Changes to wind driven ocean circulation amplify externally forced warming over the historical period in CESM2

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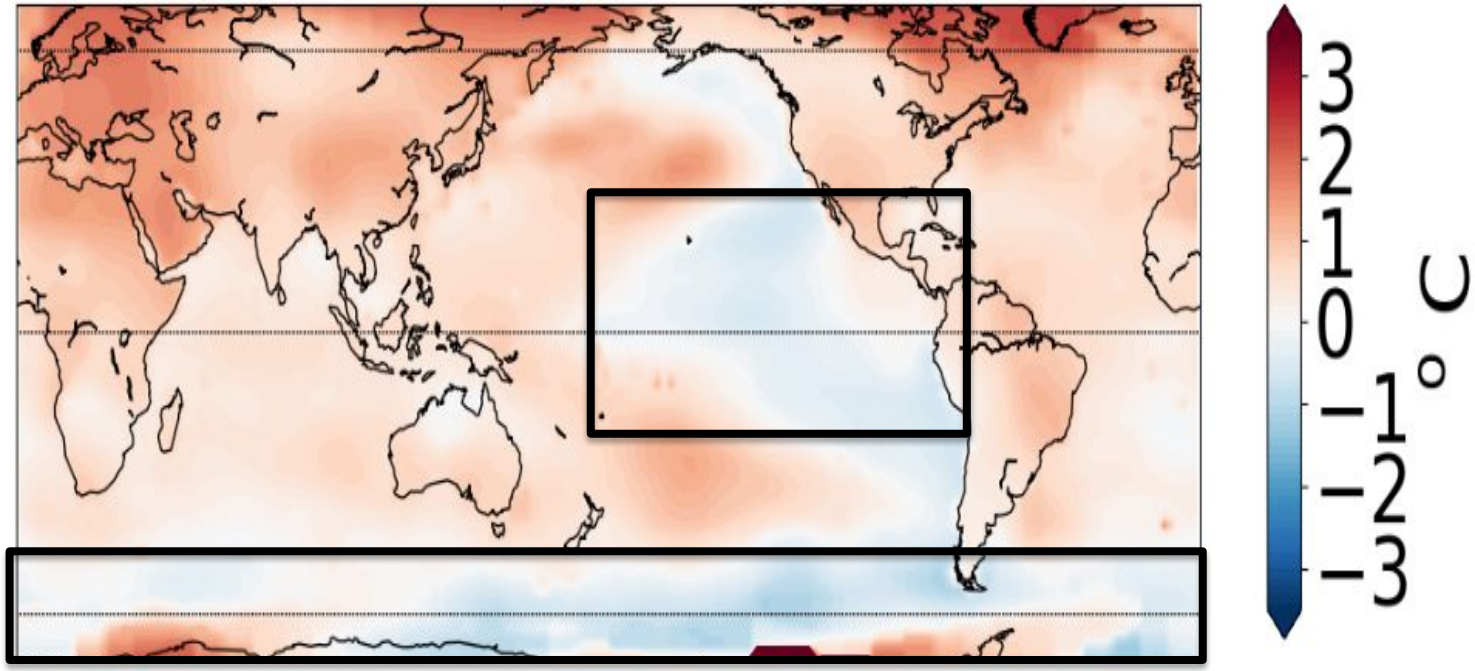
Recently accepted by GRL

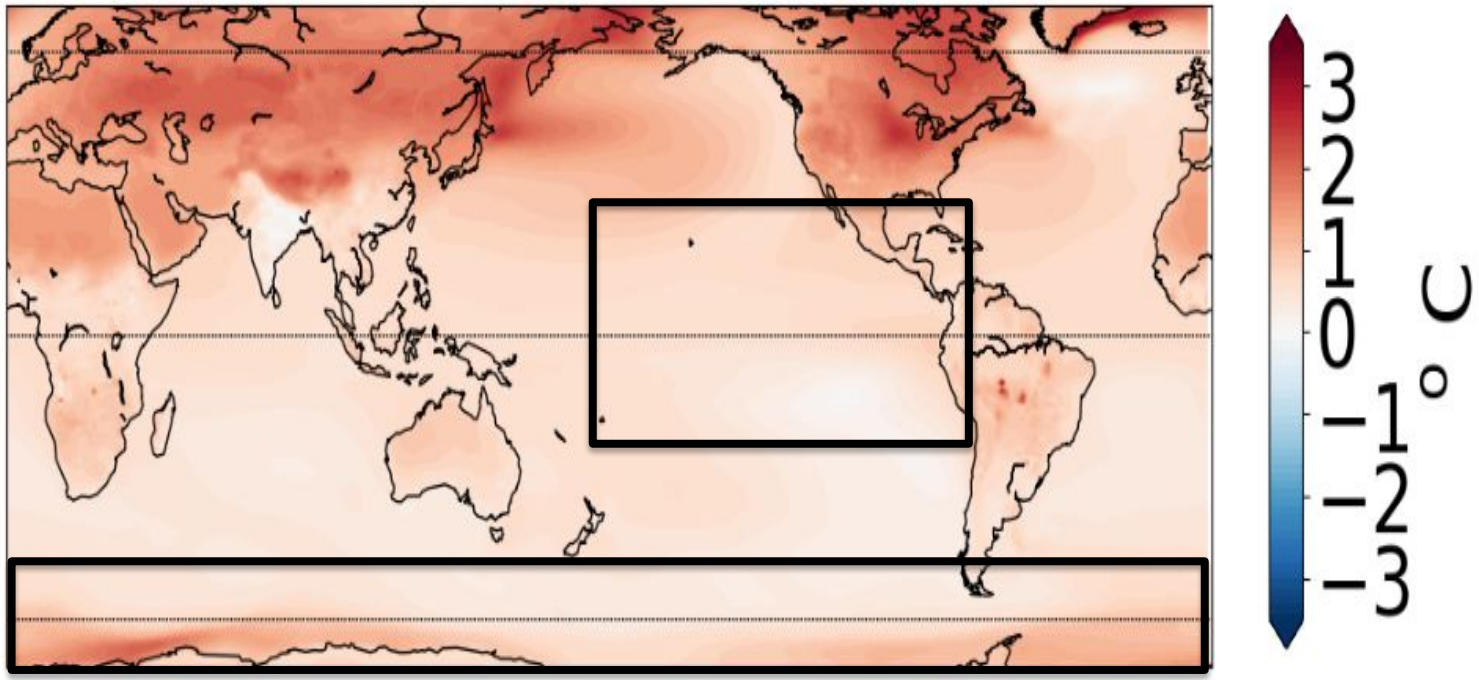
Increase in greenhouse gases (plus aerosols, internal variability) leads to spatially varying surface warming pattern



Very little warming in Southern Ocean, East tropical Pacific

Observed surface temperature warming over 1979-2014 (GISTEMP)

Increase in greenhouse gases (plus aerosols, internal variability) leads to spatially varying surface warming pattern



CESM2 large ensemble, ensemble mean surface temperature warming over 1979-2014

This is *not* the pattern we see in CESM2 (or CMIP models more generally)

Why does this pattern matter?

Radiative feedbacks depend on the pattern "pattern effect" (e.g. Armour et al. 2013)

Pattern of warming can be altered by ocean circulation changes

- Ocean observations show that ocean circulation has changed over the past several decades (e.g. Roemmich et al., 2009, 2015, 2016; Beal & Elipot, 2016; Shi et al., 2021)
- How have these changes in ocean circulation impacted the global warming rate and pattern?

Atlantic Meridional Overturning Circulation (AMOC)

Wind driven ocean circulation

AMOC redistributes heat

Studies that quantify the role of all ocean circulation changes on the rate of global warming focus on AMOC changes (2x and 4x CO2 experiments; Winton et al., 2013; Trossman et al., 2016; Garuba et al., 2018)

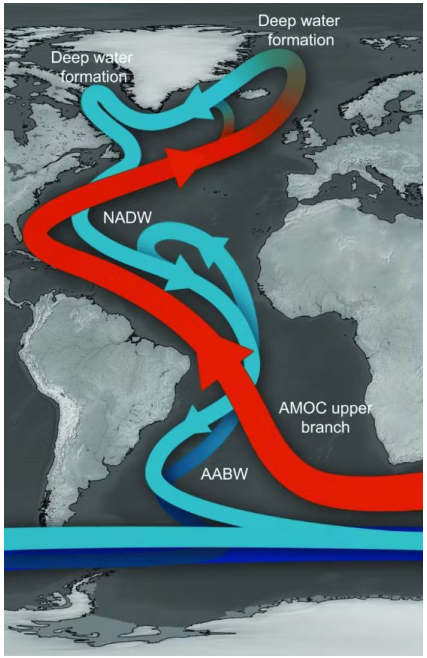


Photo: Stefano Crivellari, University of São Paulo/Research Gate

Climate projections show weakening of AMOC

Cools North Atlantic and increases deep ocean heat update

Reduces global surface warming rate

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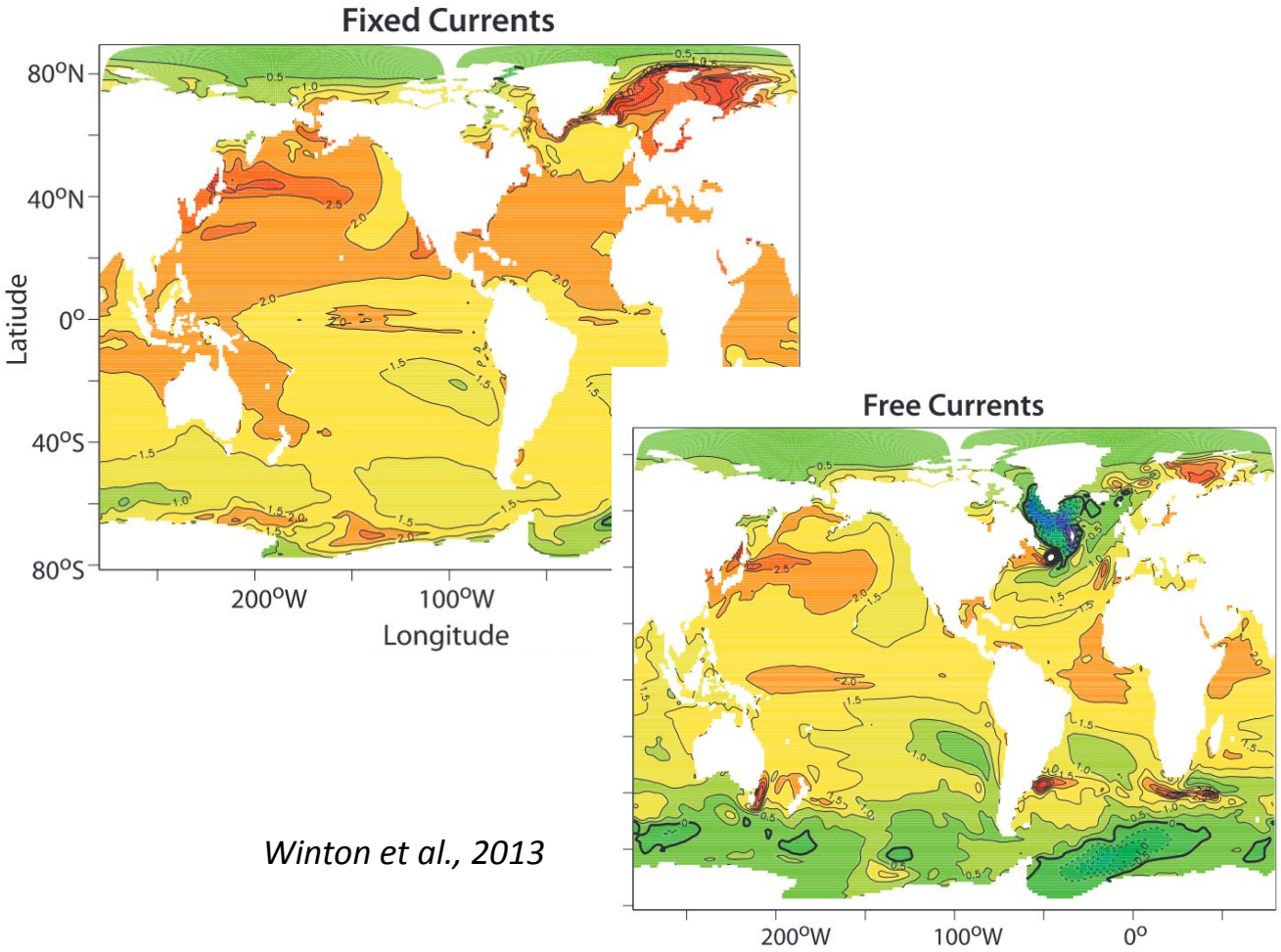

Winton et al., 2013

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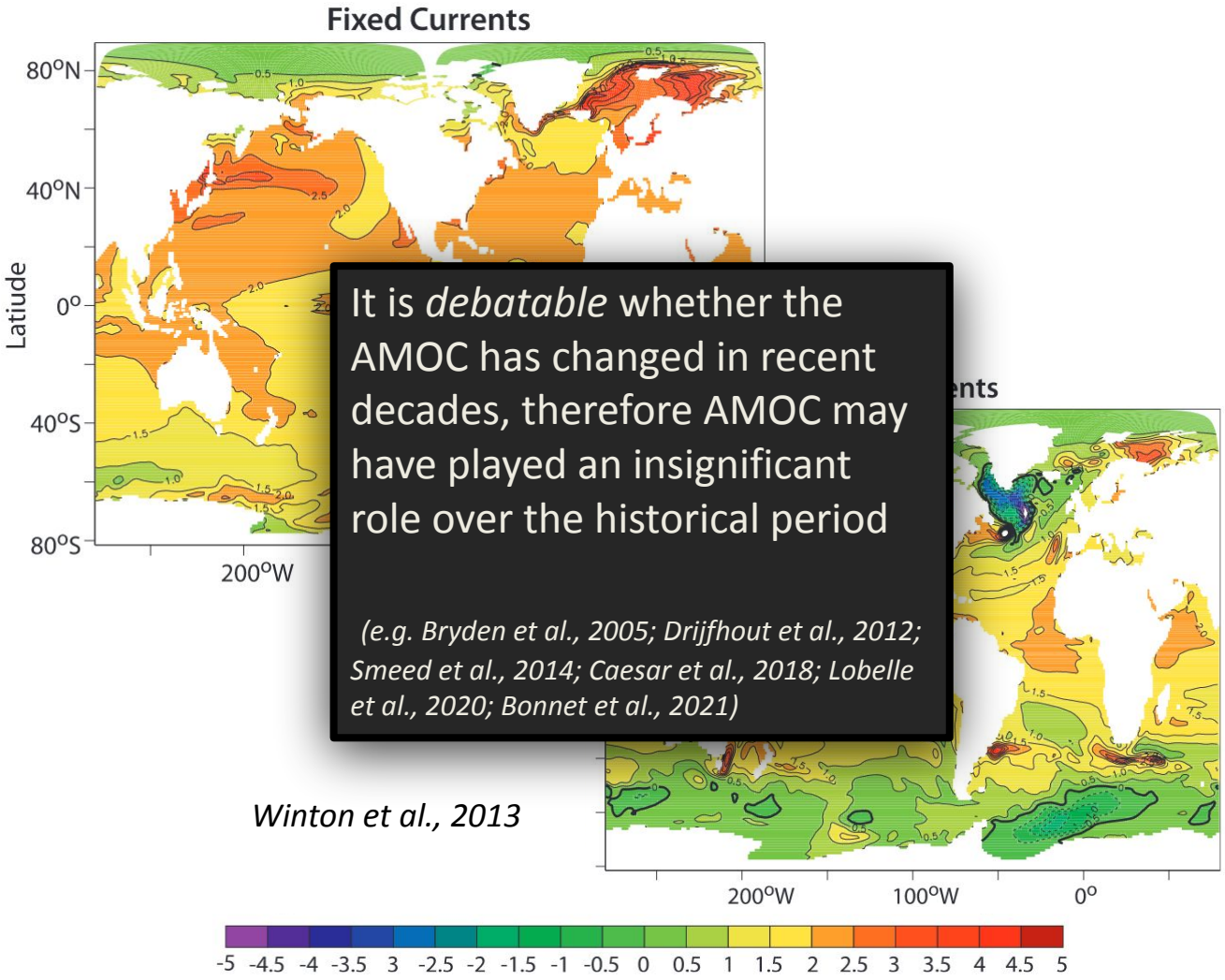


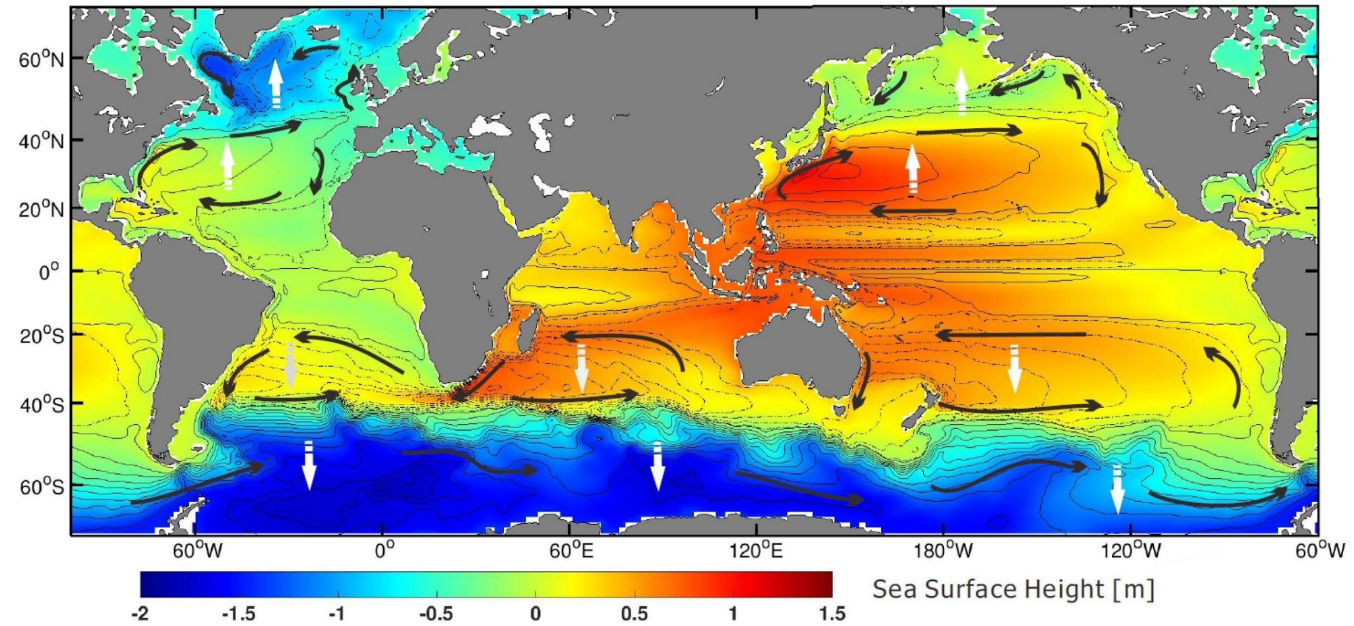
It is *debatable* whether the AMOC has changed in recent decades, therefore AMOC may have played an insignificant role over the historical period

(e.g. Bryden et al., 2005; Drijfhout et al., 2012; Smeed et al., 2014; Caesar et al., 2018; Lobelle et al., 2020; Bonnet et al., 2021)

Winton et al., 2013

Photo: S

Wind driven ocean circulation also redistributes heat



Yang et al., 2020

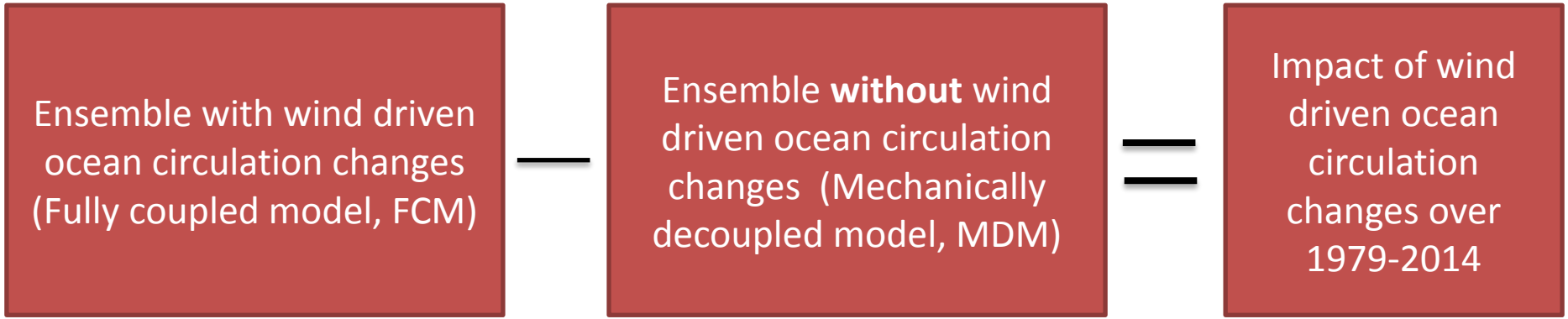
Many of the observed ocean circulation changes are likely wind driven and connected to atmospheric circulation changes

Strengthening and shifting of Southern Hemisphere westerlies (Thompson et al., 2002, 2011), stronger Pacific trades (Timmermann et al., 2010)

Scientific question

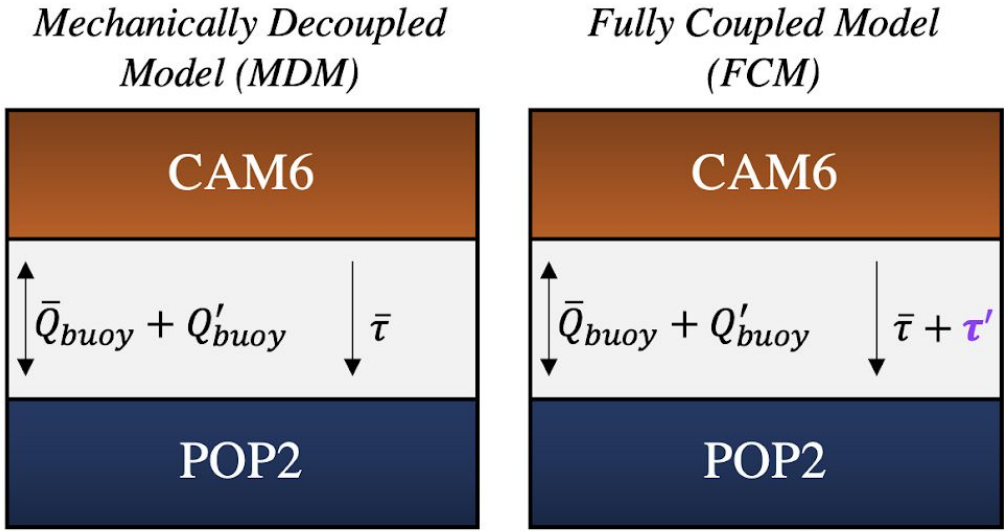
How do externally forced changes to wind driven ocean circulation alter the pattern of surface warming and the rate of global averaged surface warming?

Approach: compare 2 historical CESM2 ensembles



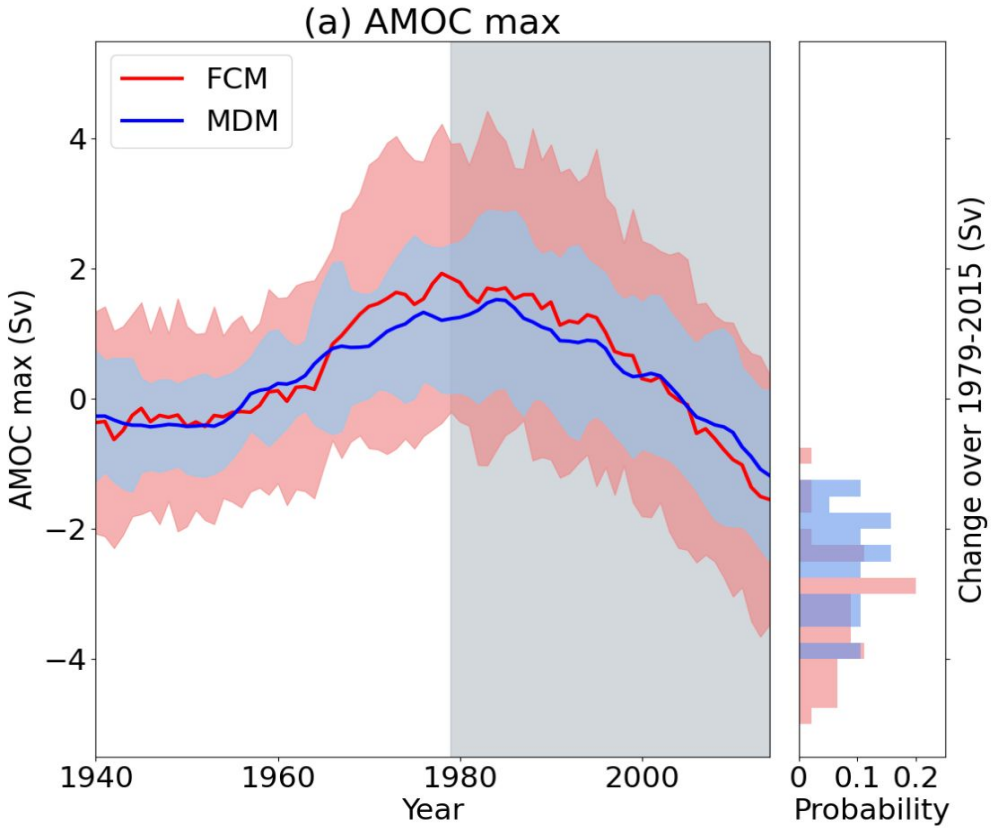
CESM2 historical ensembles (1850-2014)

- Historical forcing with smoothed biomass burning (Fasullo et al., 2022)
- Fully coupled model (**FCM**): 50 members
- Mechanically decoupled model (**MDM**): 20 members, wind stress forcing on ocean is fixed to 6 hourly pre-industrial climatology



Experiment validation

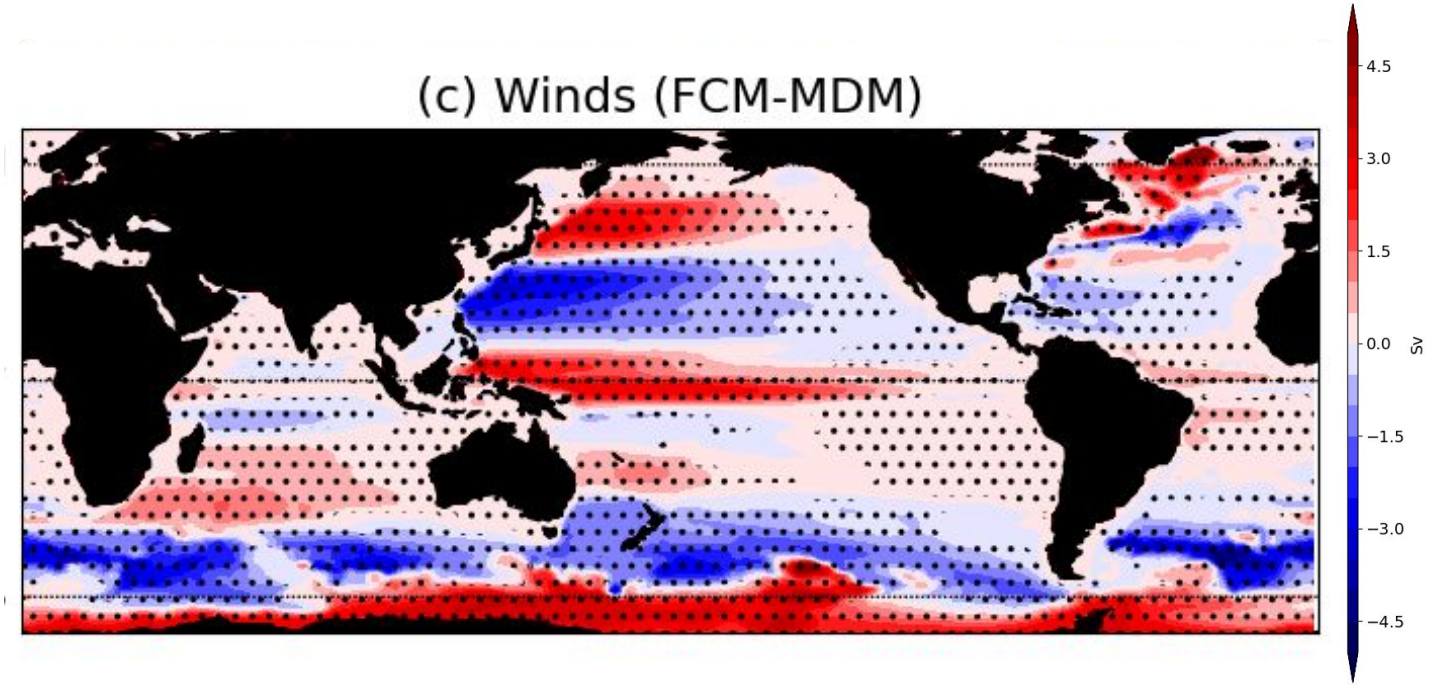
- AMOC trends are similar in both ensembles
- Simulated AMOC decline is primarily due to changes in buoyancy, not winds



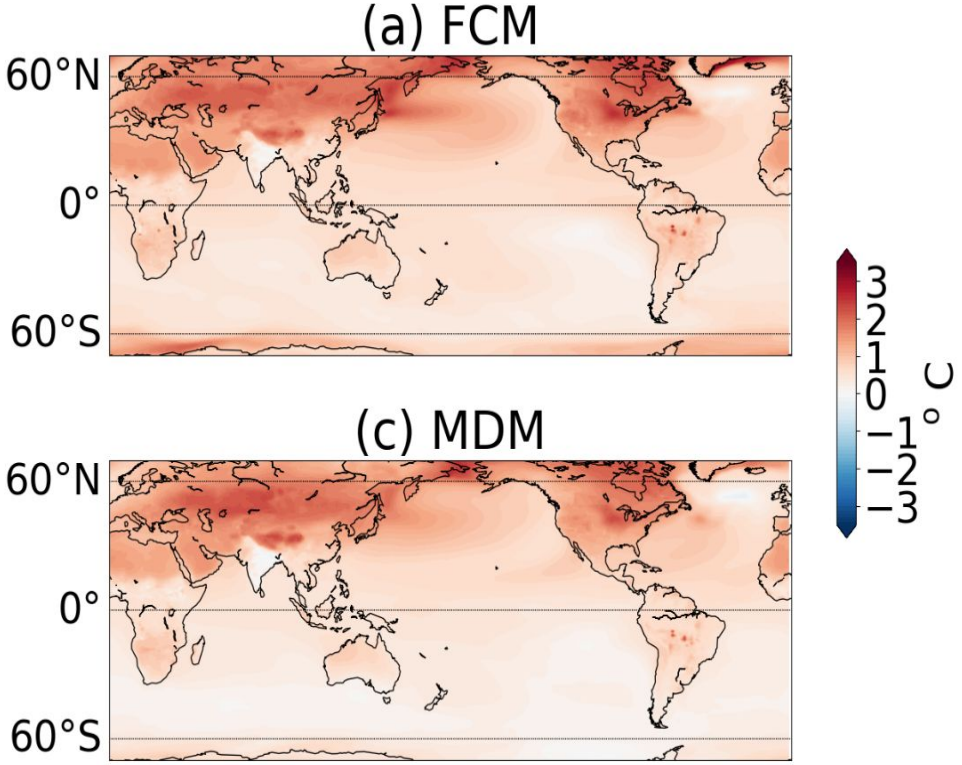
Wind driven ocean circulation trends over 1979-2014 in CESM2

Strengthening and shifting of Antarctic Circumpolar Current, tied to changes in Southern Hemisphere westerlies. *Generally consistent with reanalysis wind trend*

Weakening of tropical and N Pacific circulations, tied to a weakening of the trade winds. *Inconsistent with reanalysis wind trend*



Surface air temperature trends

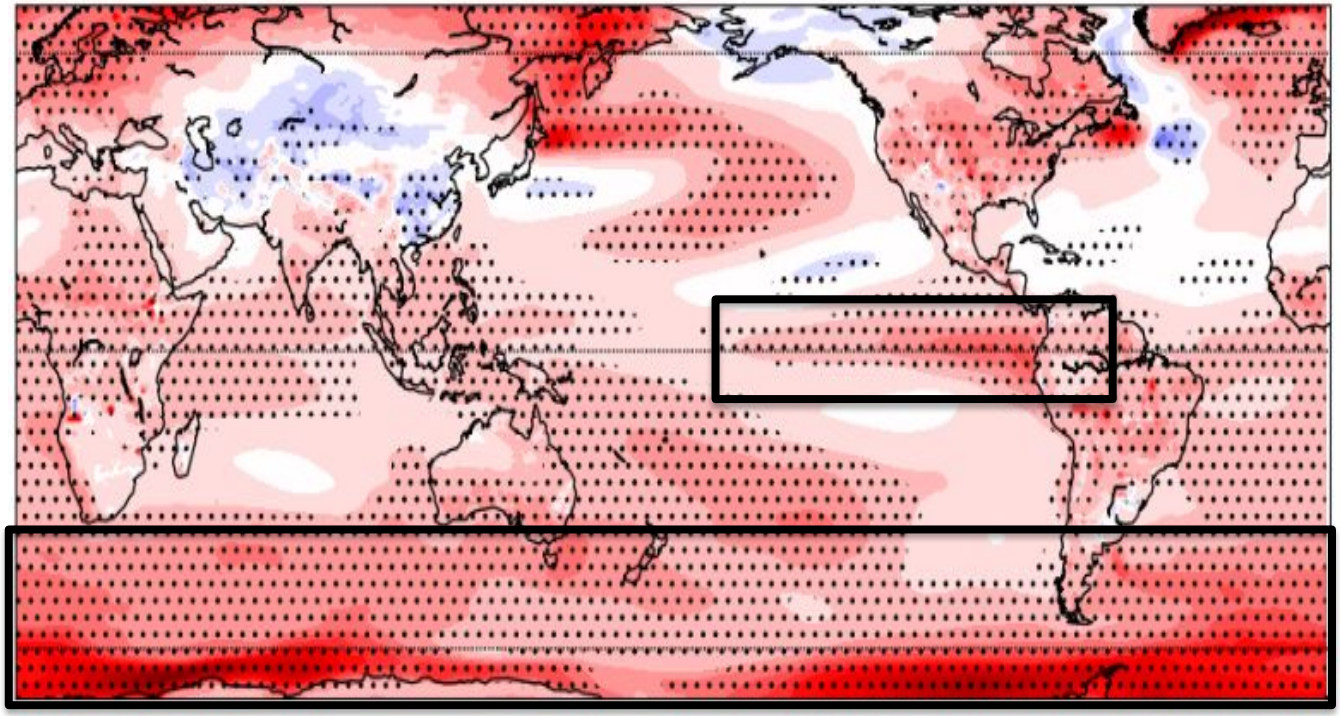


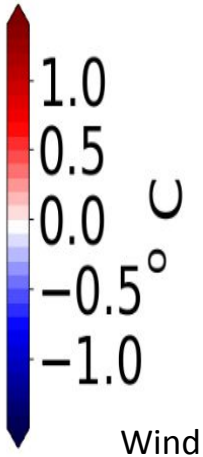
Warming nearly everywhere

Similar North Atlantic warming hole in both experiments

Surface air temperature trends

Winds (FCM – MDM)

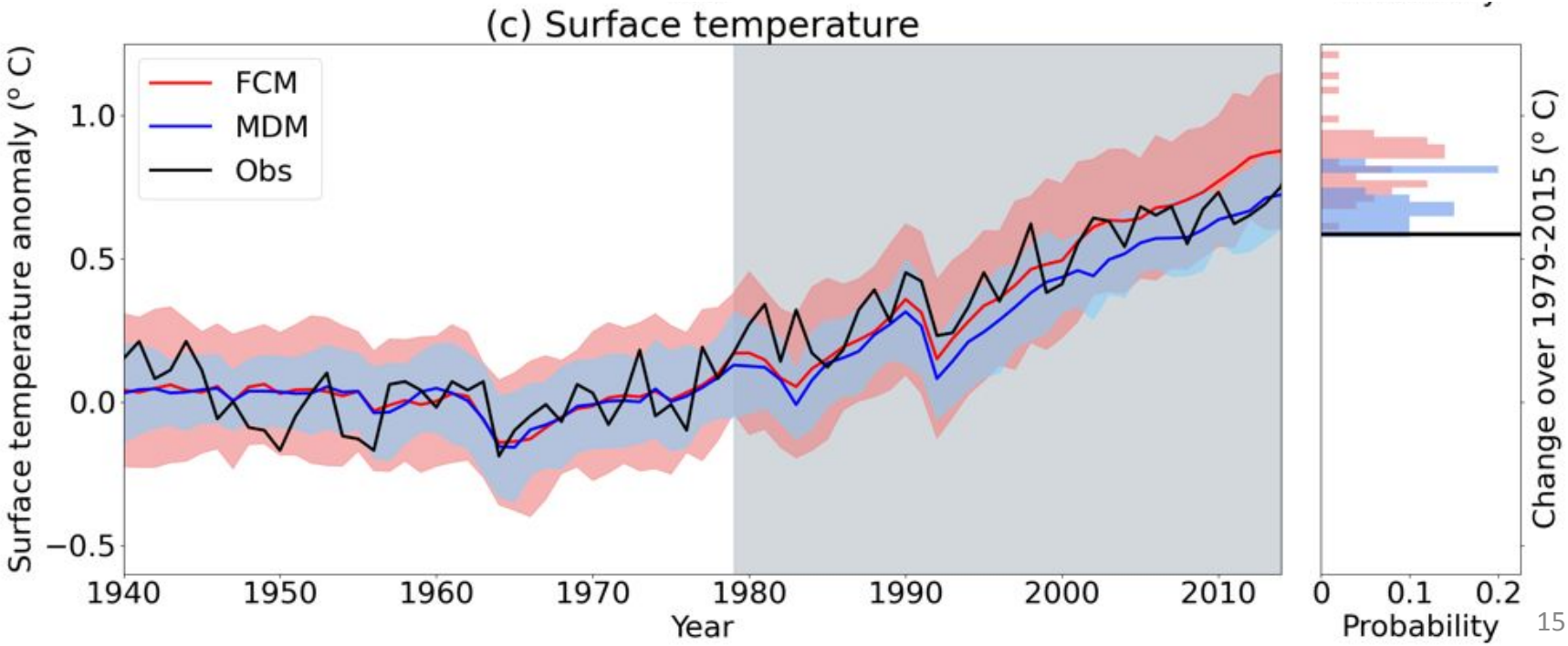




Wind driven ocean circulation changes **enhance** warming

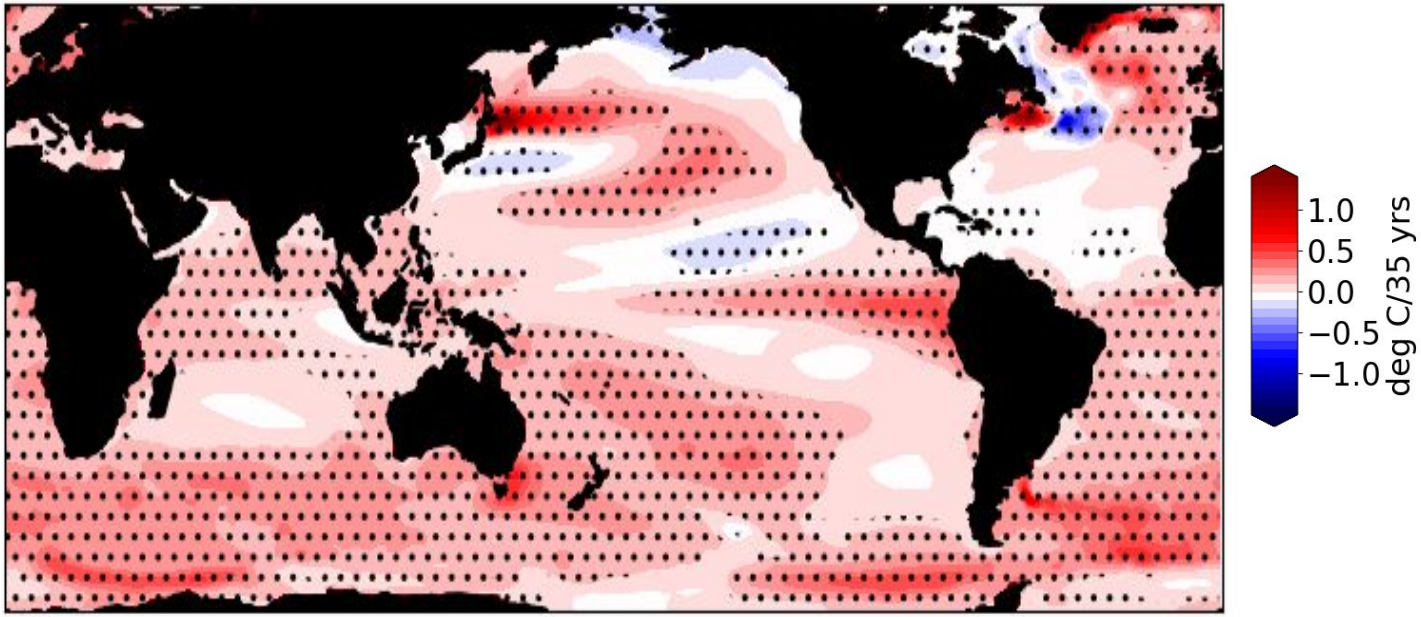
Wind driven ocean circulation changes reduce warming

Global averaged surface air temperature trends are 17% different over 1979-2014



Sea surface temperature trends

Winds (FCM - MDM)



Wind driven ocean circulation changes **enhance** warming

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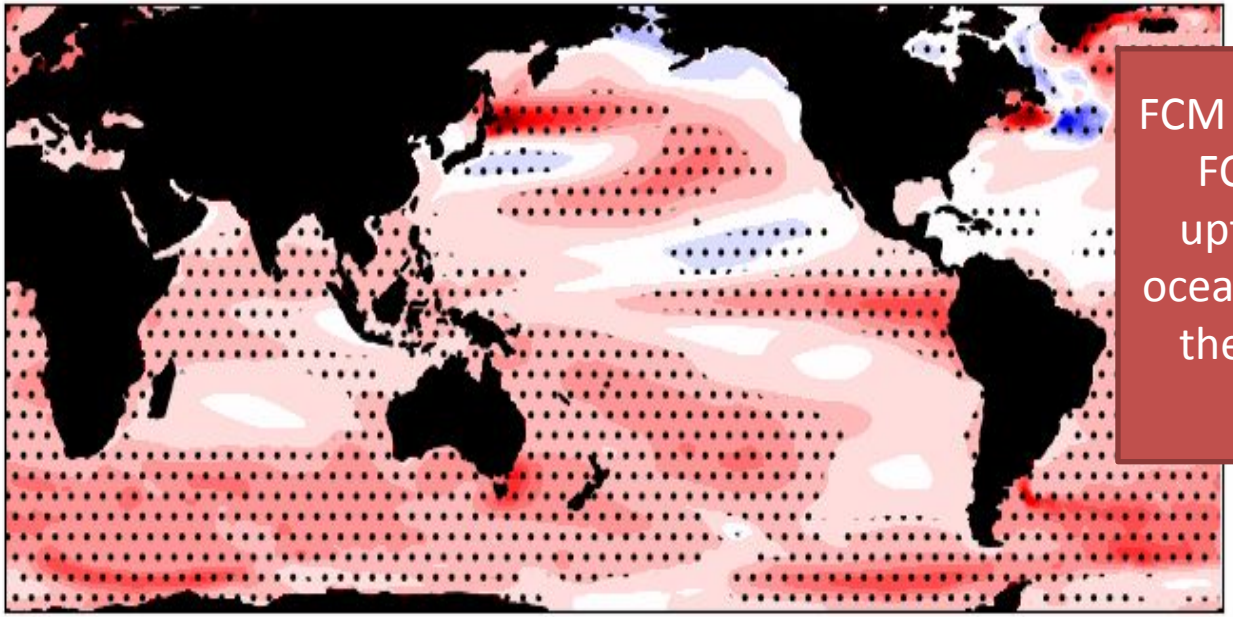
Sea surface temperature trends

Winds (FCM - MDM)



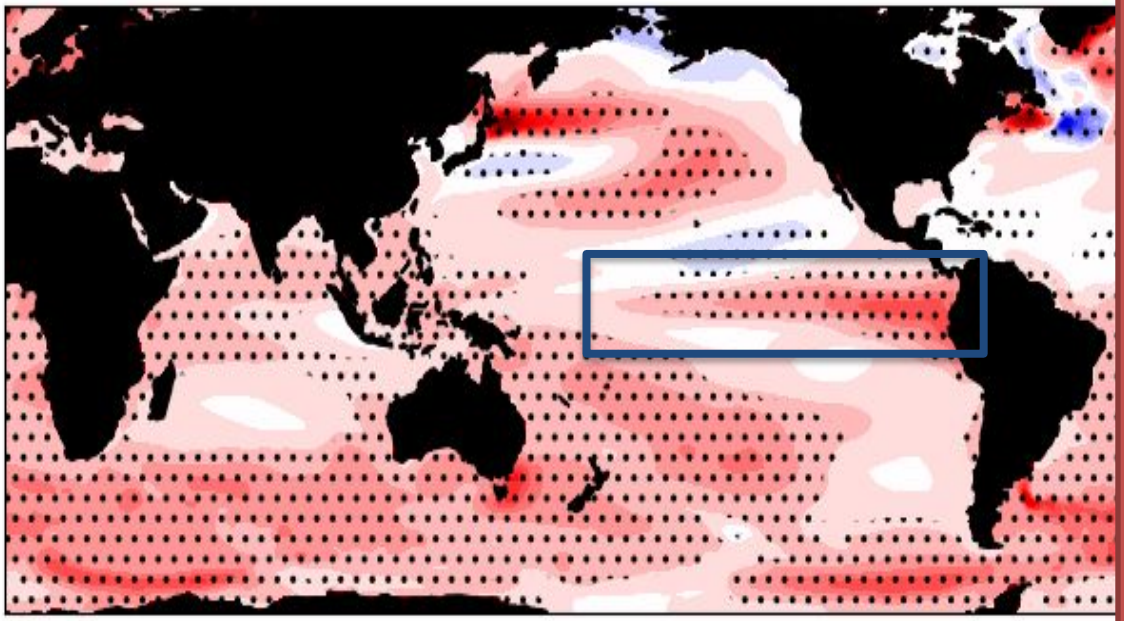
Wind driven ocean circulation changes **enhance** warming

FCM warms more than MDM, and FCM has greater ocean heat uptake than MDM. Therefore, ocean heat uptake cannot explain the difference of the warming rates.

Wind driven ocean circulation changes reduce warming

Sea surface temperature trends

Winds (FCM - MDM)



Amplified warming of SSTs in eastern tropical Pacific

↓

Reduction in low cloud coverage (e.g. Dong et al., 2020)

↓

Increased downward shortwave radiation

↓

Enhanced global warming

Conclusions

Changes in the wind driven ocean circulation alter the warming pattern and amplify the rate of global averaged surface warming by 17% over 1979-2014 in CESM2

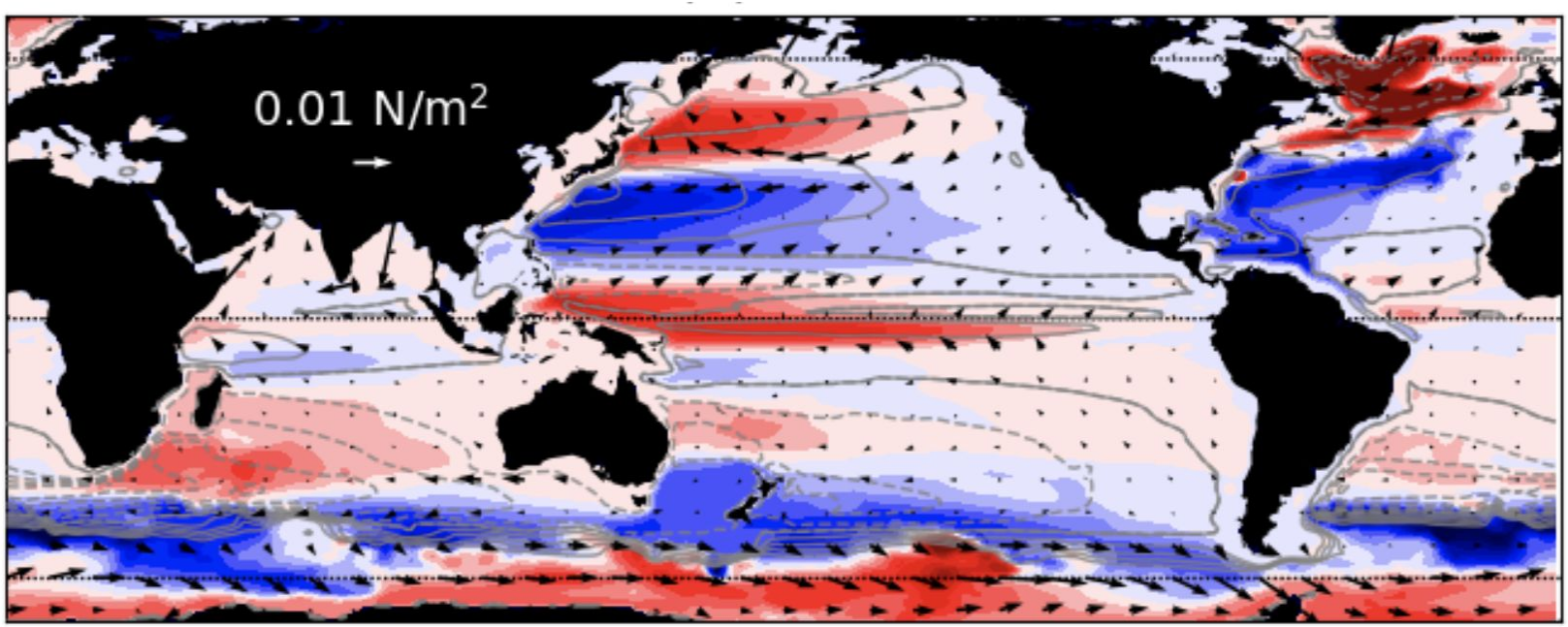
Implications:

- Wind driven ocean circulation changes have likely impacted the surface warming rate and pattern in the real world
- Atmospheric circulation changes may be a significant source of bias in historical and future climate projections

We need to adequately observe, understand, and simulate the wind driven ocean circulation to improve climate projections!

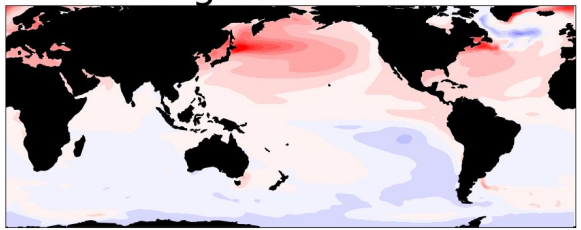
Contact: ktmcmoni@ncsu.edu

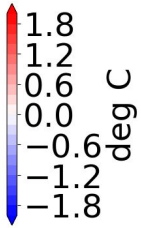
FCM wind stress and BSF trends 1979-2014



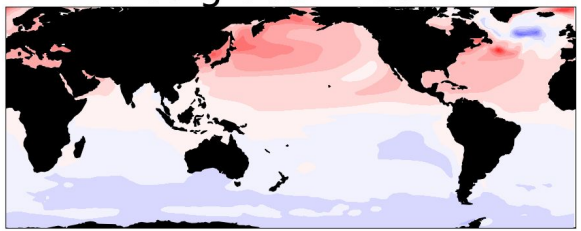
N Atlantic Warming Hole is in both models, implying it is *not* caused by wind driven ocean circulation changes

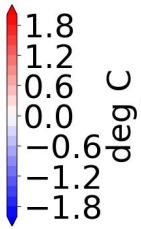
FCM minus global mean warming



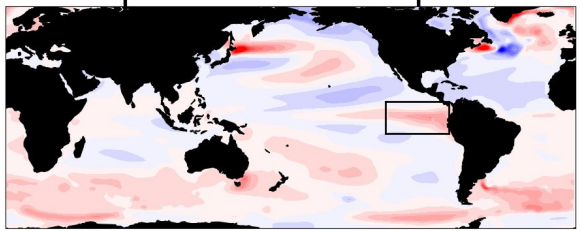


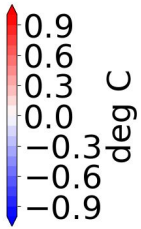
MDM minus global mean warming





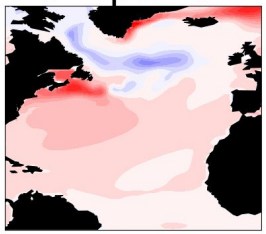
FCM pattern - MDM pattern

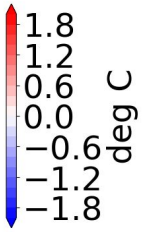




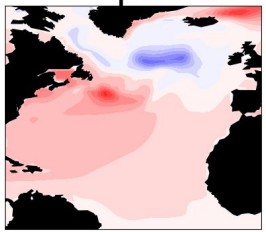
Zoomed in…

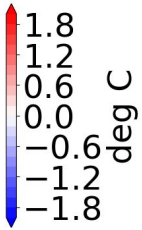
FCM pattern



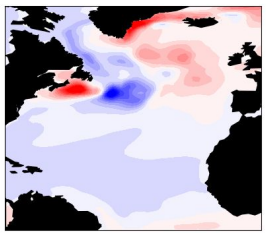


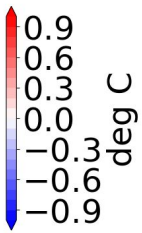
MDM pattern



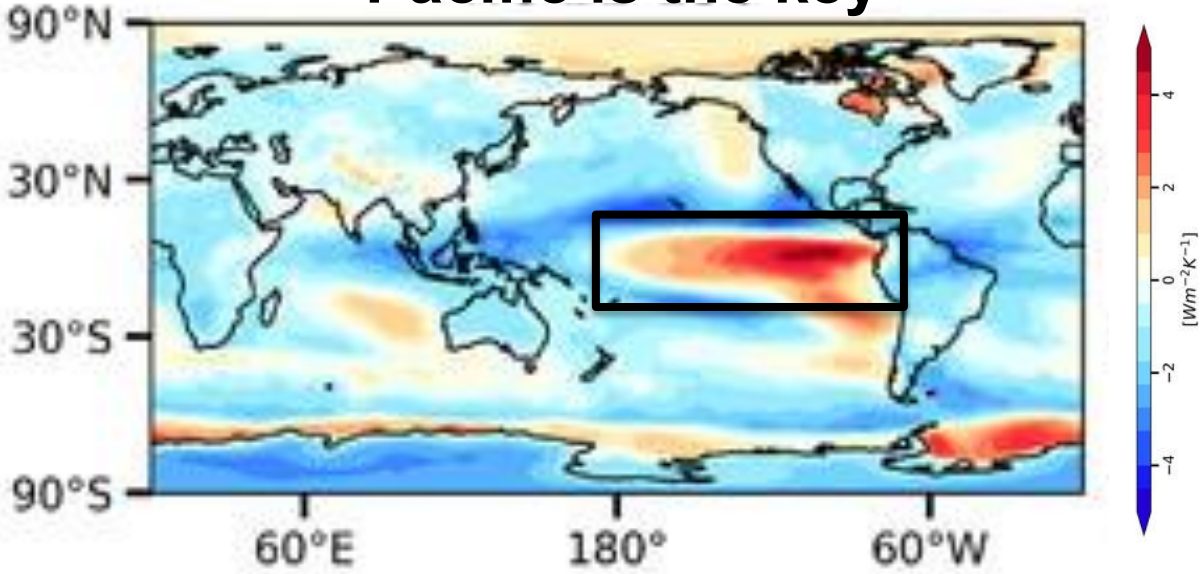


FCM - MDM





Agreement with Pattern Effect research that E tropical Pacific is the key



Dong et al., 2020: “the positive changes in the net feedback primarily come from the tropical eastern Pacific…. warmer surface temperatures and weaker low-level stability in this region both reduce low cloud cover… (Zhou et al. 2016; Ceppi and Gregory 2017).”