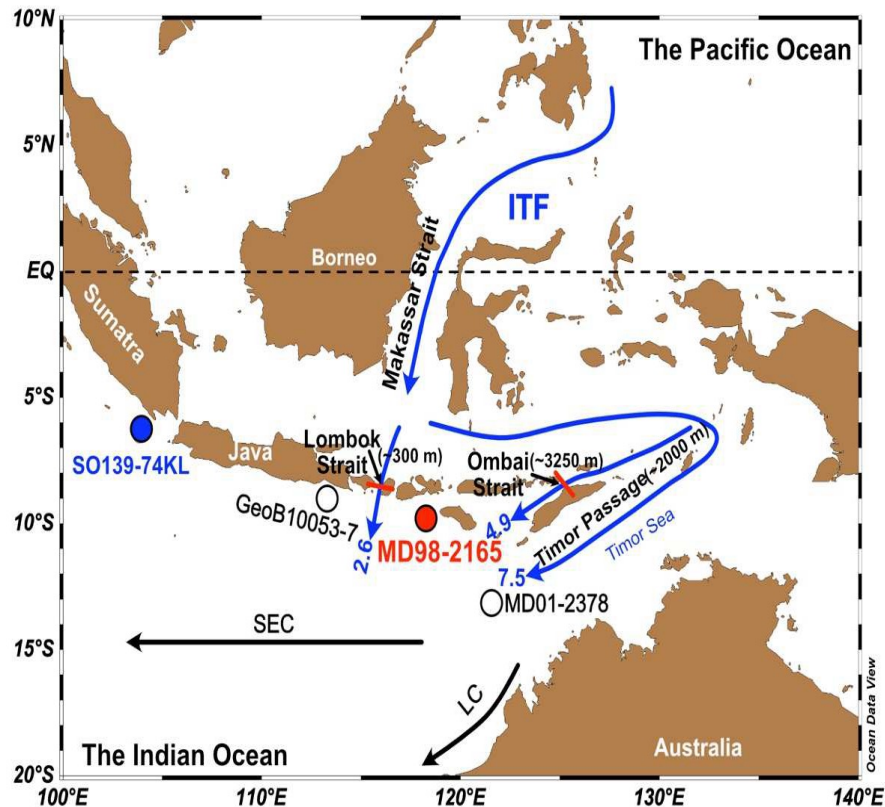
Global Oceans Linked by Ocean Circulation



“Great Conveyor Belt” is named by Broecker (1987):

- AMOC is **the origin** of global ocean conveyor belt.
- AMOC plays a key role in global climate.
- AMOC is a hot research topic, like ENSO 20-30 years ago.

Pacific and Indian Oceans Linked by the ITF



- The ITF provides an oceanic pathway for **warm and fresh** water to move from the Pacific to Indian Oceans (**~15 Sv**; 1 Sv=10⁶ m³/s).
- A weaker (stronger) ITF during El Niño (La Niña) in response to the Pacific trade-winds.
- PDO⁺ (PDO⁻) decreases (increases) heat transport from the Pacific to Indian Oceans.
- A reduction of **32%** during the 21st century (Feng et al. 2017, *GRL*), **consistent with the reduction of AMOC** (they did not emphasize).

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Influence of the Indian Ocean on the Pacific

ENSO affects the Indian Ocean which in turn modifies Pacific climate in following spring and summer via the atmosphere (e.g., Watanabe and Jin 2002; Wu and Kirtman 2004; Annamalai et al. 2005; Kug et al. 2006; Yuan et al. 2008; Xie et al. 2009, 2016; Du et al. 2009; Wu et al. 2009, 2017).

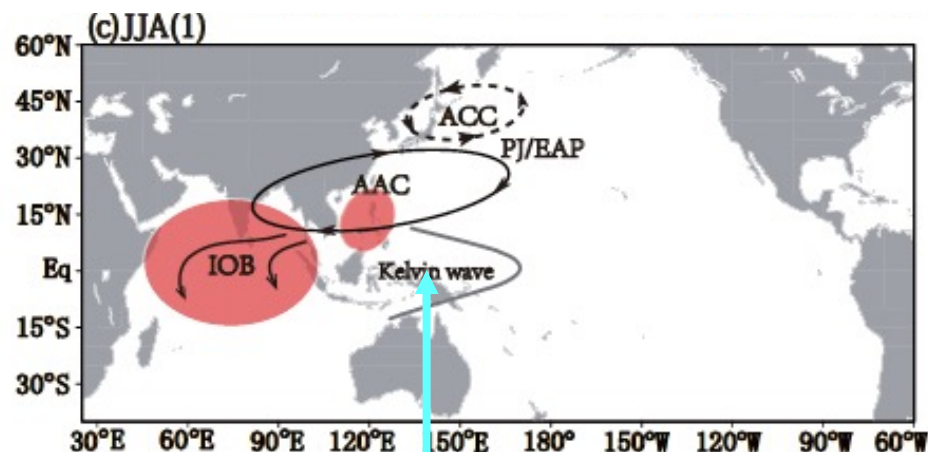
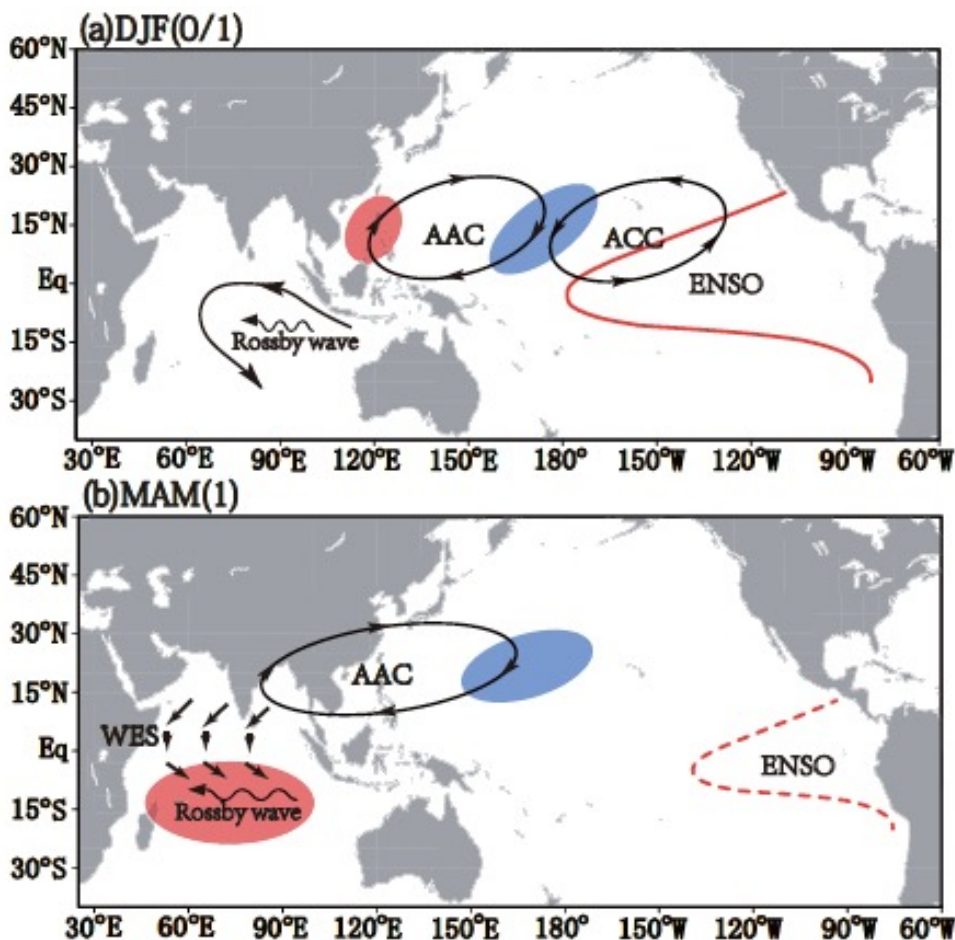


Figure from Xie et al. (2016, *AAS*)

IO's influence in following spring and summer: Capacitor Effect (印度洋电容器效应)

Influence of Indian Ocean on ENSO via Atmosphere

A negative (positive) IOD may help initiate La Niña (El Niño) through the changes of the atmospheric Walker circulation.

LETTERS

PUBLISHED ONLINE: 21 FEBRUARY 2010 | DOI: 10.1038/NCEO760

nature
geoscience

Influence of the state of the Indian Ocean Dipole on the following year's El Niño

**Takeshi Izumo^{1,2}★†, Jérôme Vialard³, Matthieu Lengaigne³, Clément de Boyer Montegut^{1,4},
Swadhin K. Behera¹, Jing-Jia Luo¹, Sophie Cravatte⁵, Sébastien Masson³ and Toshio Yamagata^{1,2}**

Impact of the Indian Ocean on the Pacific via ITF

A positive Indian Ocean dipole (IOD) may help terminate El Niño or initiate La Niña through ITF transport (Yuan et al. 2013).

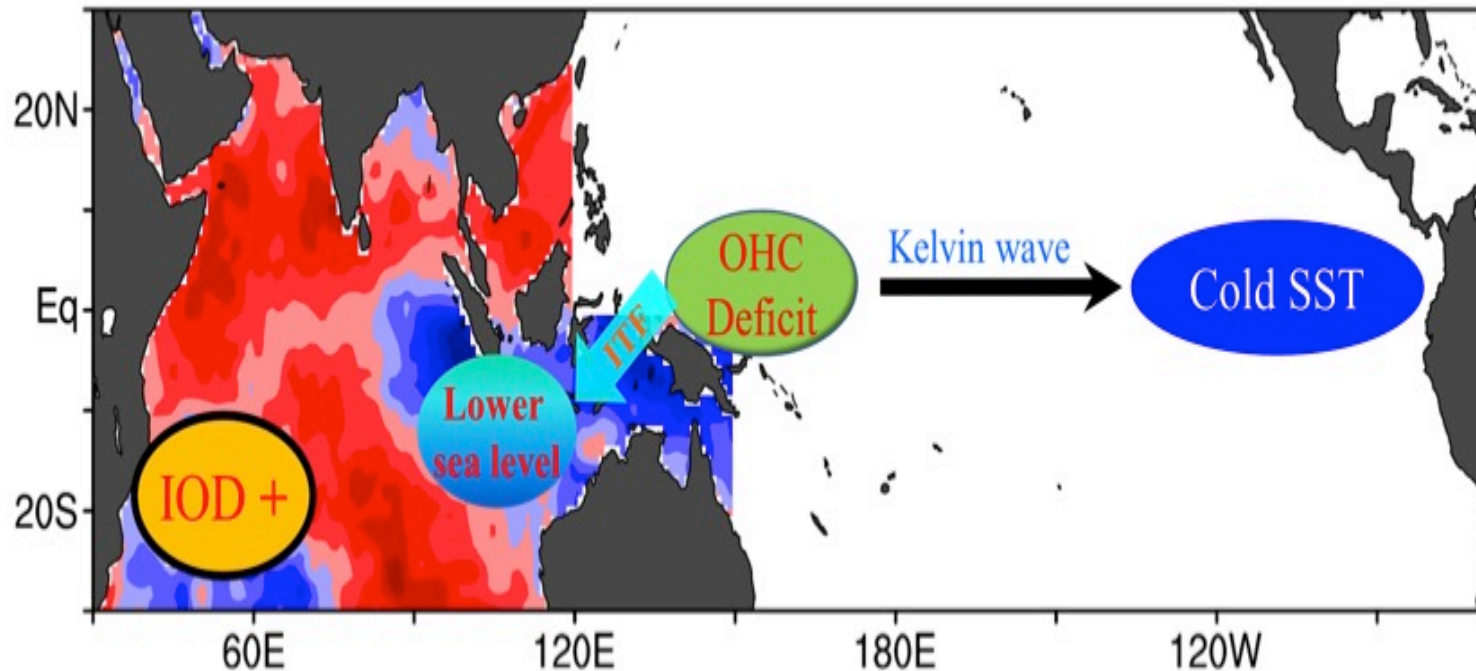
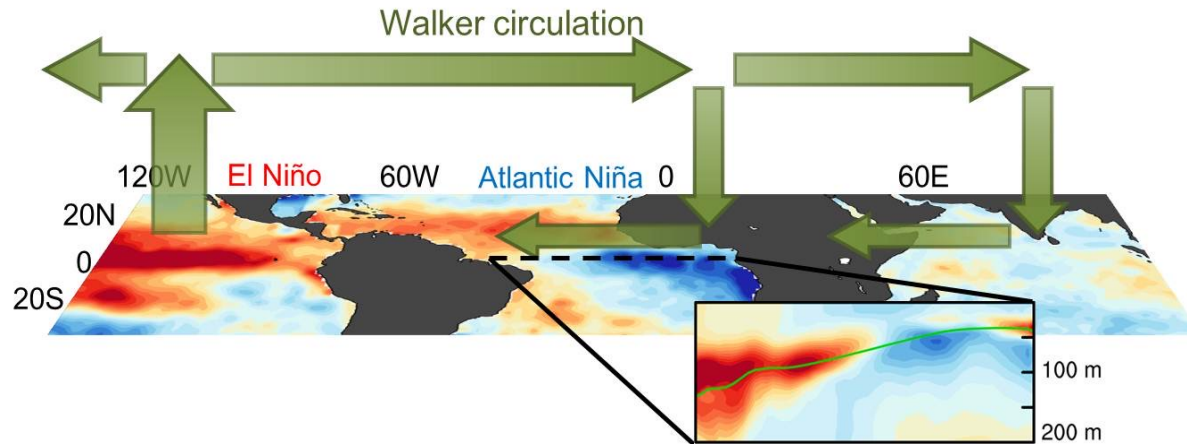


Figure from Wang (2019, *CD*)

Lower sea level → a pressure gradient force across the Indonesian seas → increase ITF transport → decrease ocean heat content (OHC) → upwelling Kelvin wave → initiate La Niña.

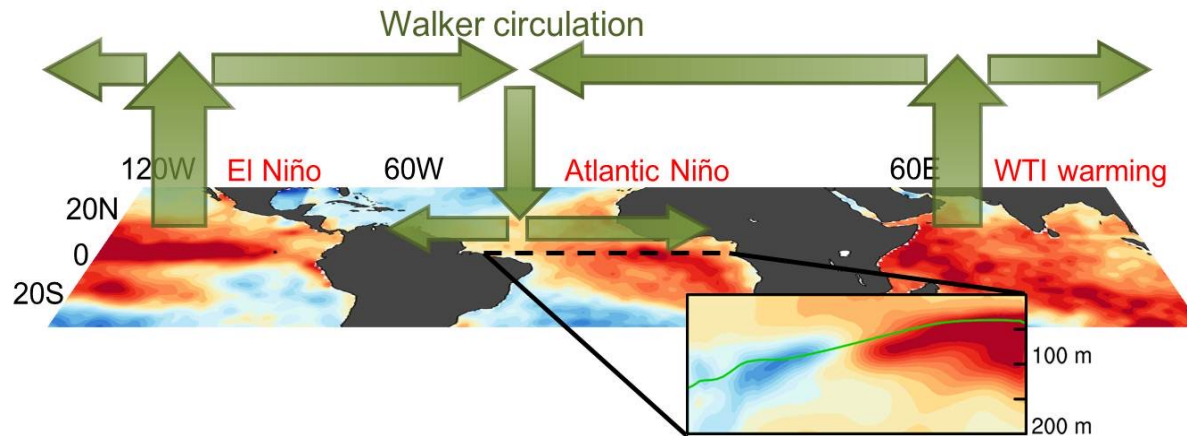
Influence of the Indian Ocean (IO) on the Atlantic

a) Tropical Atlantic cooling dominated by El Niño



**Without IO's Effect:
Atlantic Niña**

b) Tropical Atlantic warming dominated by WTI warming



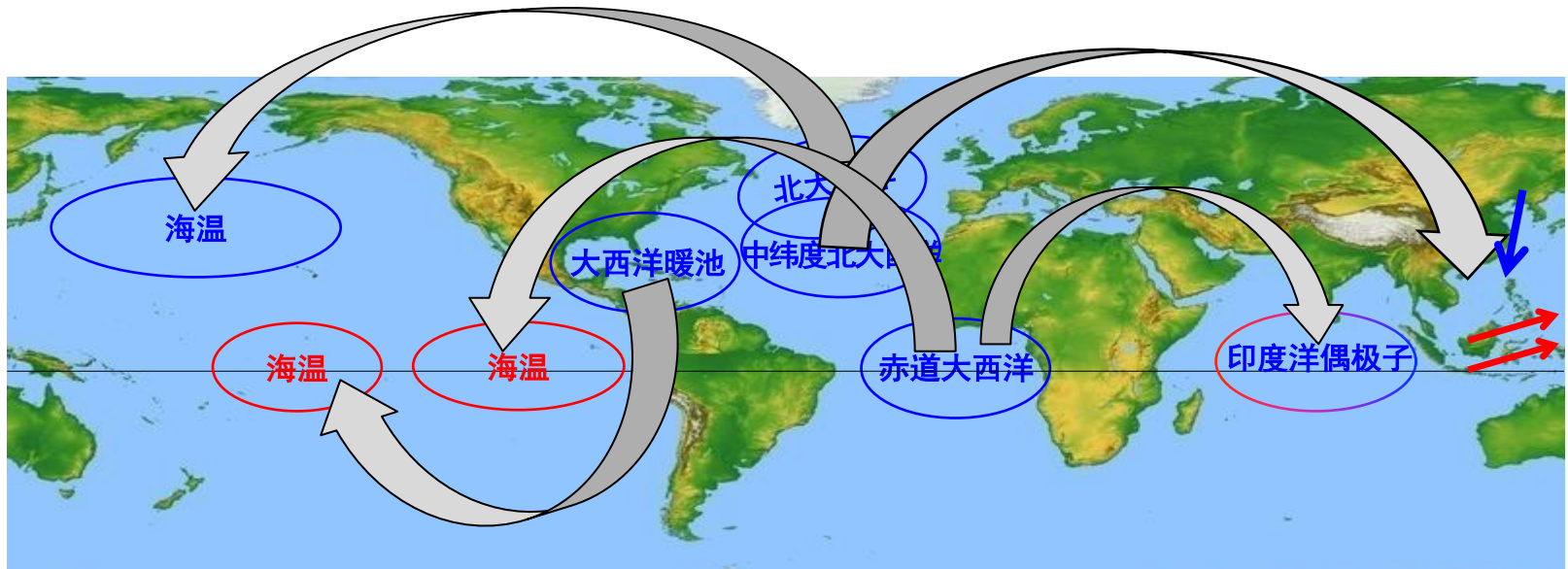
**Warm IO's Effect:
Atlantic Niño**

SST in the western Indian Ocean determines whether an Atlantic Niño or Atlantic Niña follows a Pacific El Niño (Liao & Wang 2021, *GRL*).

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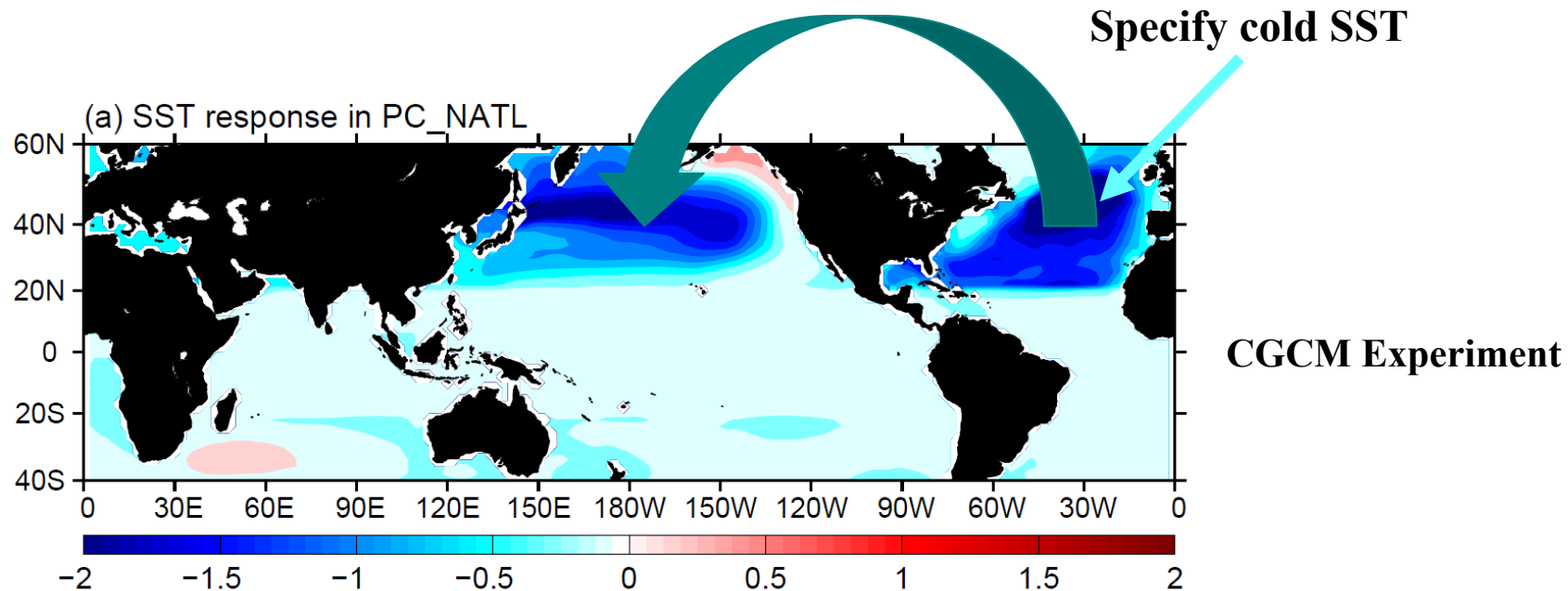
Influence of the Atlantic on the Pacific & Indian Oceans



The Atlantic has a rich climate effect!

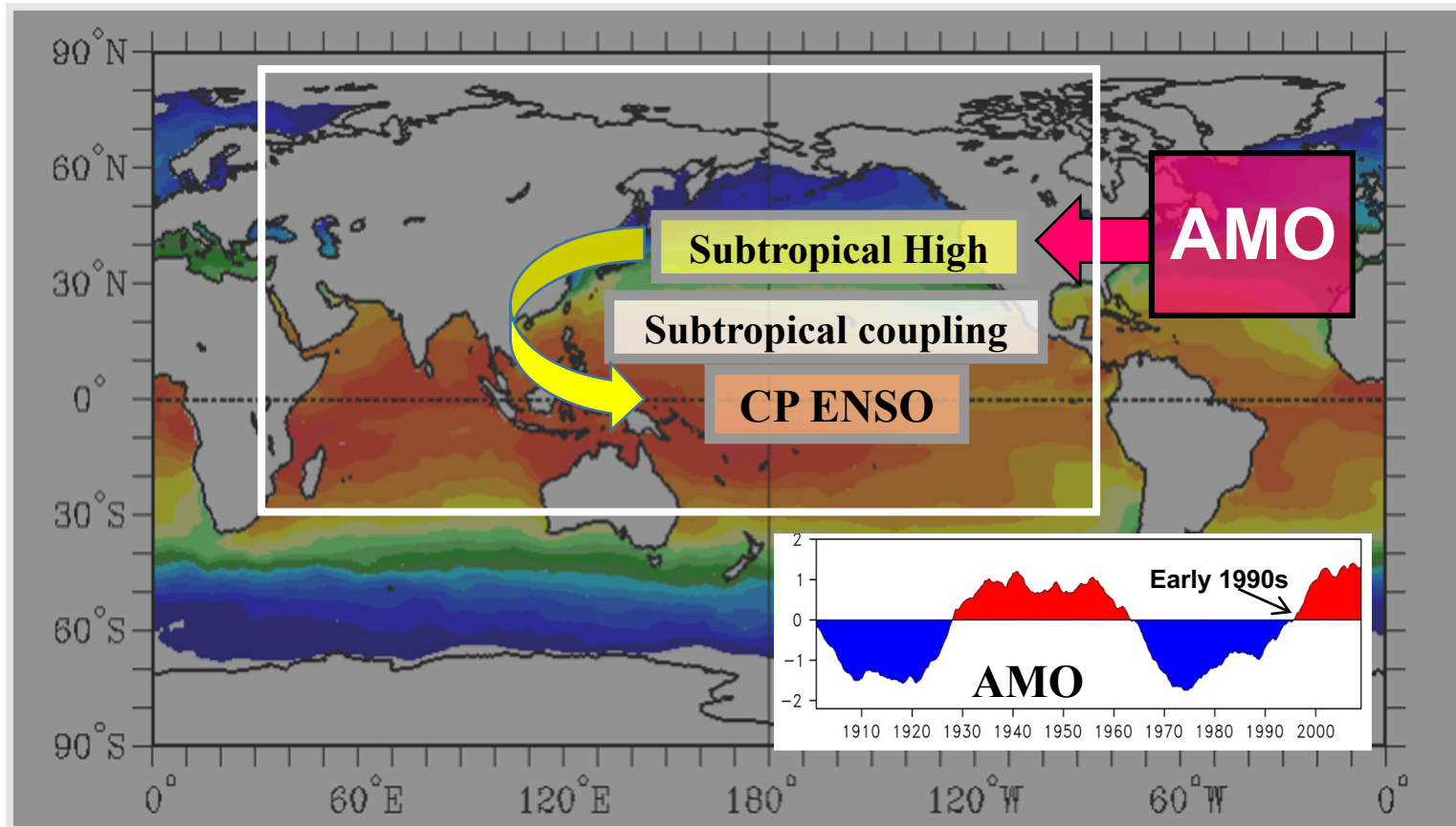
Influence of the North Atlantic on the North Pacific

The North Atlantic can affect the North Pacific via “annular mode” (e.g., Zhang and Delworth 2007; Timmermann et al. 2007; Wu et al. 2007, 2008; Wang et al. 2014).



So it is possible that the AMO can initiate the PDO.

The AMO Induces CP-type ENSO Events

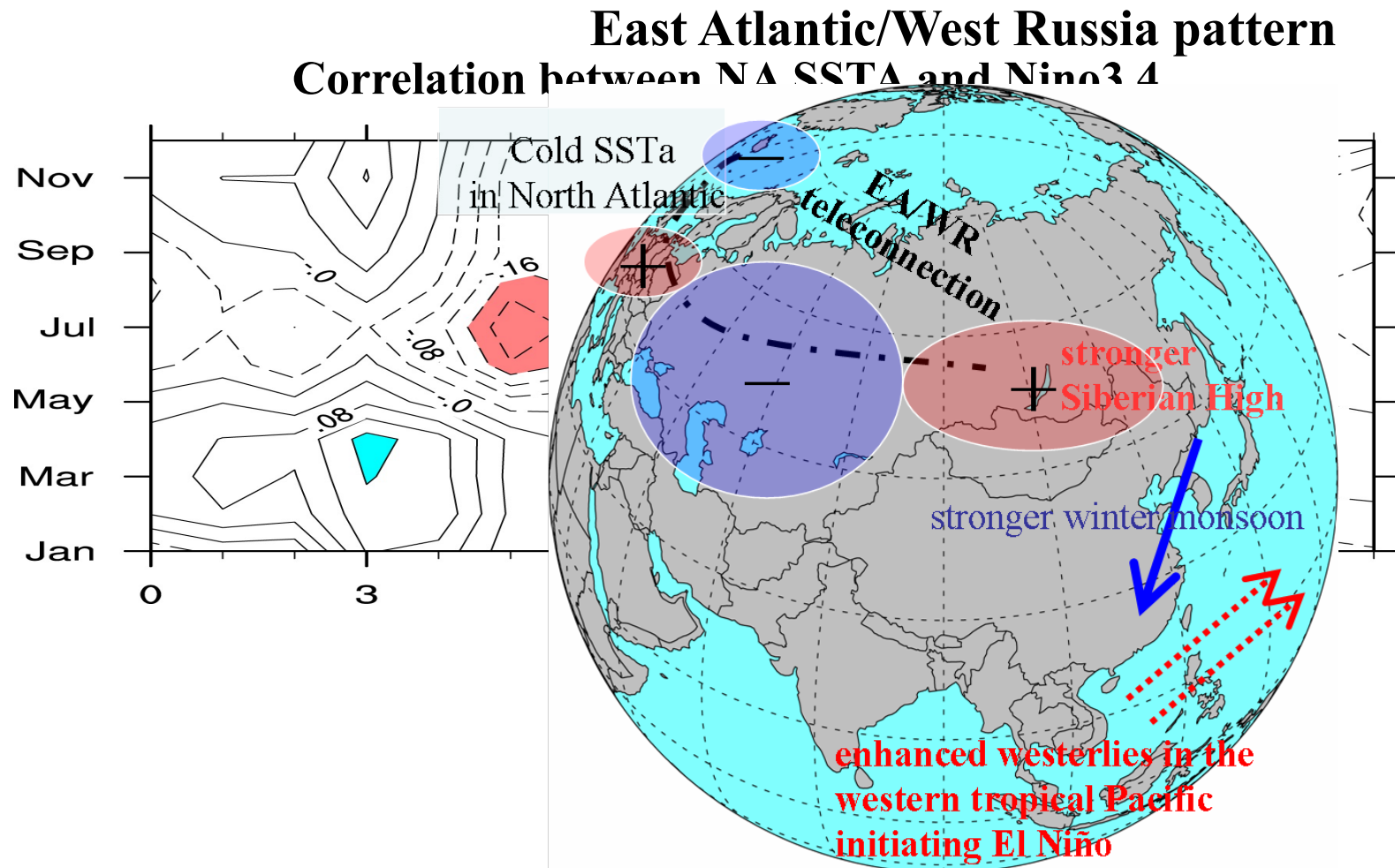


Yu et al. (2015, *JC*)

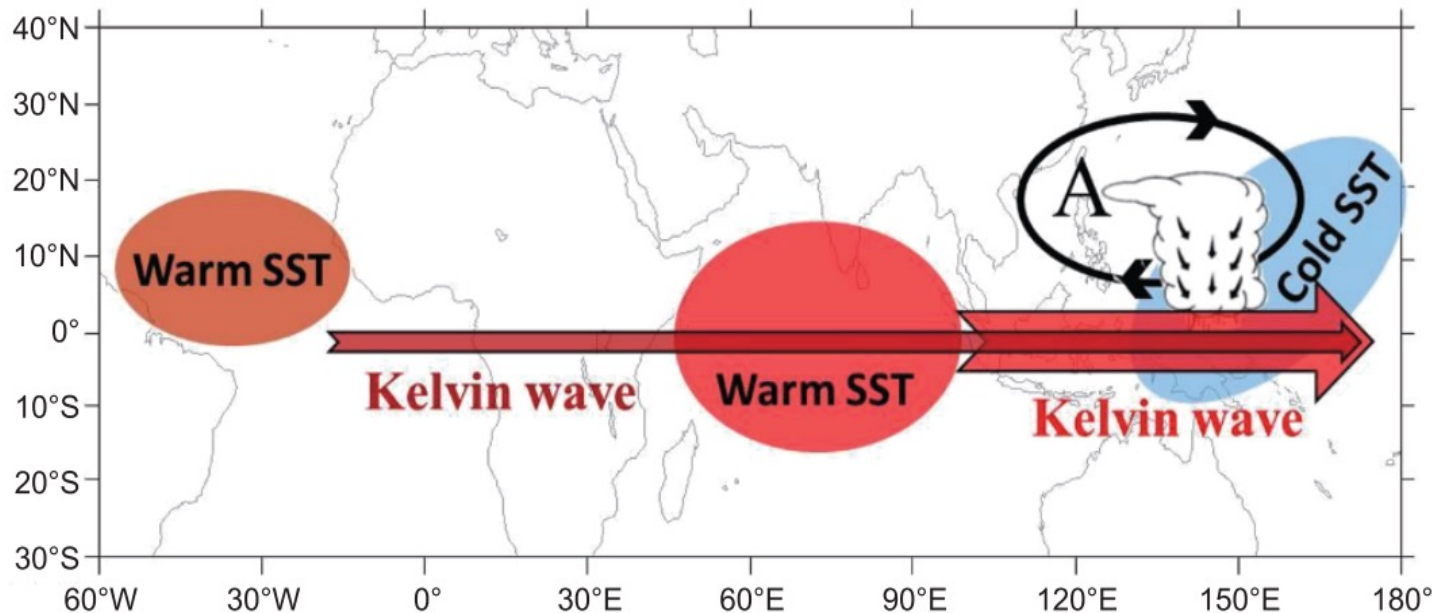
- Explains why CP-type El Niño increases after the 1990s.
- Global warming increases CP-type El Niño (Yeh et al. 2009, *Nature*).
- Which one is right?

Influence of the North Atlantic on Pacific ENSO

A cold North Atlantic Ocean in summer helps initiate a Pacific El Niño in subsequent year (Wang et al. 2009, 2011, 2013).



Influence of tropical North Atlantic on Pacific



Lu and Dong (2005, *JGR-Atmosphere*)
Rong et al. (2010, *Chinese Sci. Bull.*)

- Warming in TNA allows **easterly anomalies** associated with Kelvin waves to stretch from the Indian Ocean to the western Pacific.
- **Easterly anomalies** dampen convective activity through the **divergence** caused by Ekman pumping, which help the formation of anticyclone.

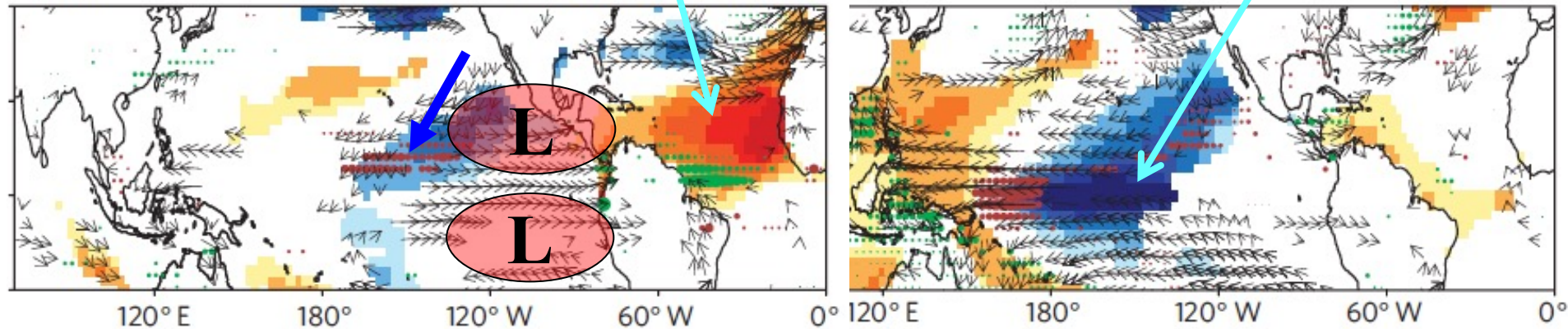
Influence of the tropical North Atlantic on ENSO

Influence of the tropical North Atlantic (TNA) on ENSO events: A warm TNA in spring can induce a Pacific La Niña in subsequent winter (e.g., Rong et al. 2010; Ham et al. 2013; Ding et al. 2017; Wang et al. 2017).

Spring A warm TNA A cold La Niña
Winter

MAM

ParReg ((NTA) - NINO3.4)

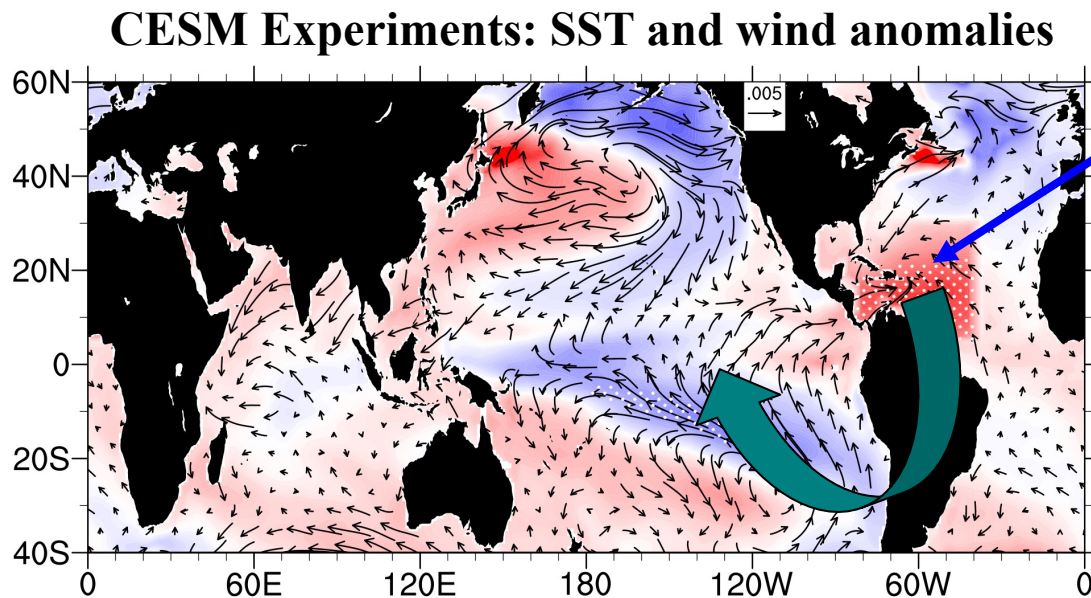


Ham et al. (2013, *Nature Geosci*)

The TNA induces a CP-type ENSO event!

Influence of the Atlantic Warm Pool on ENSO

Influence of the Atlantic Warm Pool (AWP) on Pacific ENSO via the Hadley circulation: **A large AWP can induce a CP-type La Niña** event (Wang et al. 2010, 2021).



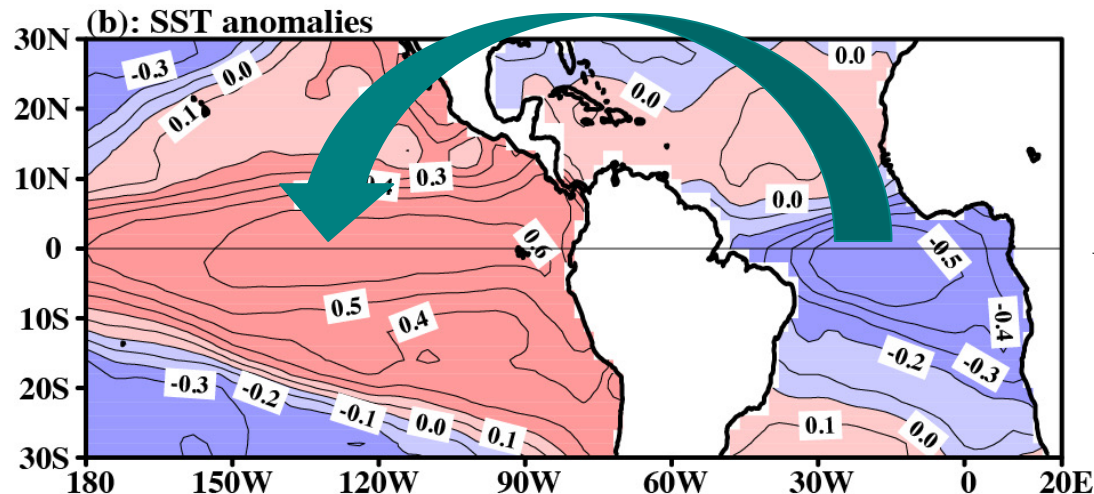
Specify SST

Wang et al. (2021, *CD*)

A large AWP induces a CP-type La Niña!

Influence of Atlantic Niño on Pacific ENSO

Influence of Atlantic Niño/Niña on Pacific ENSO event via the Walker circulation: An Atlantic Niña event in summer can help induce an **EP-type El Niño** in winter (e.g., Wang 2006; Wang et al. 2009; Keenlyside et al. 2013; Kucharski et al. 2011, 2015; Polo et al. 2015; Richter and Tokinaga 2021).



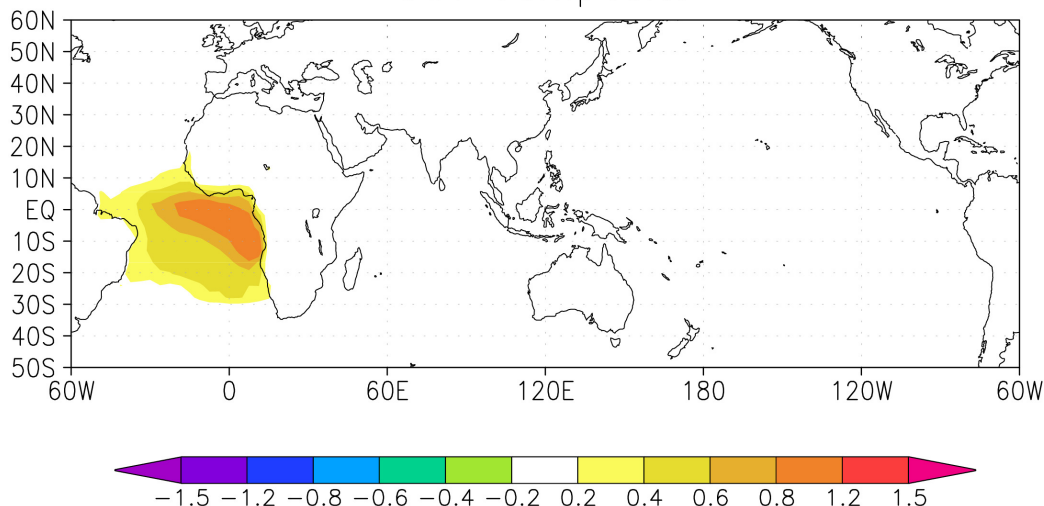
Wang (2006, *GRL*)

Atlantic Niña (Niño) induces an EP-type El Niño (La Niña)!

Influence of the Atlantic on the Indian Ocean

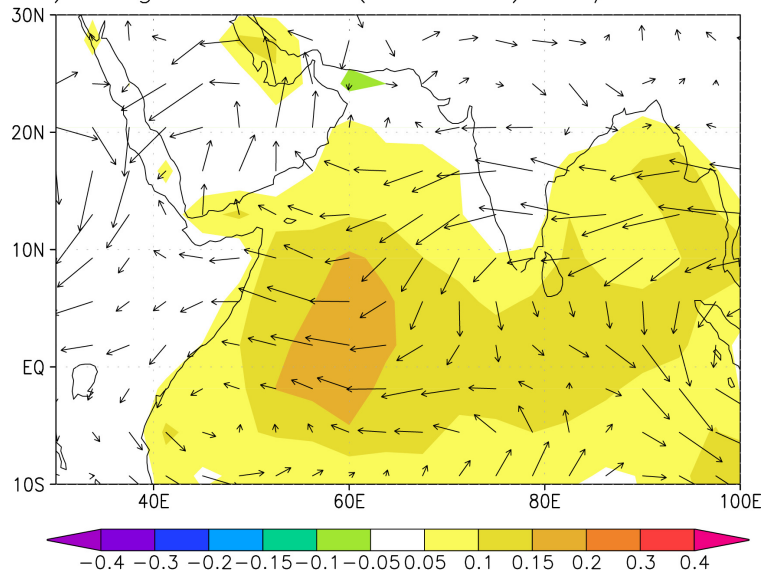
Atlantic Niño induces a warming in the tropical western Indian Ocean (Wang et al. 2009), and African and Indian monsoon rainfall (Kucharski et al. 2009)

SST composite

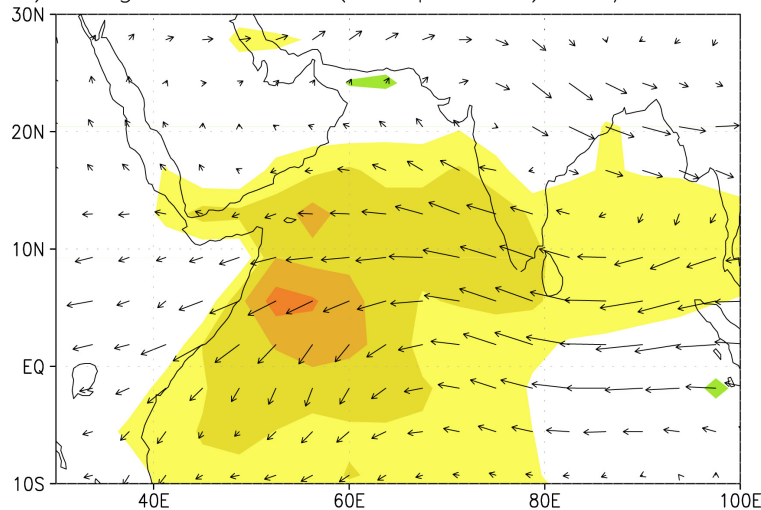


Wang et al. (2009, *Meteorol. Z.*)

a) Reg STA-SST (HadISST) 50/99



b) Reg STA-SST (Coup Mod) 50/99



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Cutting edge of research: Three-ocean interactions

CLIVAR/Tropical Basin Interaction (CLIVAR/TBI) Research Focus



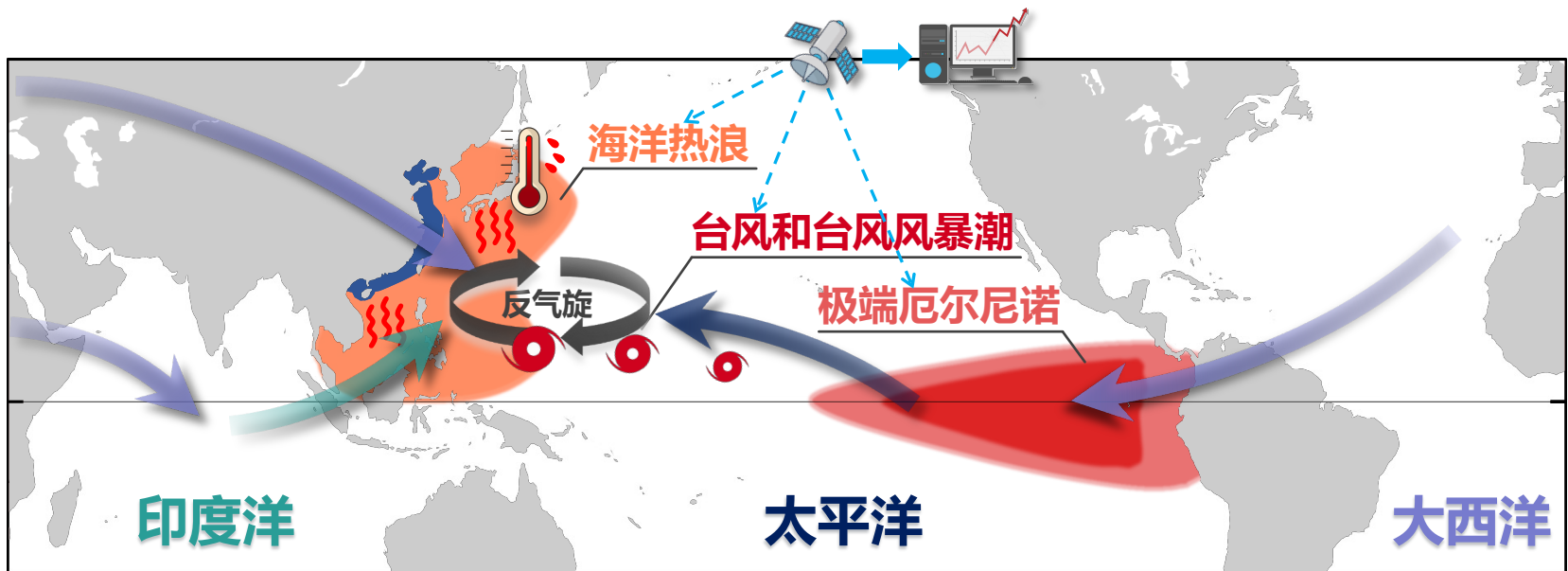
CLIVAR/TBI Online Meetings



- **WG1: Coordinated CGCM experiments (Outputs will be available to the climate community like CMIP models).**
- **WG2: Conceptual models and theory.**
- **WG3: Observations.**
- **WG4: Paleo proxies.**

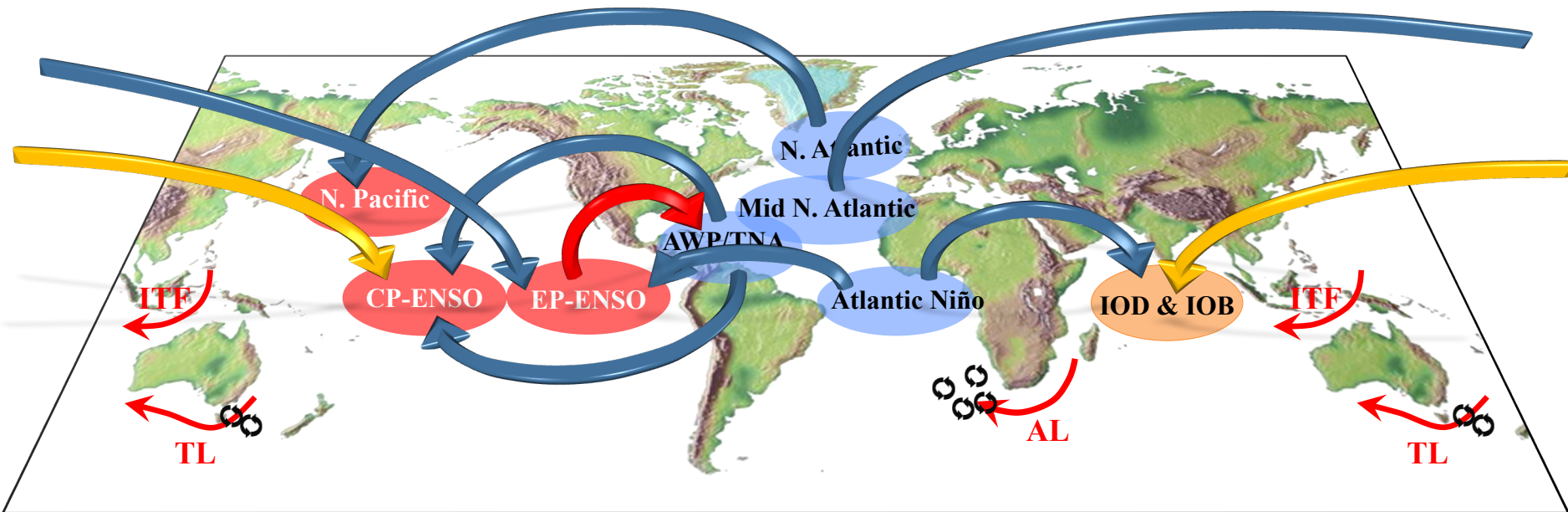
Two large projects of three-ocean interactions in China

- **National Key R&D Program of China: “Three-ocean interaction mechanisms and their influences on climate”, PI: C. Wang, 6 institutes, 27 scientists, 20 million dollars.**
- **National Natural Science Foundation of China: “Impacts of inter-ocean interactions on marine disasters in the Pacific Ocean and associated mechanisms”, PI: C. Wang, 6 institutes, 30 scientists, 15 million dollars.**



Summary: Processes of Three-Ocean Interactions

(1) Oceanic Pathways and (2) Atmospheric Bridges



Wang (2019, *Clim. Dyn.*)

- Three-ocean interactions can initiate and/or modulate climate
- Global change is a problem of global oceans

You are invited to attend ...

**12TH INTERNATIONAL CONFERENCE ON TROPICAL
MARINE ENVIRONMENTAL CHANGES (MEC 2023):**

**NOVEMBER 18-20, 2023
GUANGZHOU, CHINA**

Conference website: <http://ic.lto.scsio.ac.cn/>

Theme:

Tropical Ocean and Its Climatic and Environmental Effects

Four Sessions:

- **Role of the tropical ocean in climate**
- **Multi-scale ocean dynamical processes**
- **Ocean ecological and biogeochemical processes**
- **Marine geological processes and hazards**

Thanks for your attention!

Email: cwang@scsio.ac.cn

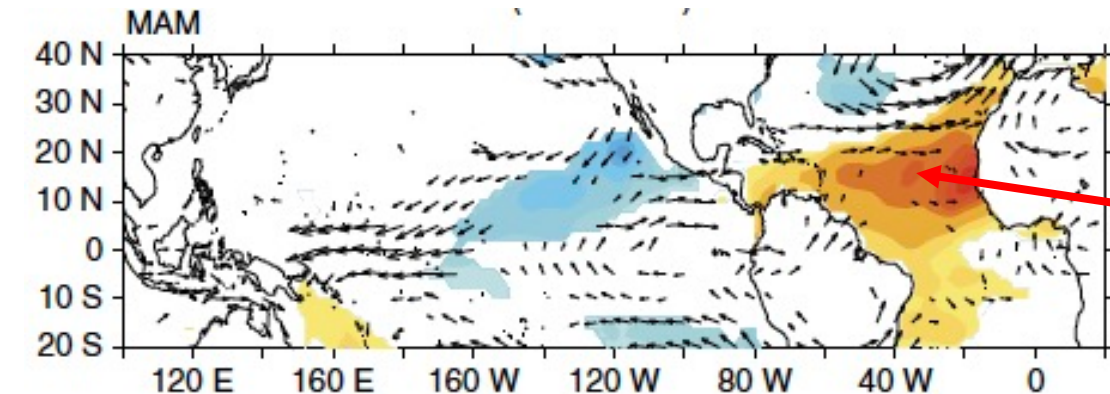
Wang, C., 2019: Three-ocean interactions and climate variability: A review and perspective. *Clim. Dyn.*, 53, 5119-5136.

Wang, J.-Z., and C. Wang, 2021: Joint boost to super El Niño from the Indian and Atlantic Oceans. *J. Climate*, 34, 4937- 4954.

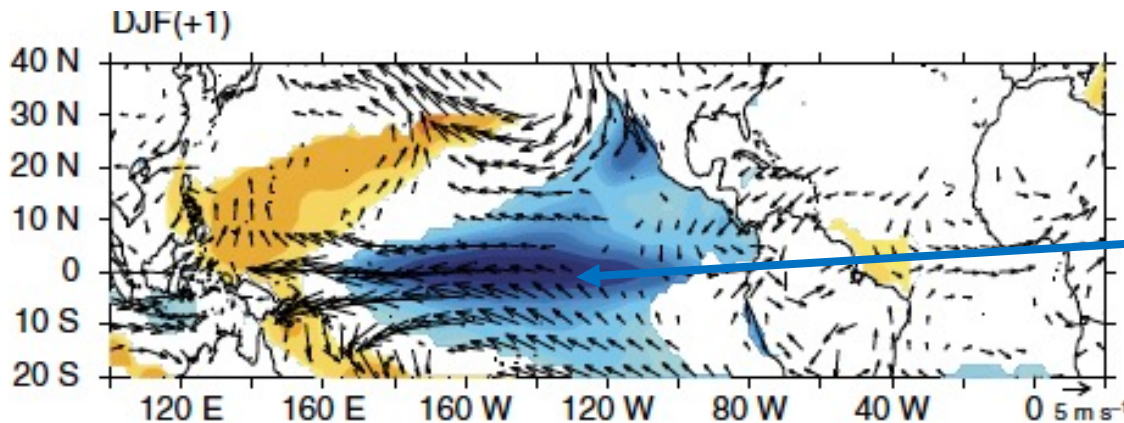
Backup Slides

Atlantic capacitor: Enhanced Pacific biennial variability

‘Charging’ process: ENSO warms TNA SST; ‘Discharging’ process: The warm TNA SST triggers the following ENSO. Since the early 1990s, the processes have enhanced biennial variability in the Pacific (Wang et al. 2017).

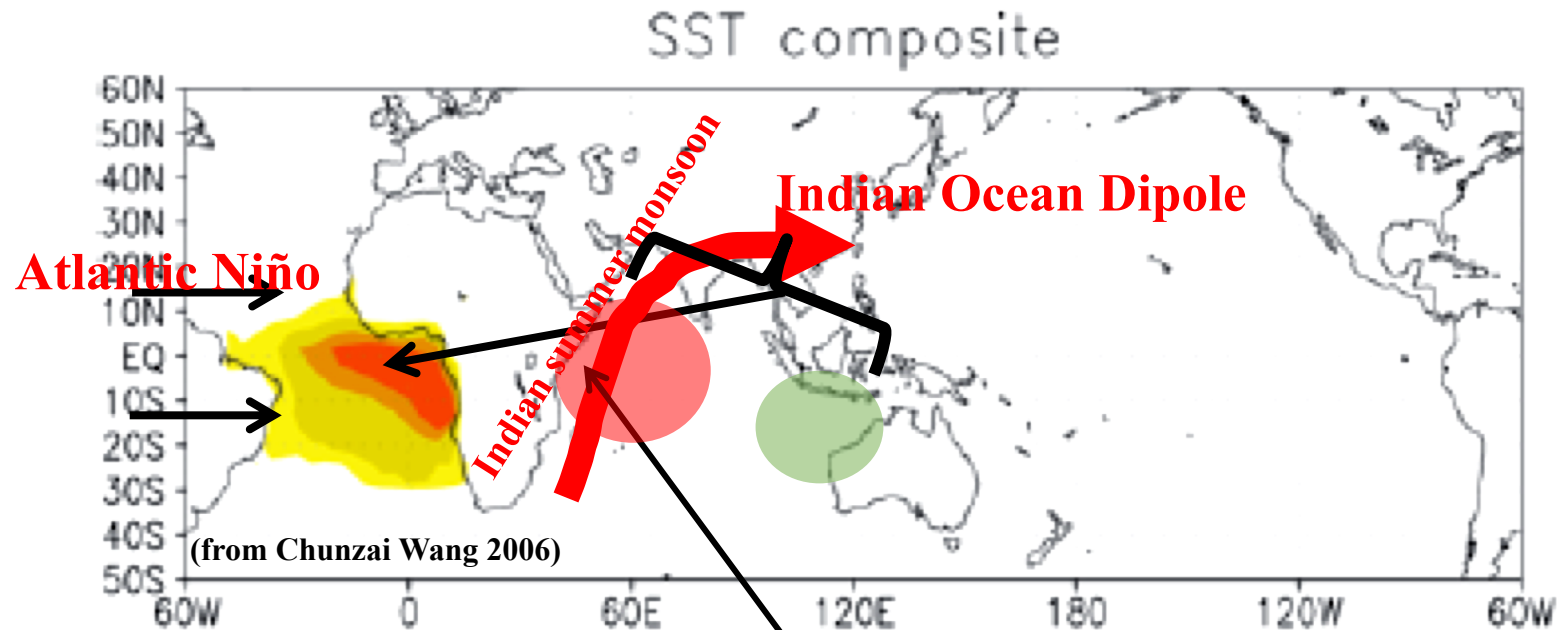


Charging: Warm TNA



Discharging: La Niña

Atlantic Niño → Indian Ocean Dipole

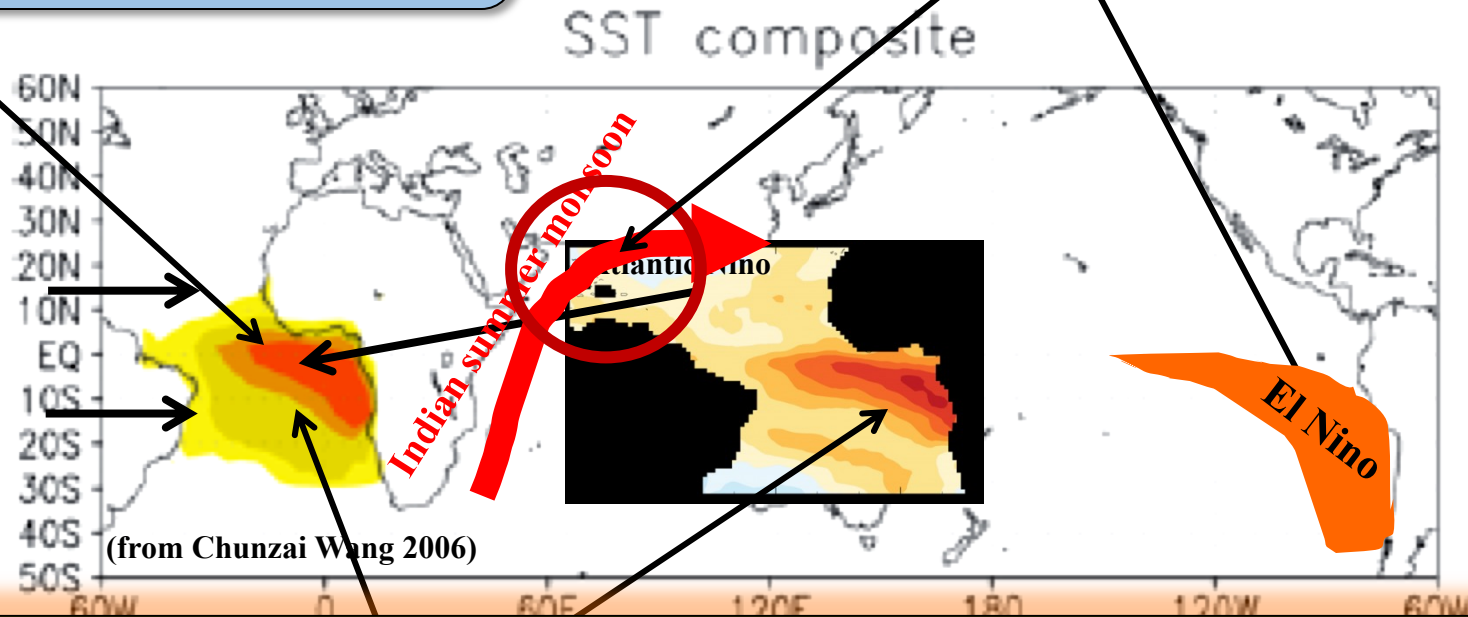


- Weaken Somali Jet
- Reduce surface evaporation
- Weaken coastal upwelling
- Warm up western Indian Ocean
- Turn on Bjerknes feedback
- Produce Indian Ocean dipole

Atlantic Niño → Indian Summer Monsoon

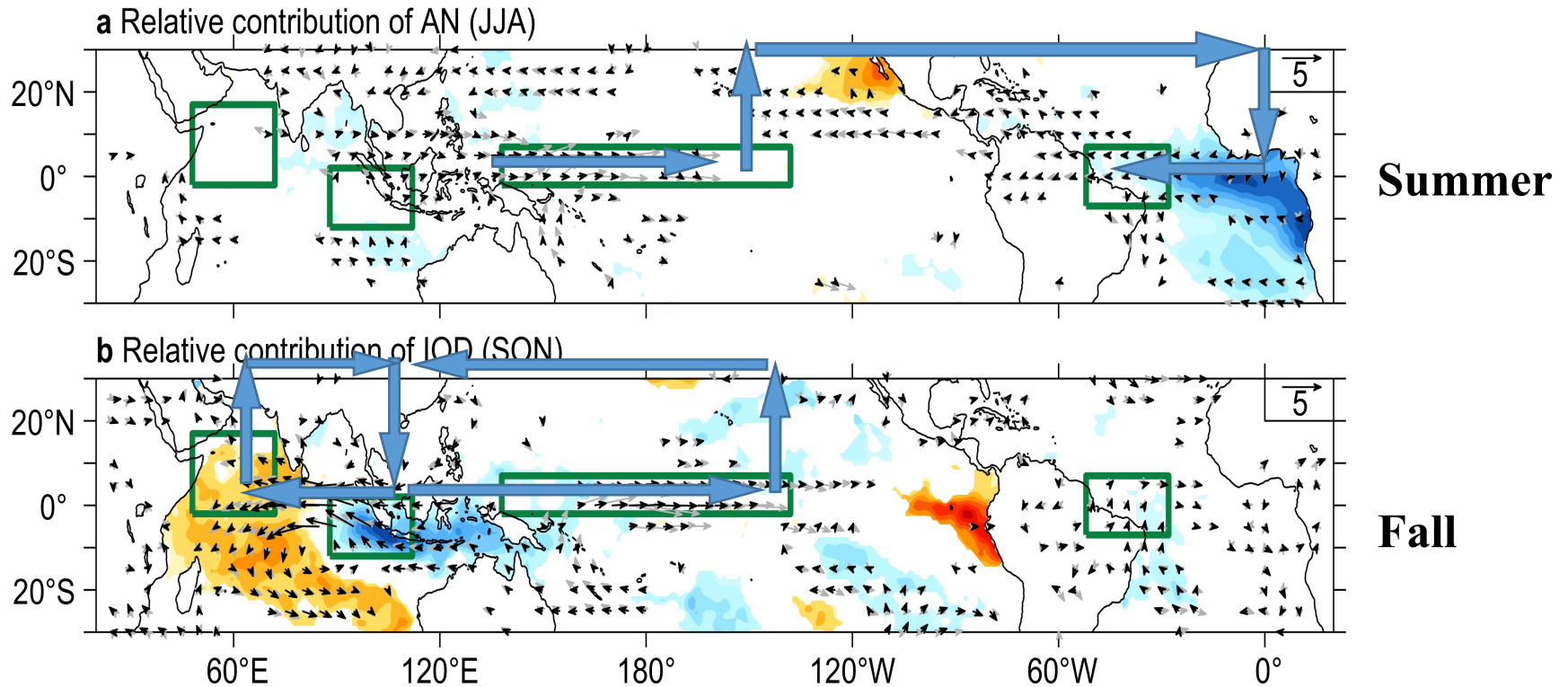
Atlantic SST anomalies most correlated with Indian summer monsoon variability

Weakens Indian summer monsoon



- ❑ Positive SST anomalies in both Pacific and Atlantic Oceans act to decrease the Indian monsoon.
- ❑ But if the SSTs in the two basins are anti-correlated, their influences on the Indian monsoon tend to cancel each other.

Contributions of IAB to super El Niño



Wang & Wang (2021, *J. Clim.*)

- Atlantic Niña contributes about **1 m/s** westerly wind anomaly in summer.
- IOD contributes about **1-2.5 m/s** westerly wind anomaly in fall.
- **IAB**, as a self-excited mechanism, **produces additional Bjerknes' feedbacks for super El Niño.**