Indian Ocean warming as a driver of the North Atlantic "warming hole": atmospheric versus oceanic mechanisms

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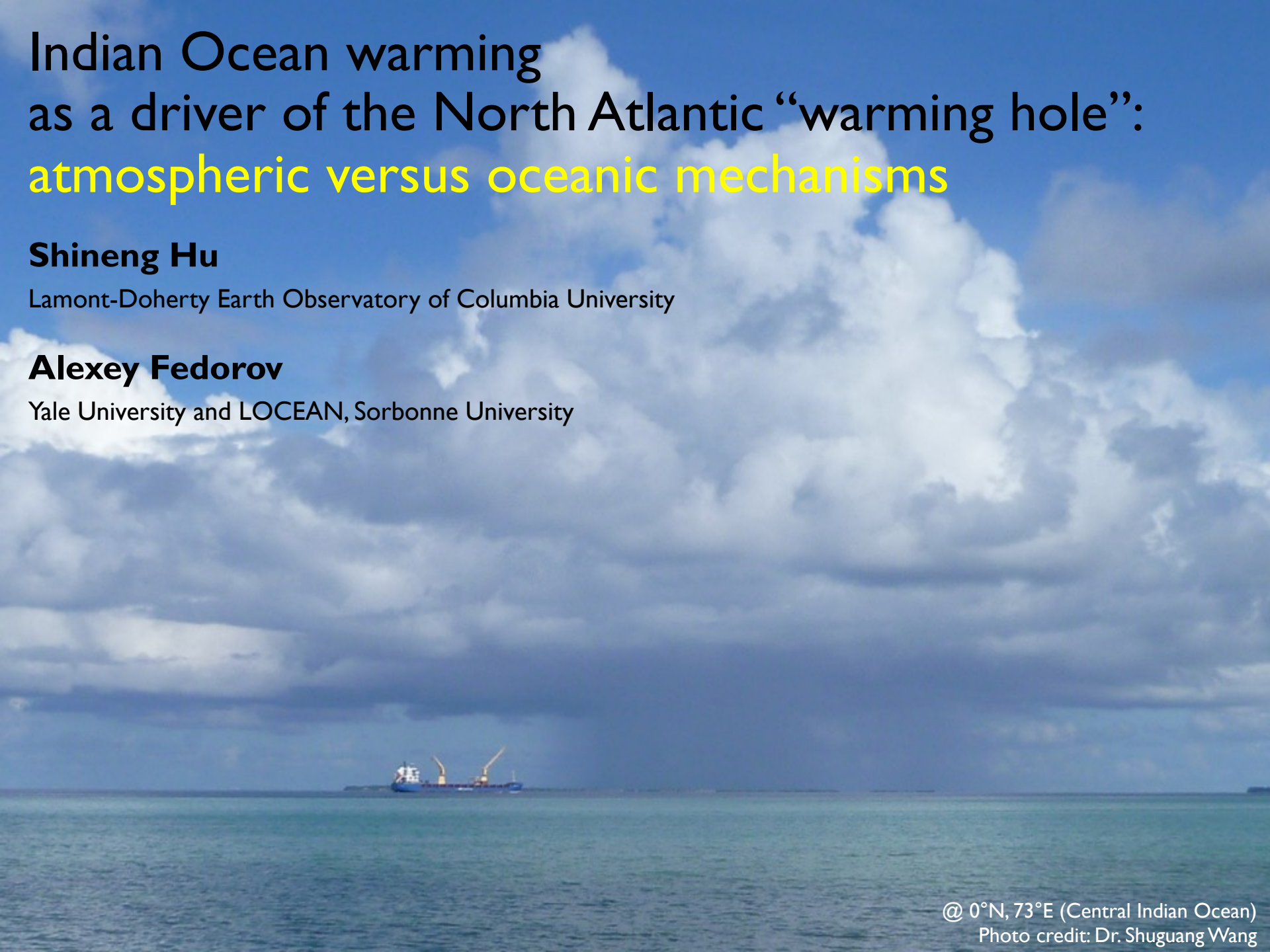


@ 0°N, 73°E (Central Indian Ocean)
Photo credit: Dr. Shuguang Wang

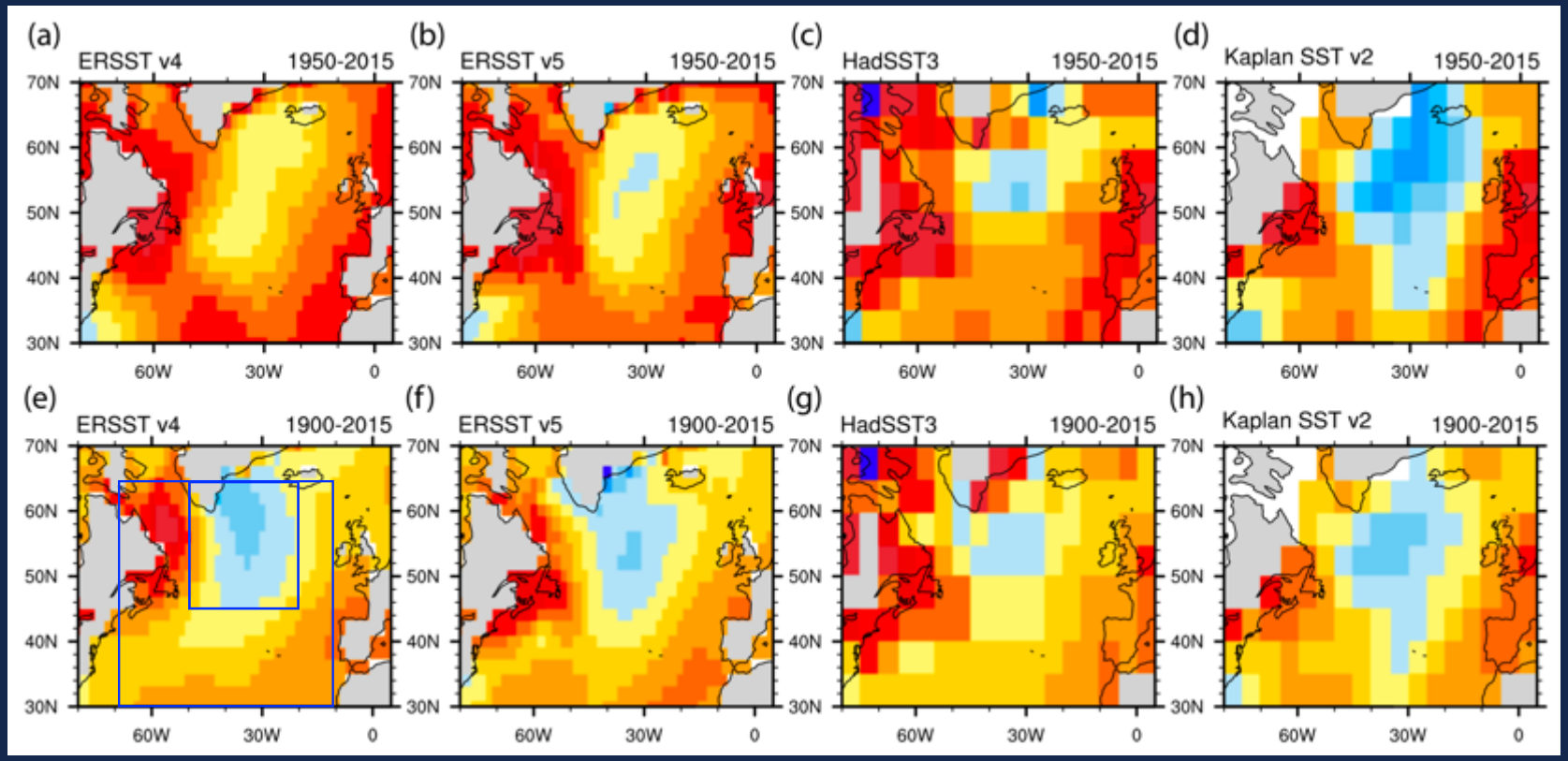
Observed North Atlantic "warming hole" (NAWH)

Long-term trend in annual-mean SST

ERSST v4 ERSST v5 HadSST3 Kaplan SST v2

1950-2015

1900-2015

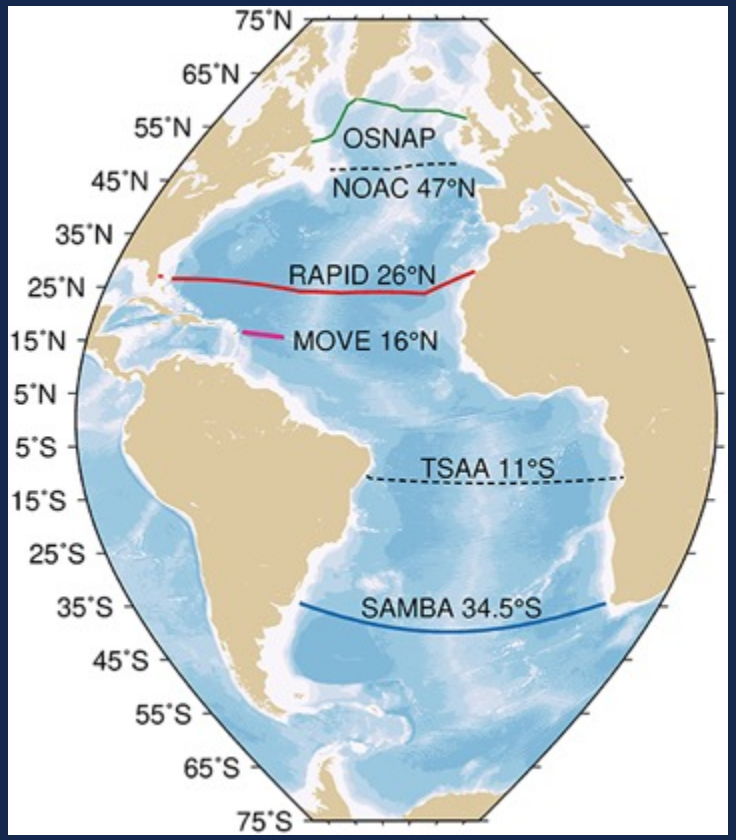


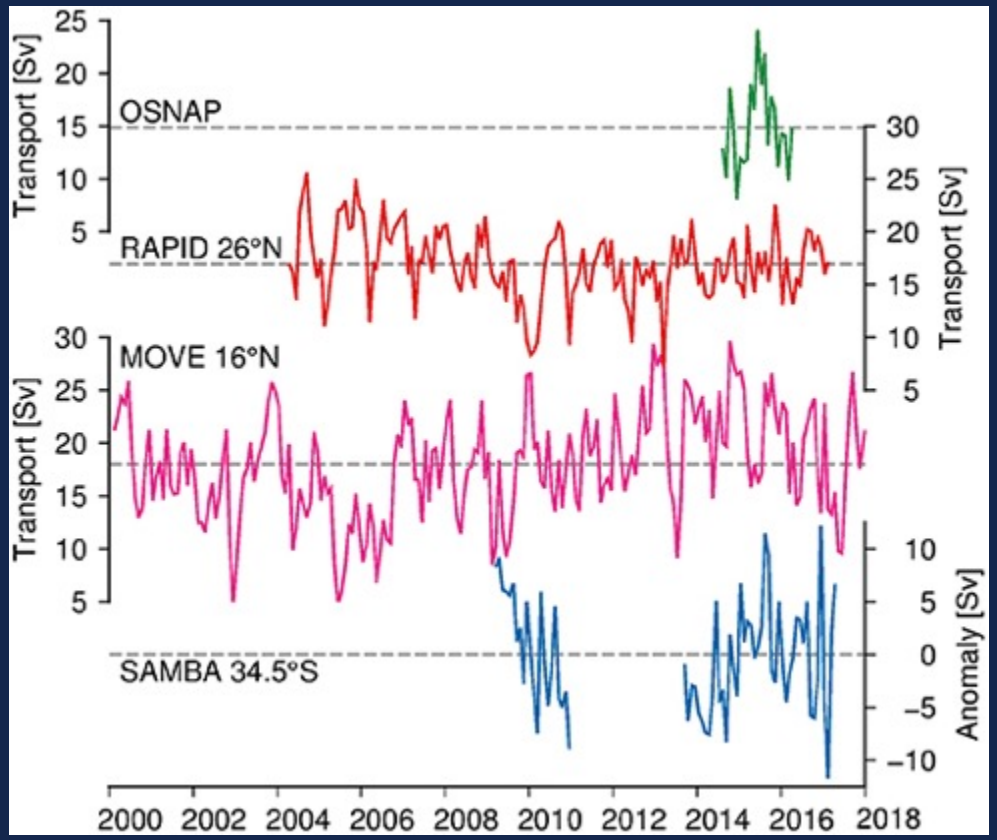
NAWH index = "small box" SST – "big box" SST

What was the cause of NAWH?

- AMOC slowdown? (e.g. Drijfhout et al. 2012; Menary and Wood 2018)

  Observational record is too short.



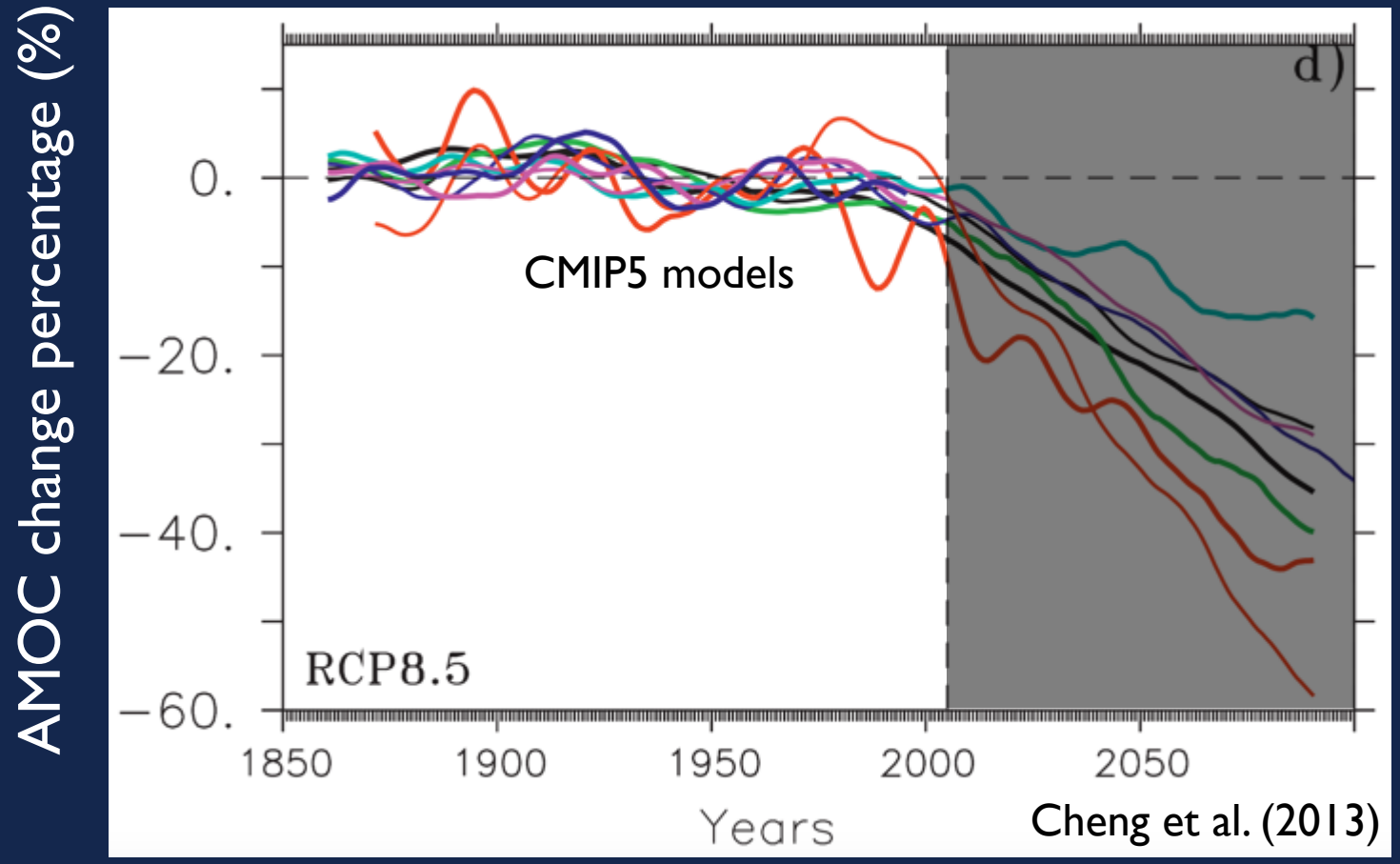


Frajka-Williams et al. (2019)

What was the cause of NAWH?

- AMOC slowdown? (e.g. Drijfhout et al. 2012; Menary and Wood 2018)

  Not supported by coupled climate simulations for the past century.

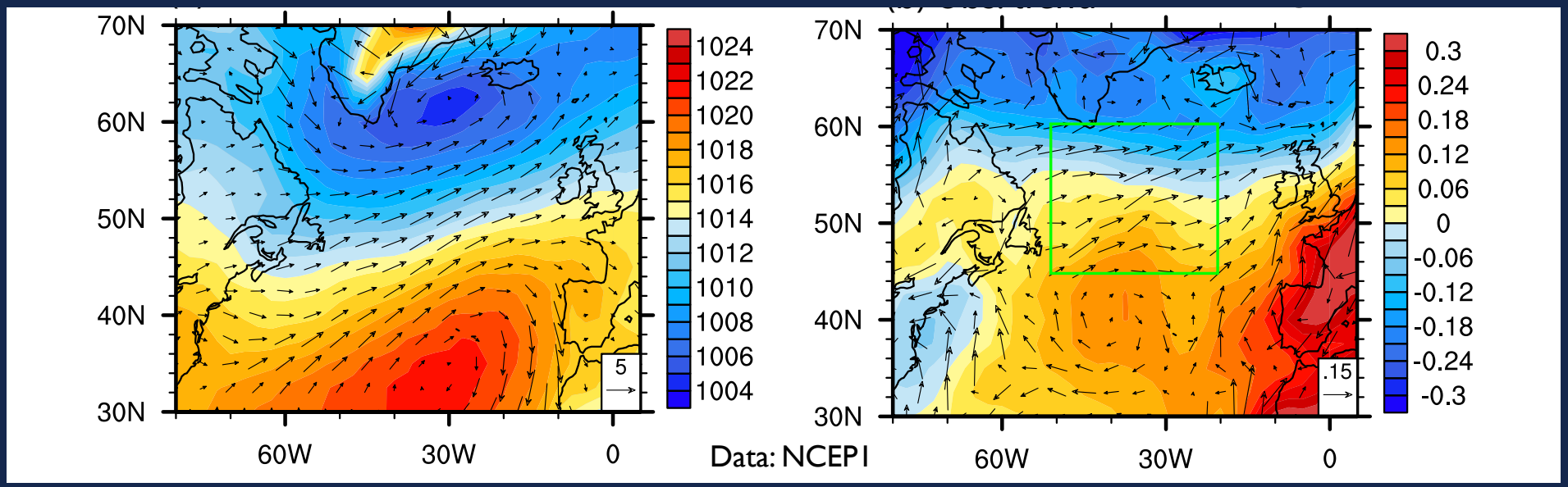


Cheng et al. (2013)

Westerly wind strengthening over the subpolar North Atlantic

Mean sea level pressure (mb) & surface winds (m/s)

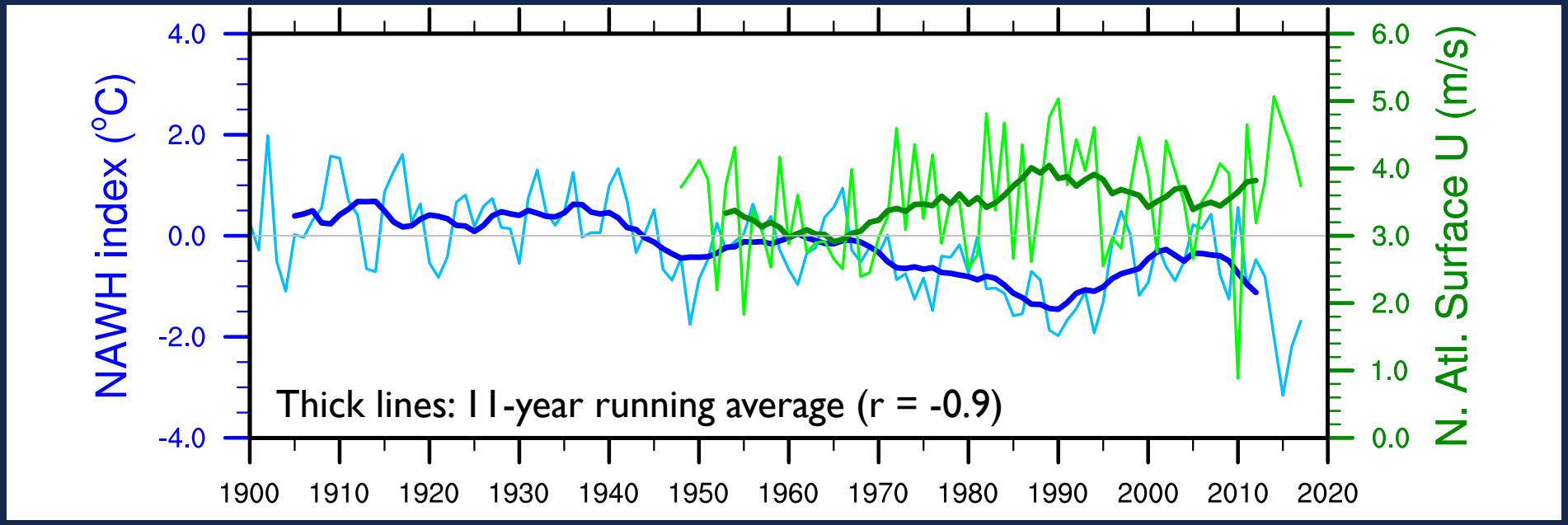
1950-2015 trends in sea level pressure (mb/dec) & surface winds (m/s/dec)



The subpolar N. Atl. westerly strengthening

- is accompanied by an upward trend in the North Atlantic Oscillation (NAO) index (Hurrell and Deser 2010).
- can cool the surface ocean by enhancing surface turbulent heat flux and driving southward Ekman transport (e.g. Kushnir 1994; Seager et al. 2000; Marshall et al. 2001; Delworth and Zeng 2016).

An atmospheric mechanism for NAWH: observational evidence



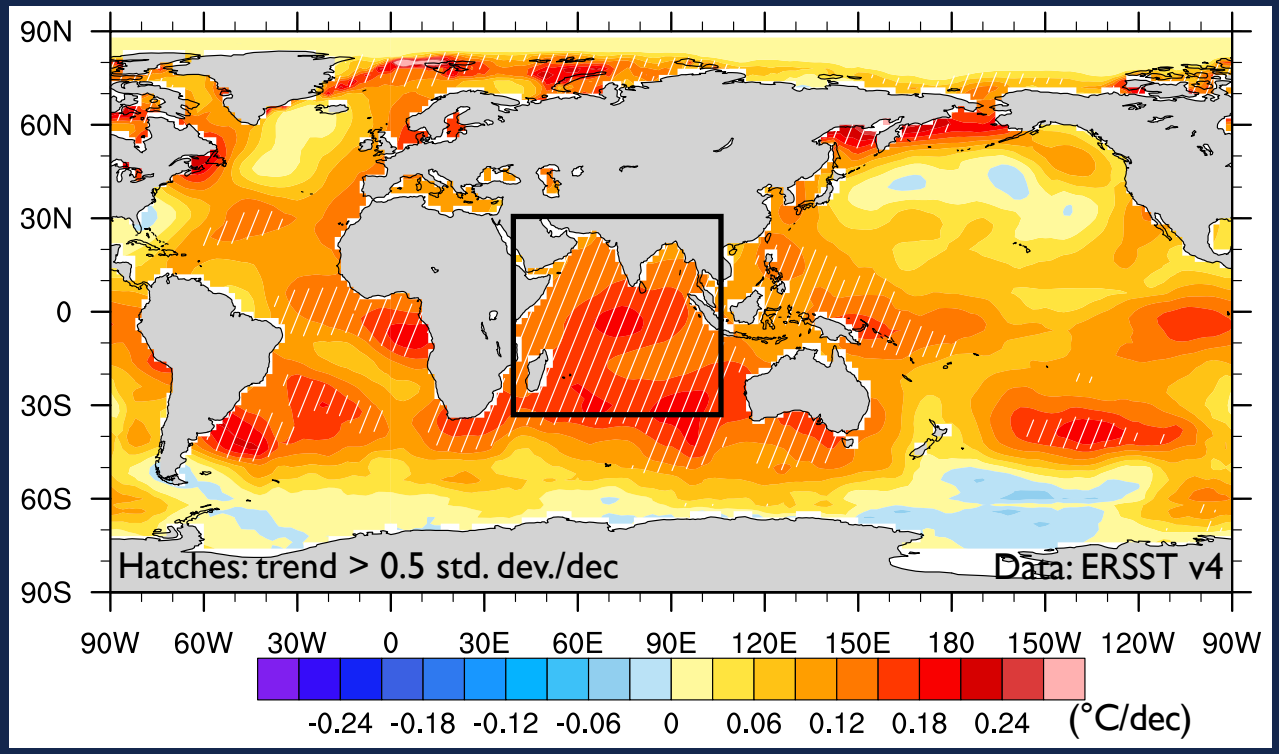
Hu and Fedorov (2020), *under review*

Hypothesis:

Indian Ocean warming → N. Atl. westerly strengthening (positive NAO) → NAWH

Enhanced tropical Indian Ocean (TIO) warming

1950-2015 trend in annual-mean SST

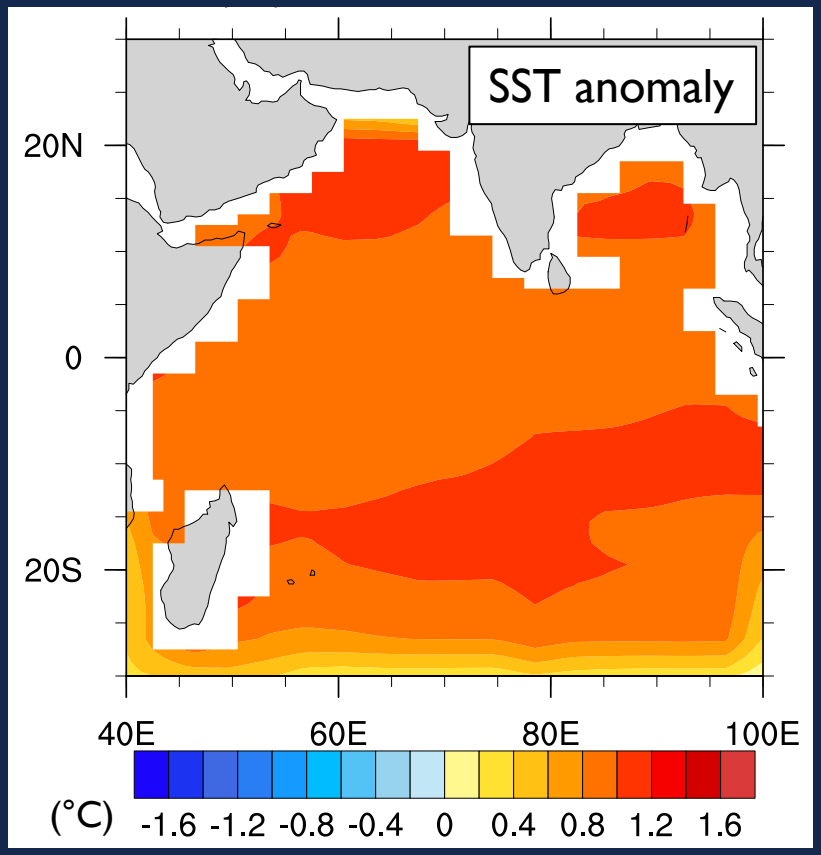


- TIO warming (Alory et al. 2007; Du and Xie 2008; Dong and Zhou 2014) is faster than the tropical Pacific and Atlantic warming by ~50%.
- Enhanced TIO warming can cause global-scale atmospheric impacts, including a positive NAO (Hoerling et al. 2001; Bader and Latif 2003; Giannini et al. 2003; Cherchi et al. 2007; Luo et al. 2012)

Ocean-atmosphere coupled model experiments

- Community Earth System Model (CESM)
- Ocean-atmosphere fully coupled (~2°C ocean, ~4°C atmosphere)
- Impose a 1°C uniform TIO warming via a restoring heat flux (τ = 10 days)
- Integrate for 200 years

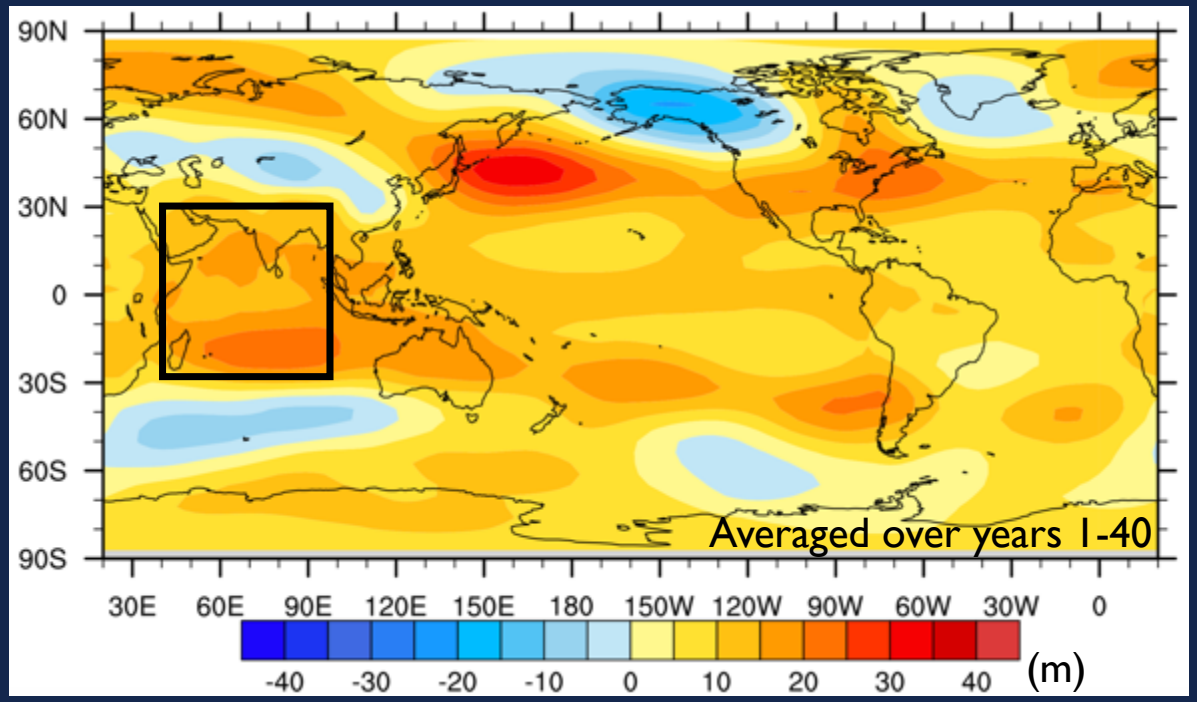
Imposed TIO warming via restoring



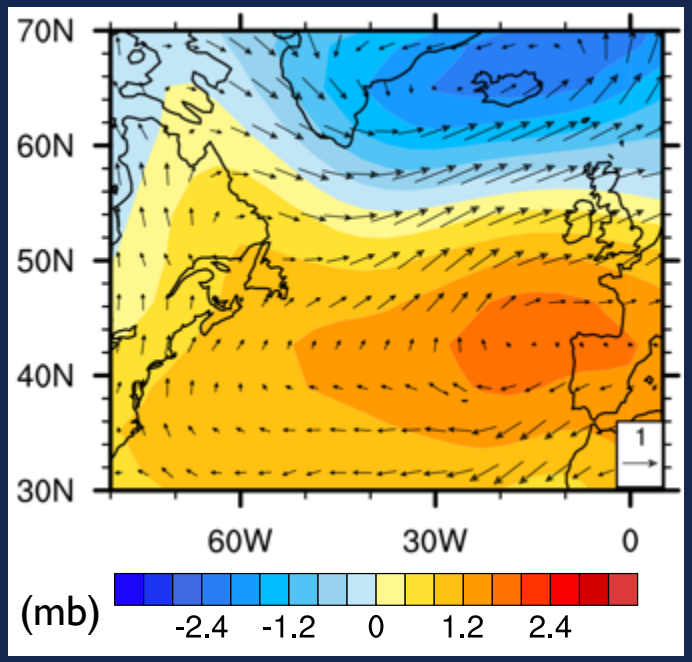
Anomaly: "TIO+1C" minus "Control"

Atmospheric wave train response to TIO warming

Anomalous 500 mb geopotential height (m)



Anomalous sea level pressure (mb) & surface winds (m/s)

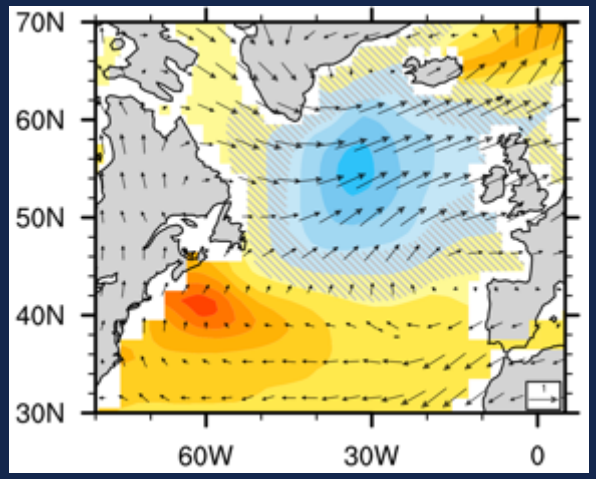


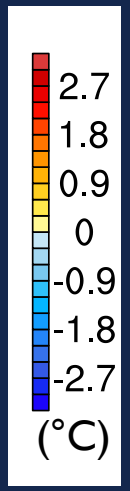
Hu and Fedorov (2020), *under review*

NAWH response to TIO warming

Anomalous SST (°C) & surface winds (m/s)

Initial (Years 1-40)

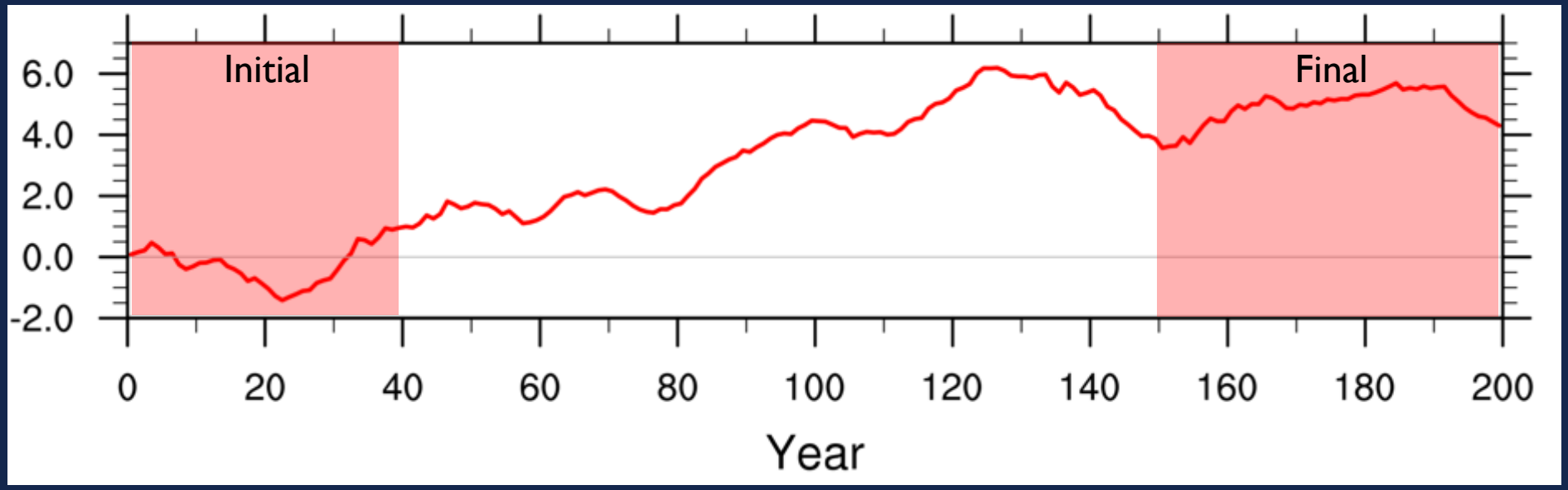




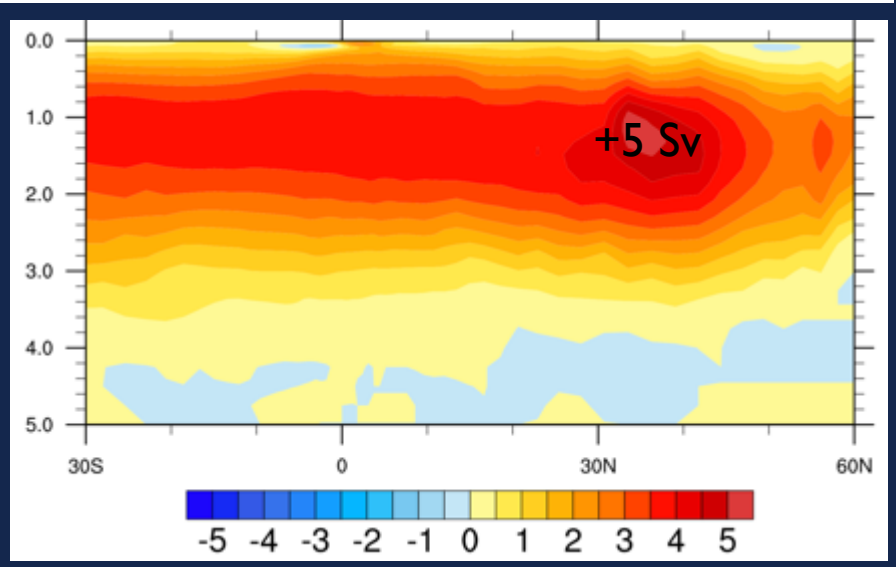
Hu and Fedorov (2020), *under review*

TIO warming can strengthen the Atlantic Meridional Overturning Circulation (AMOC)

Response of AMOC intensity to 1°C TIO warming (Sv)



TIO warming
→Trop. Atl. rainfall reduction
→Trop. Atl. salinity increase
→N. Atl. salinity increase
→AMOC strengthening

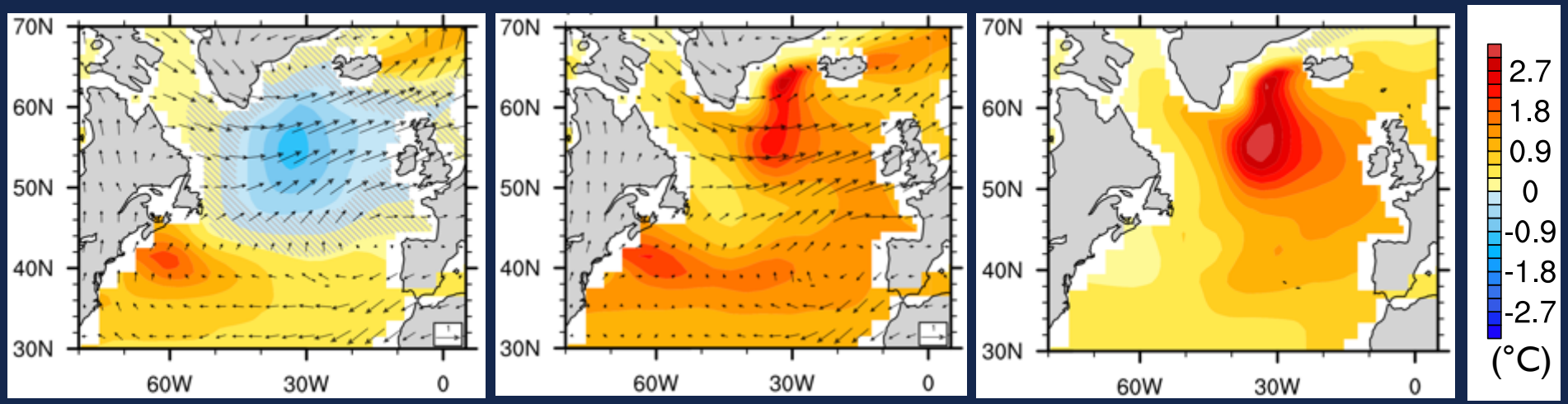


Hu and Fedorov (2019)

NAWH response to TIO warming

Anomalous SST (°C) & surface winds (m/s)

Initial (Years 1-40) | Final (Years 151-200) | Final - Initial



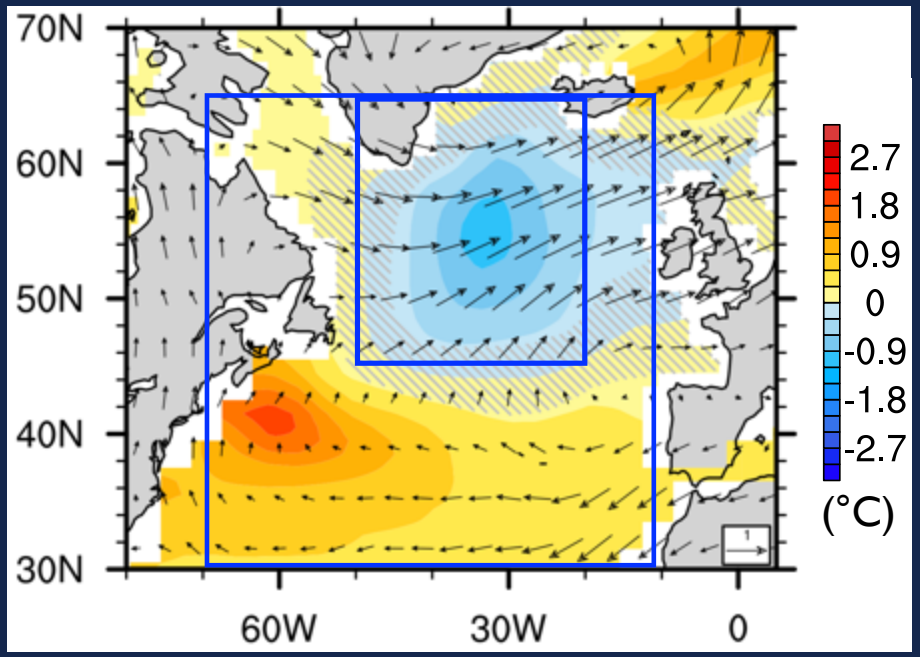
"Fast response"
(Surface westerly strengthening)

"Slow response"
(AMOC strengthening)

Hu and Fedorov (2020), *under review*

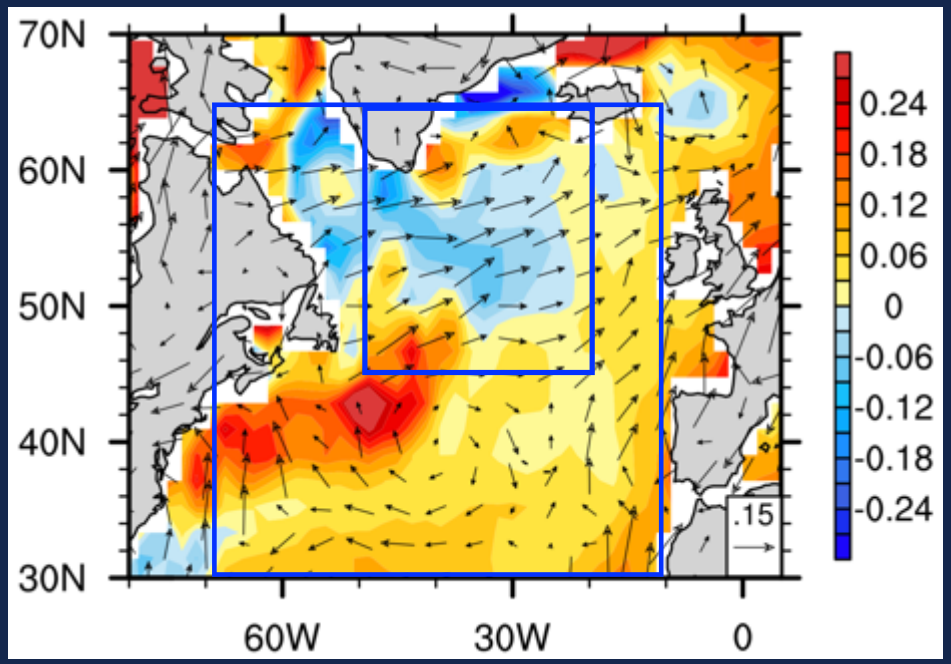
An atmospheric mechanism for NAWH: model evidence

Modelled fast response to TIO warming



SST (°C) & surface winds (m/s)

Observed climate trends in1950-2015
(Data: NCEP1)

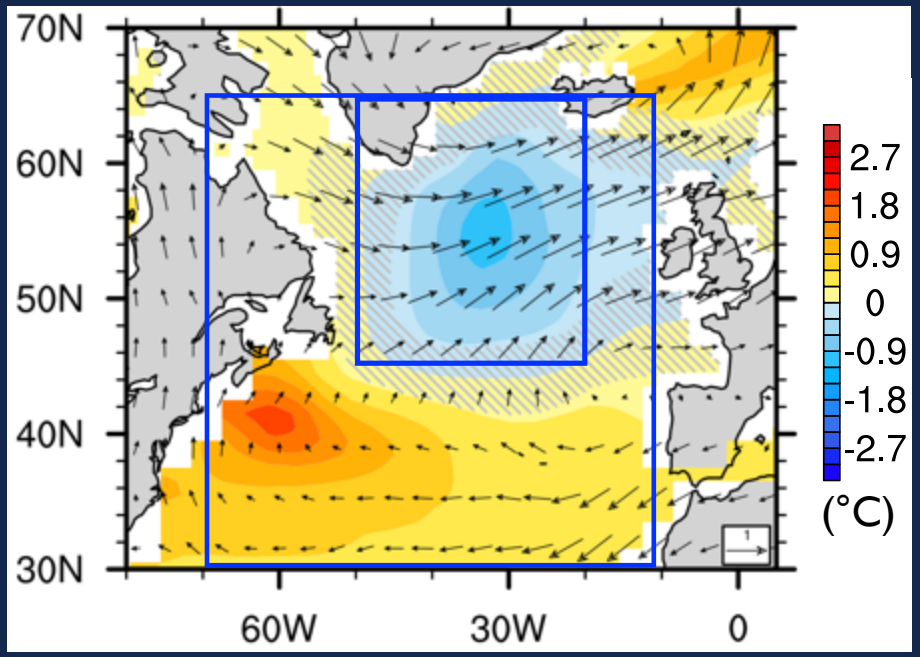


SST (°C/dec) & surface winds (m/s/dec)

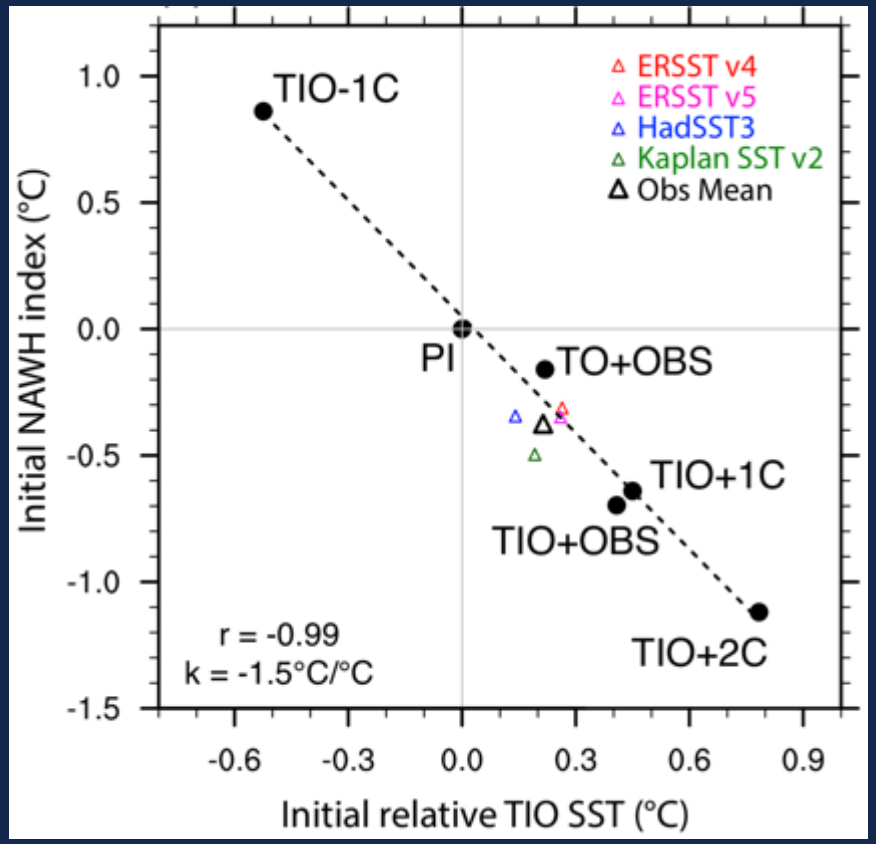
Hu and Fedorov (2020), *under review*

Enhanced TIO warming can explain ~90% of the historical NAWH

Modelled fast response to TIO warming



SST (°C) & surface winds (m/s)

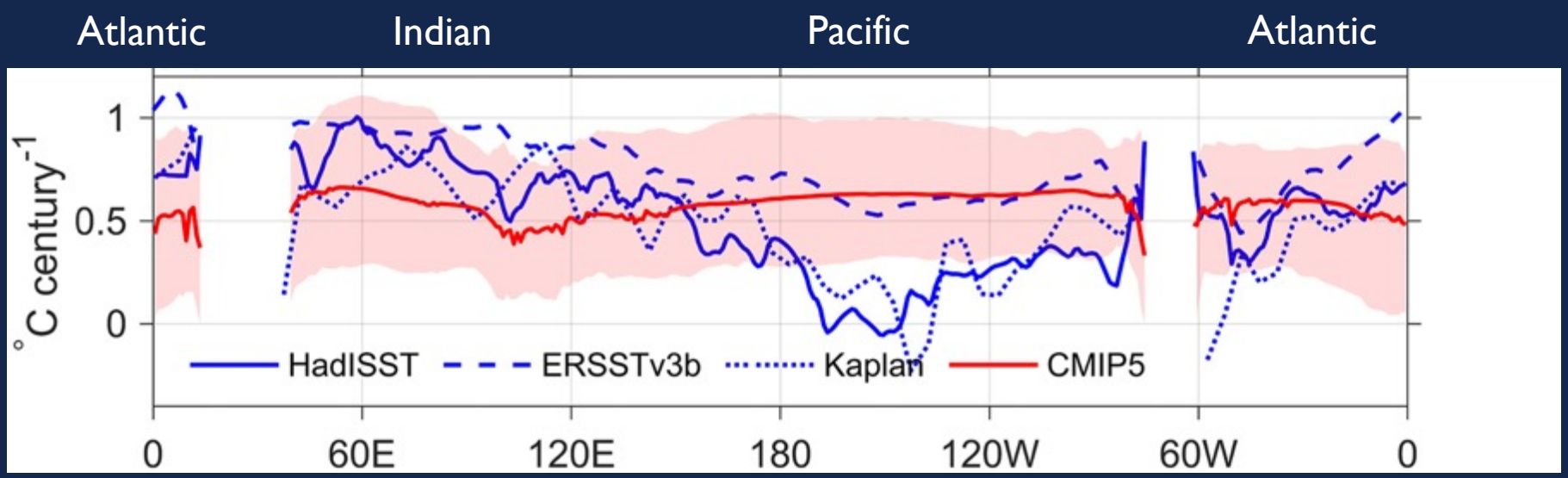


Relative TIO SST = TIO SST – Tropical mean SST
(Vecchi and Soden 2007; Xie et al. 2010; etc.)

Hu and Fedorov (2020), *under review*

Climate models are unable to reproduce enhanced TIO warming

Equatorial SST trends in 1920-2013

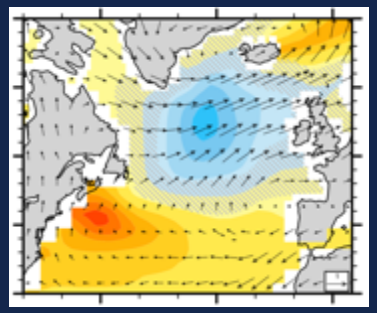


Zhang et al. (2019)

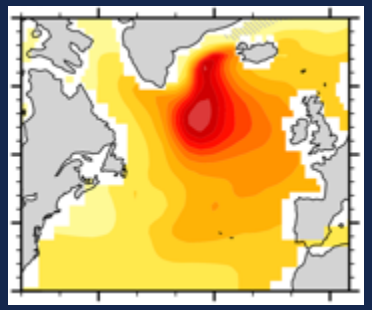
Summary

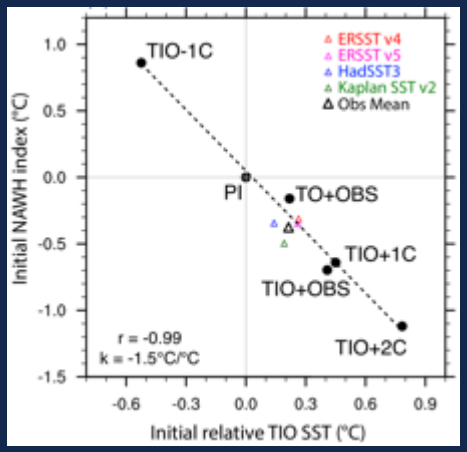
Indian Ocean warming

months - years → Enhanced westerlies in subpolar N. Atlantic →



multi-decades → AMOC strengthening →





- Atmospheric changes related to the Indian Ocean warming can potentially explain ~90% of the observed NAWH.

Hu, S. & Fedorov, A.V. (2020) Indian Ocean warming as a driver of the North Atlantic warming hole. *Nature Communications*. Under review.

Hu, S. & Fedorov, A.V. (2019) Indian Ocean warming can strengthen the Atlantic meridional overturning circulation. *Nature Climate Change* 9, 747-751.