ROSENSTIEL SCHOOL of MARINE & ATMOSPHERIC SCIENCE
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A North Atlantic warming hole without ocean circulation

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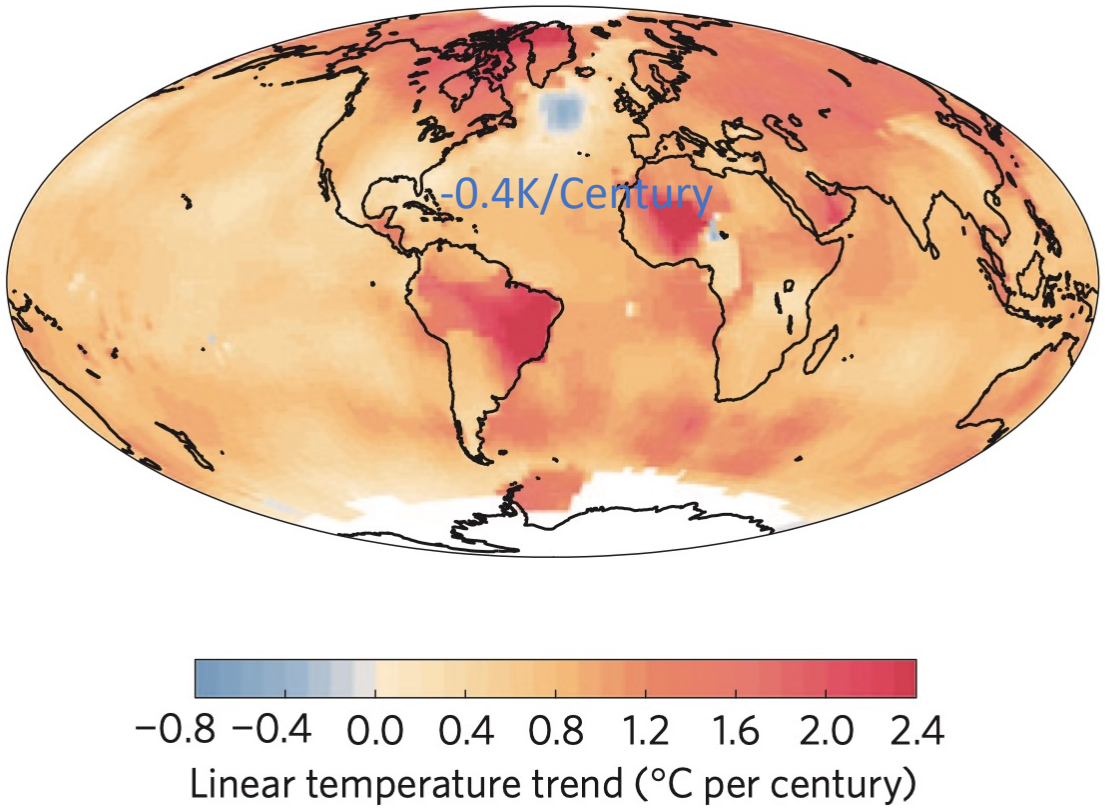


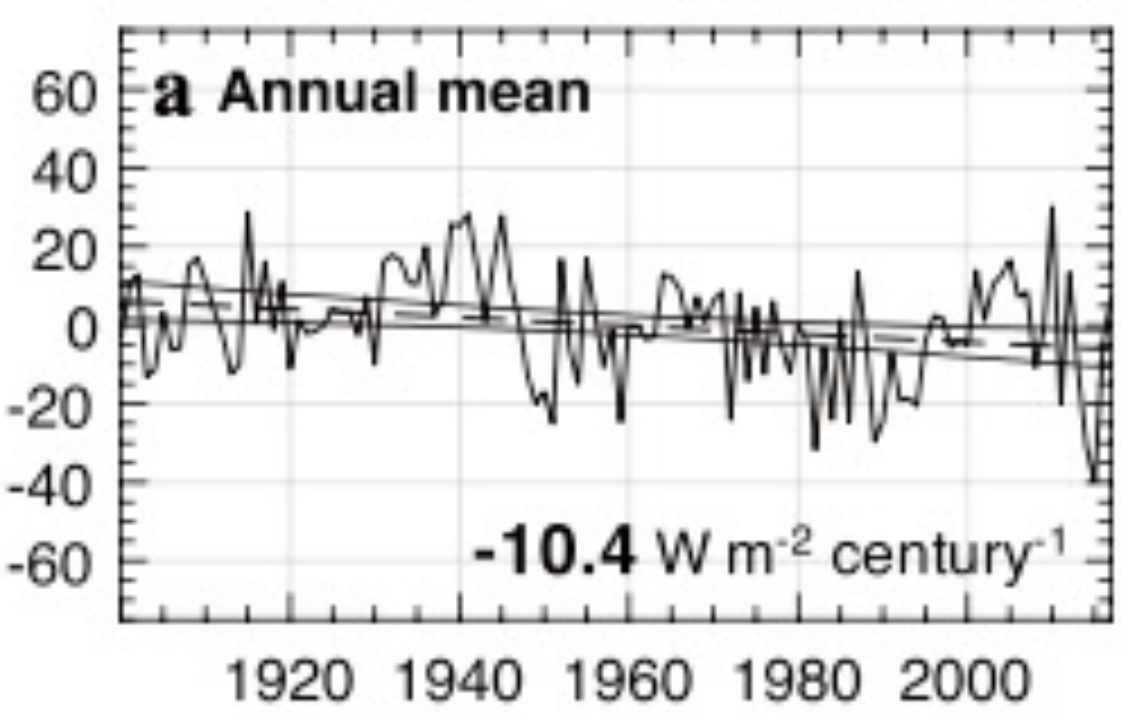
- Cooling center in the subpolar North Atlantic
- Due to slowdown of the AMOC
  - Rahmstorf et al., 2015;
  - Sévellec et al., 2017;
  - Caesar et al., 2018;
  - Gervais et al., 2018;
  - Chemke et al., 2020;
  - Liu et al. 2020.
  - Many others…
- Other ocean processes:

  Gyre (Keil et al. 2020)

  Teleconnection & Ekman Transport (Hu and Fedorov 2020)

Rahmstorf et al. 2015 Nature climate change

Surface heat flux over NAWH



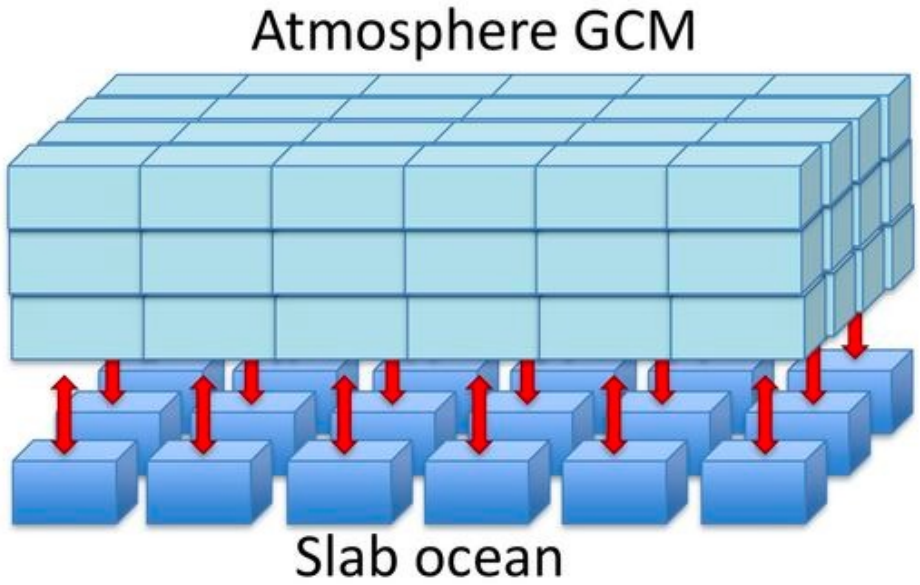
- SST is affected by both atmospheric and oceanic processes
- What is the role of atmosphere in the NAWH? → ~~Neglecting the OHT~~
- Poleward shift of westerly jet->Storminess and Entrainment
  - Li et al (2021)

Motivation

- Simple model (Li et al. 2021 CD); What if in GCM, like SOM?
- How does surface heat flux mechanically excite the NAWH?

Li et al. 2021, CD

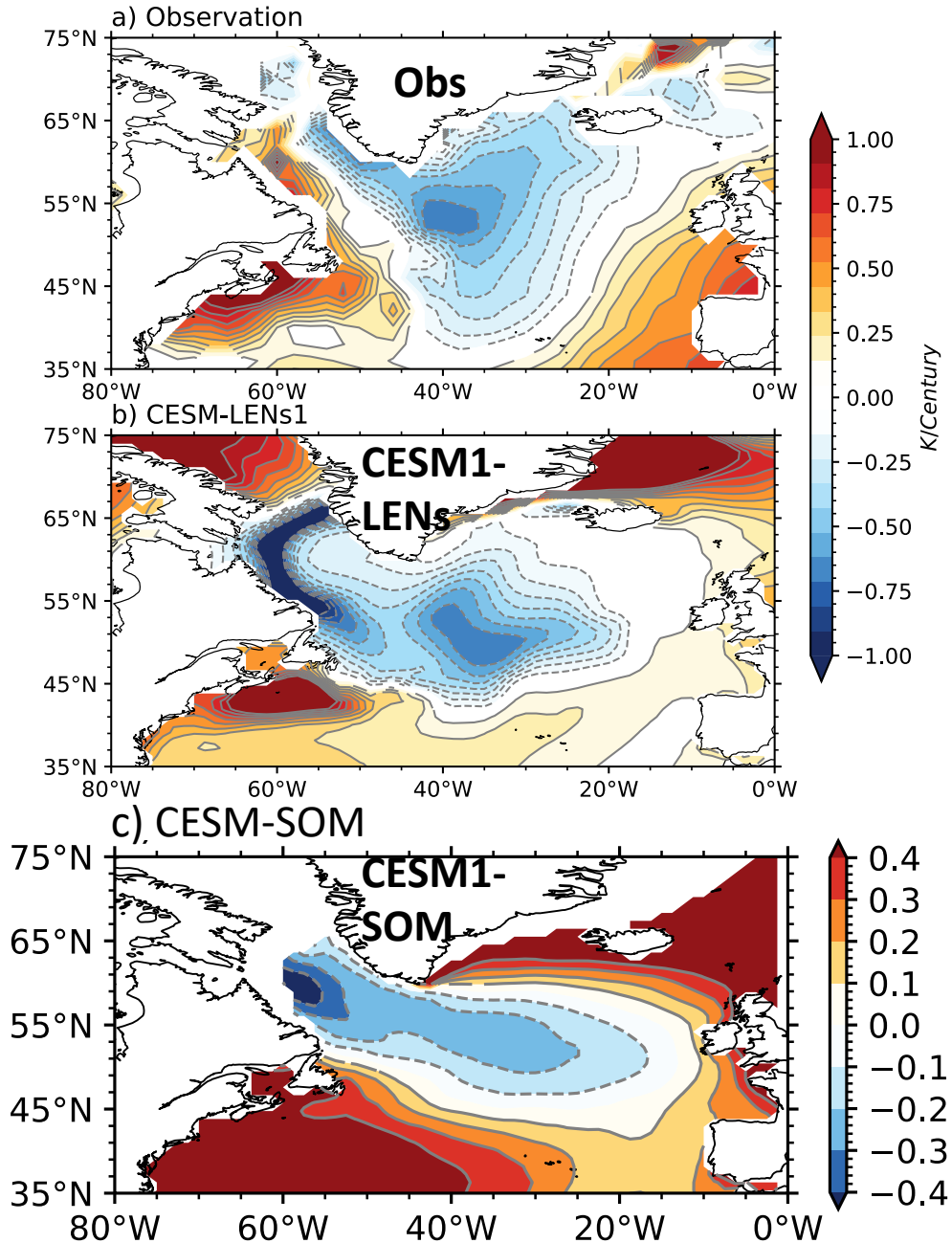
Model



$$\rho c_p h_{mix} \frac{dT_s}{dt} = Q_{net} - Q_{flx}$$

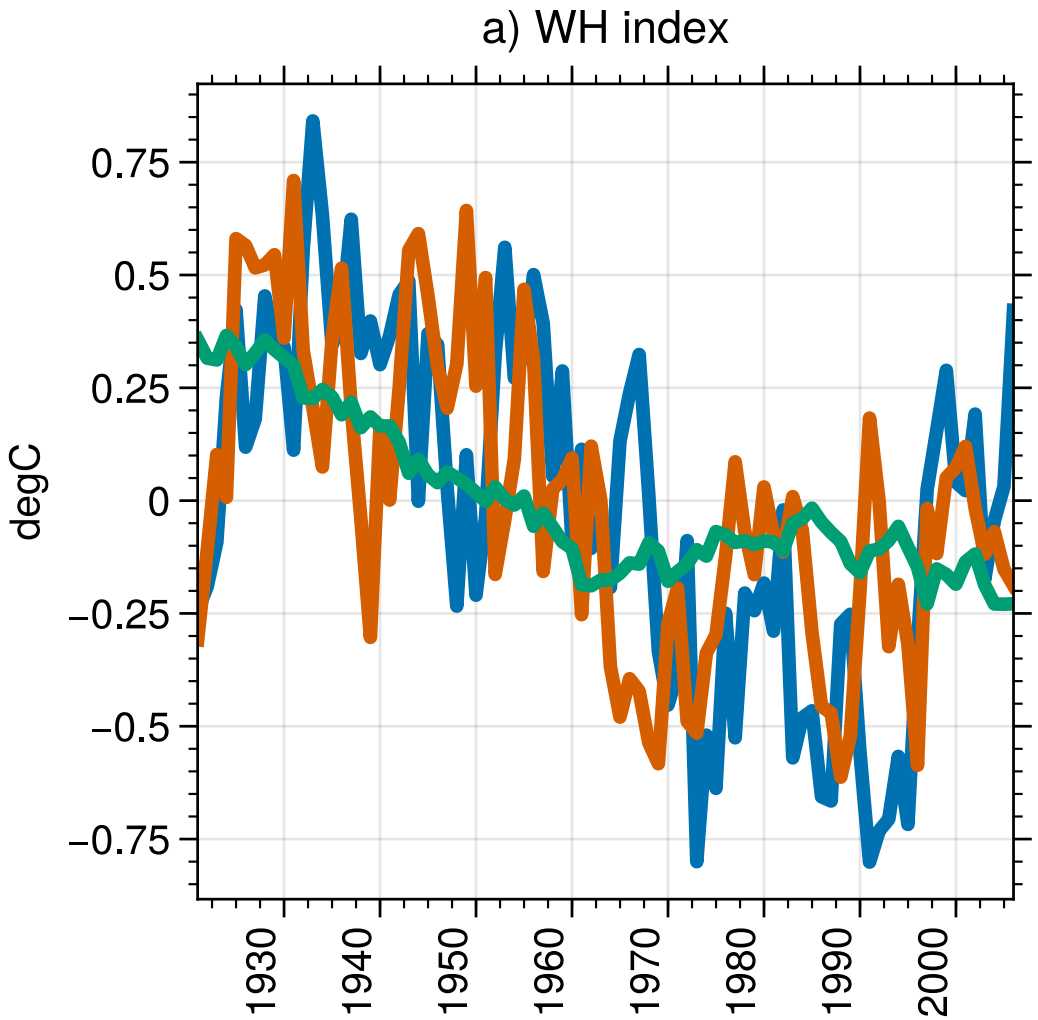
- **CESM1-SOM**
- 9-member historical simulations from 1920-2005
- Compare to **CESM1-LENs** and **Observation (NCEP and ECMWF reanalysis)** in the same period

Figure adapted from Dr. Dommenget



SST trend

- WH is reasonably reproduced in CESM1-LENs ensemble mean (EM)
- Cooling in CESM-SOM EM is likely 50% of the OBS and CESM1-LENs EM
- Pattern difference



NAWH trend

- WH index: WH temperature – Global SST

-0.87 K/Century
-0.75 K/Century
-0.7 K/Century

- Relatively close WH index, as SOM ocean warms faster

How does surface heat flux mechanically excite the NAWH?

$$\rho c_p h_{mix} \frac{dT_s}{dt} = Q_{net} - Q_{flx}$$

$$Q'_{net} = Q_{net} - Q_{flx} = \frac{\partial Q}{\partial V_1} V'_1 + \frac{\partial Q}{\partial V_2} V'_2 + \cdots$$

$$Q_{LH} = -L\rho_a C_E W q_s(T_s)\left(1 - RH e^{-\beta T_{s-a}}\right)$$

$$Q_{SH} = -\rho_a C_p C_E W T_{s-a}$$

Linearize Bulk formula

$$Q_{LW} = Q_{LW}(T_s, T_{s-a}, Cld, CO_2, \ldots)$$

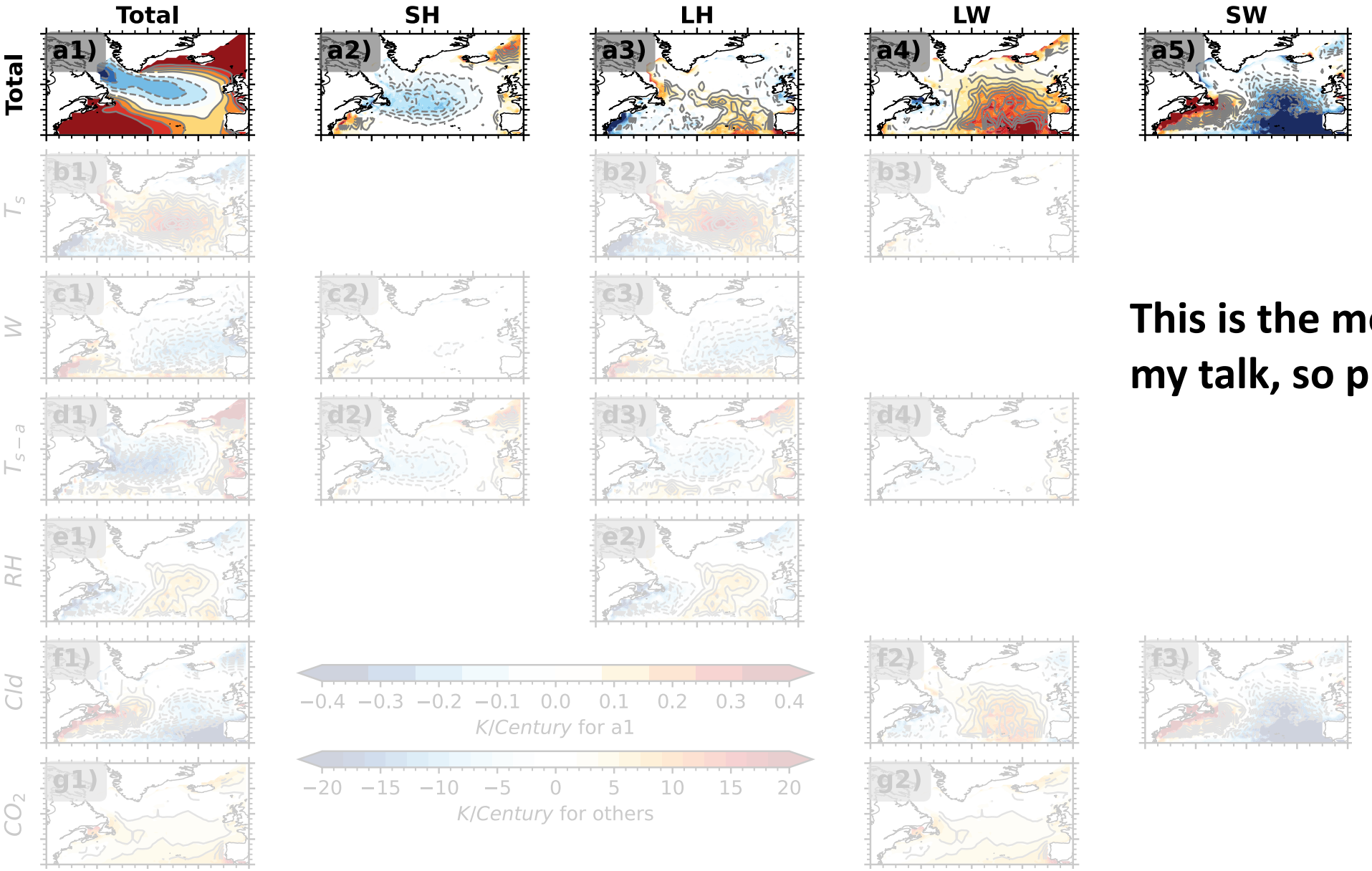
$$Q_{SW} = Q_{SW}(Cld, \ldots)$$

Multilinear regression

W: surface wind strength
T_s: surface temperature
RH: relative humidity

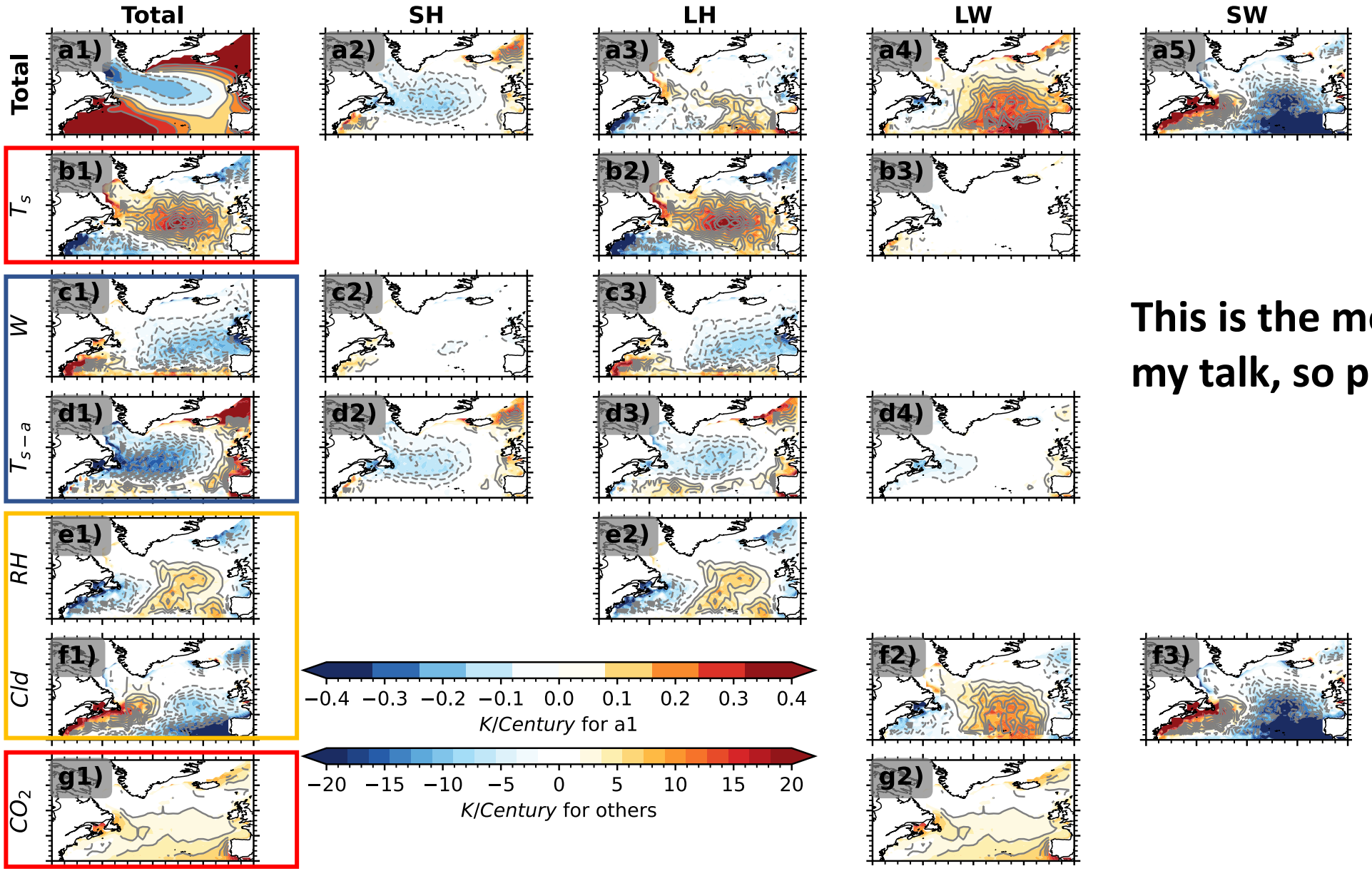
T_{s-a}: air-sea temp diff
$Cloud$: cloud cover
CO2: greenhouse gases

Full decomposition of SST trend in SOM



This is the most complicated part in my talk, so please pay attention.

Full decomposition of SST trend in SOM



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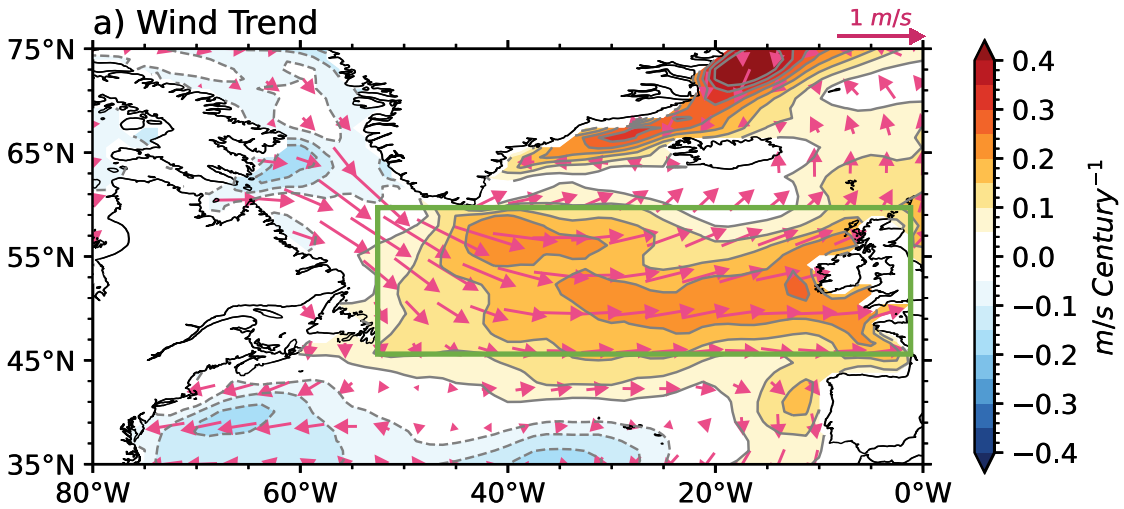
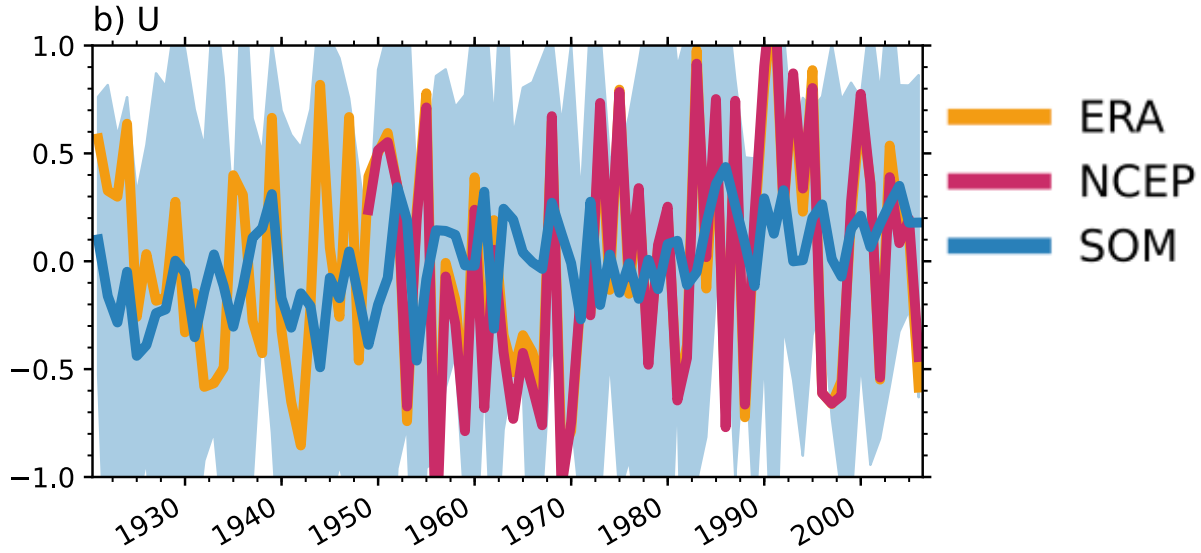
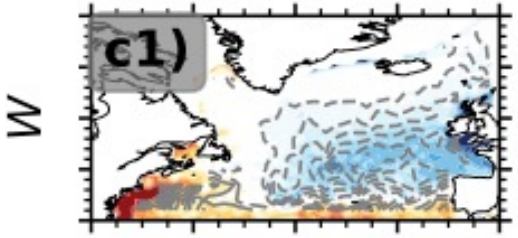
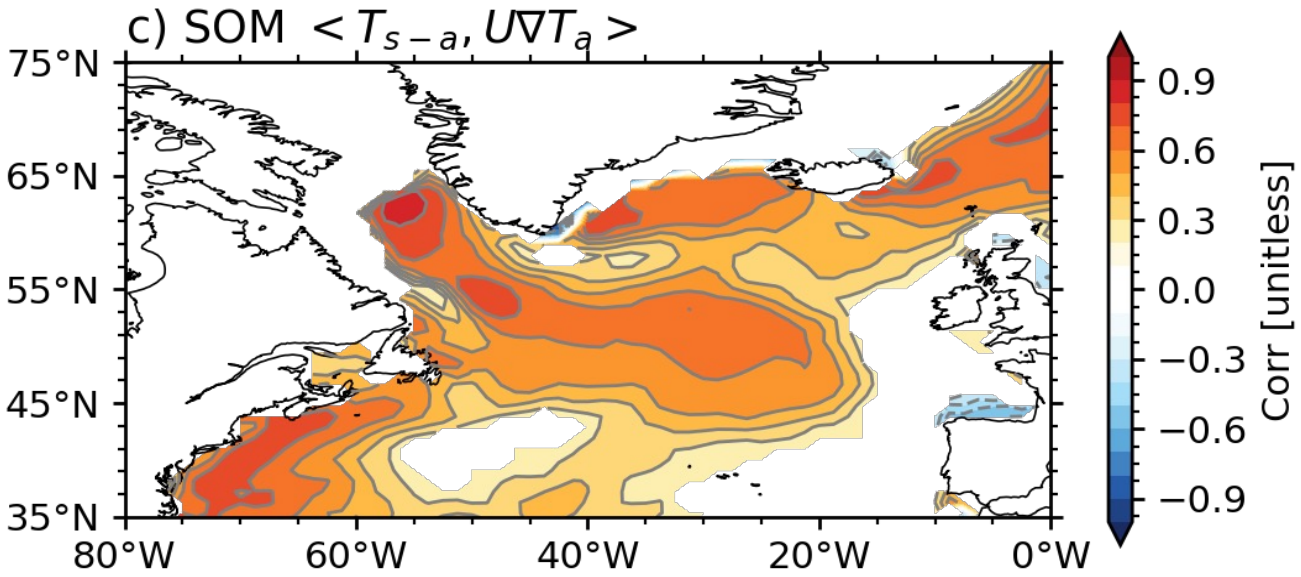




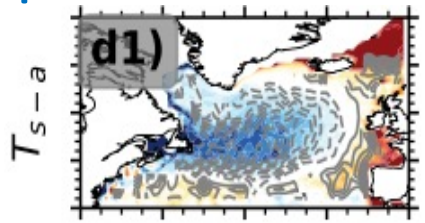
Cooling Group: The role of wind strength



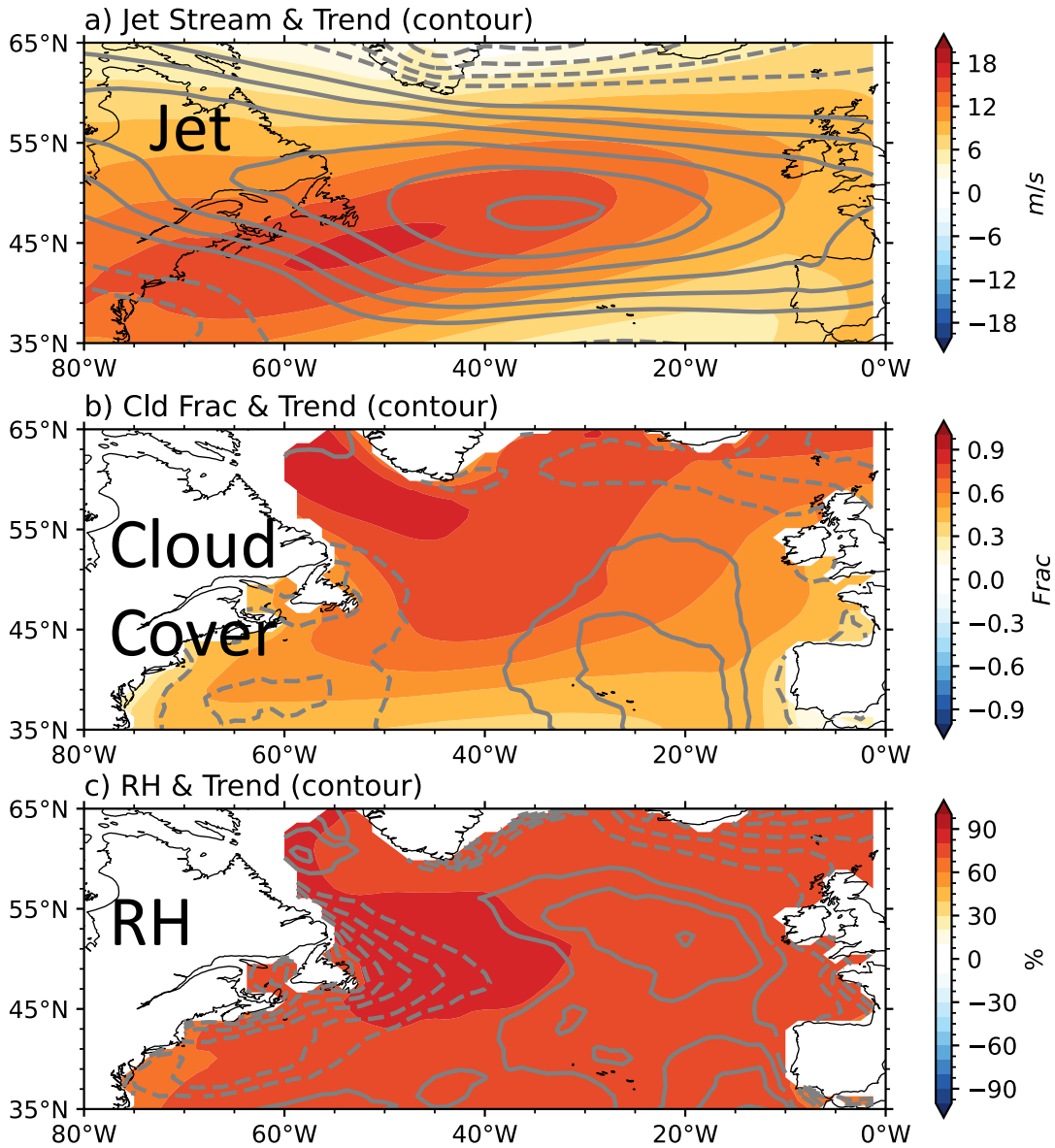
- Intensified wind strength in the subpolar NA (poleward shift of westerly)
- Enhance SH and LH, exporting energy from surface ocean
- Also seen in Observation



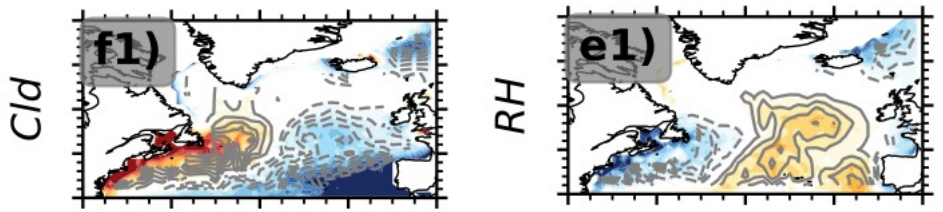
Cooling Group: air–sea temperature diff in response to surface wind



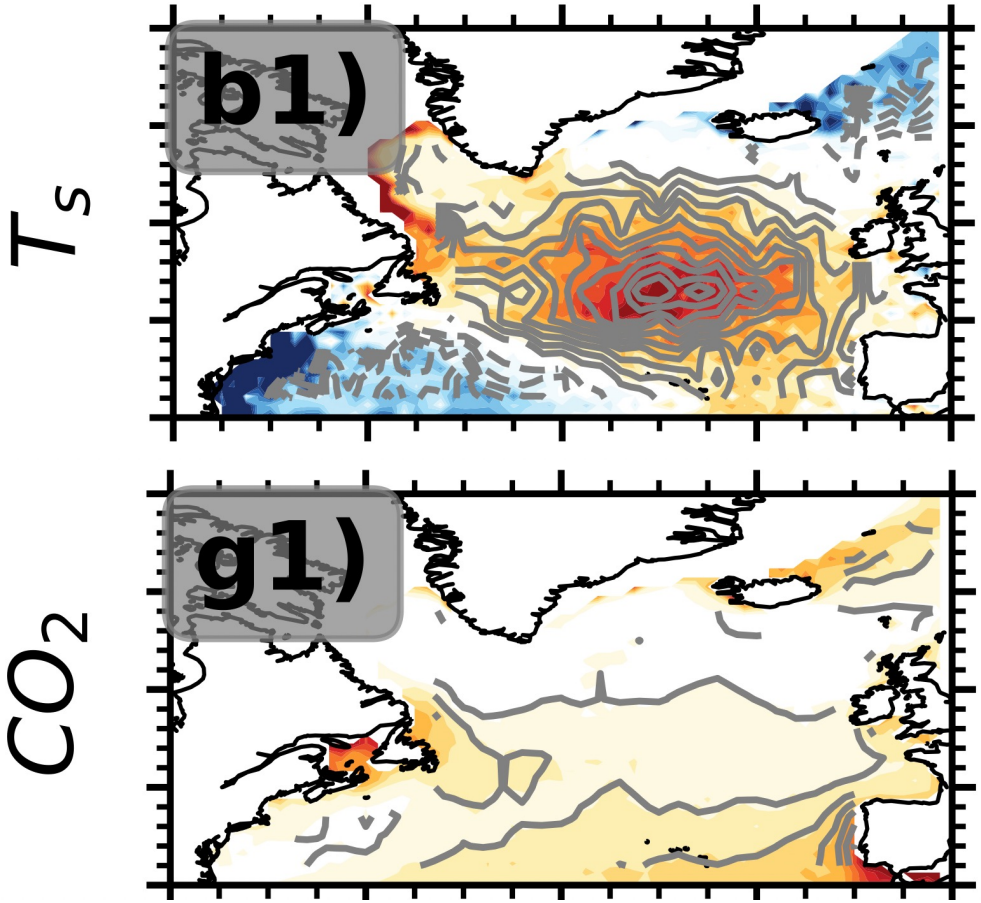
- air-sea temp diff related to wind
- Intensified surface westerlies amplifies air-sea temperature difference
- causing SH and LH exporting energy from ocean
- **Ultimately related to the wind!**



Neutral Group: cloud and RH in response to high-level westerly



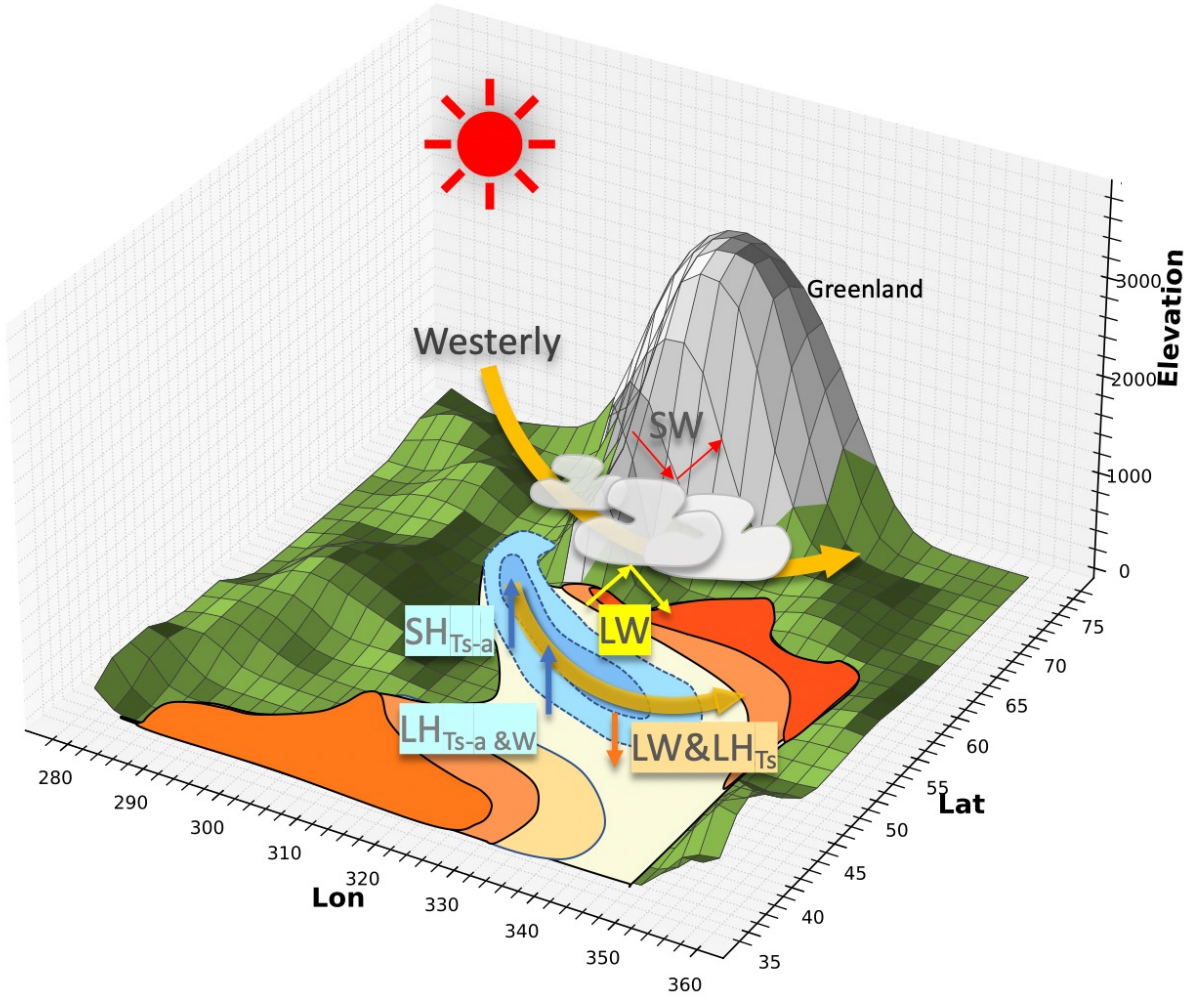
- Poleward shift of high-level westerly jet
- Dipole cloud cover trend (LW, SW)
- Dipole RH trend (LH)



Warming Group: negative feedback and GHGs

- Ts as negative feedback in LH
- CO_2 warming, LW

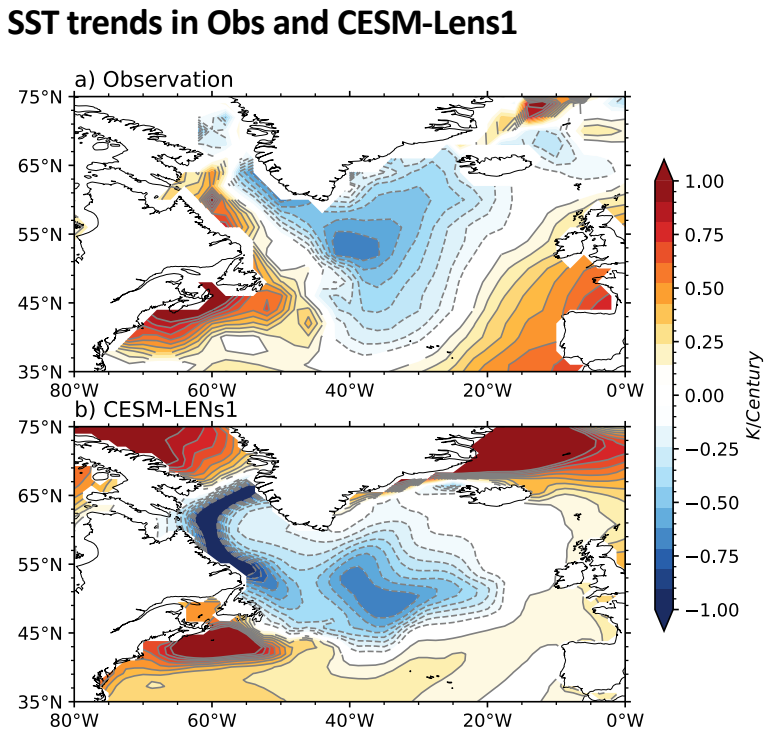
Summary

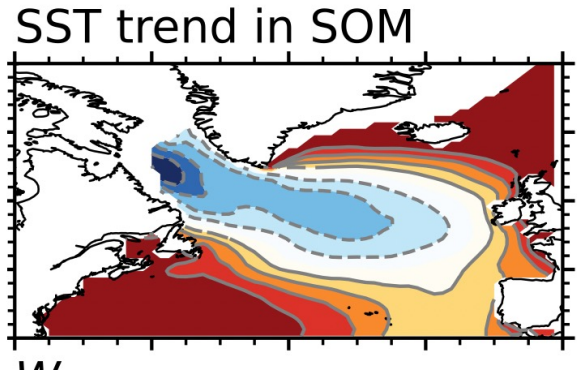


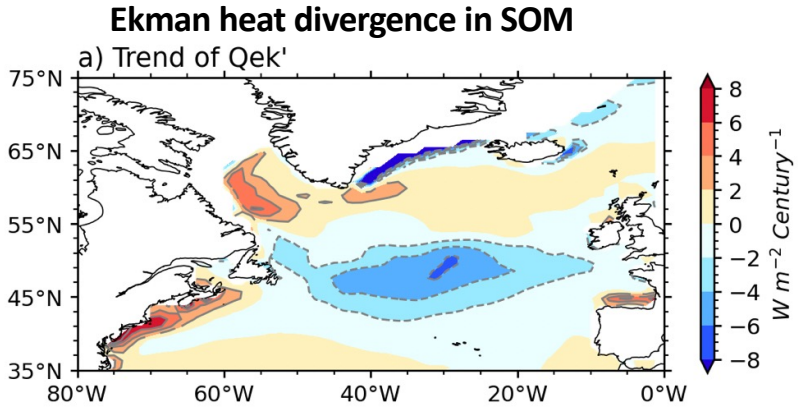
Role of atmospheric circulation

- A NAWH
- Poleward shift of westerly increases wind strength W, air-sea temperature difference Ts-a, cooling the sea surface
- Westerly also causes cloud and RH change, and cancels each other
- Damping effect due to Ts in LH and LW warms the sea surface.
- CO2

Final discussion1

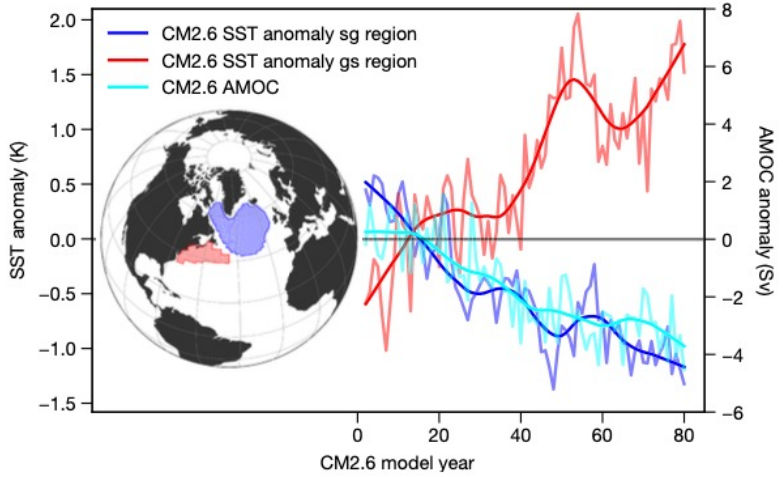


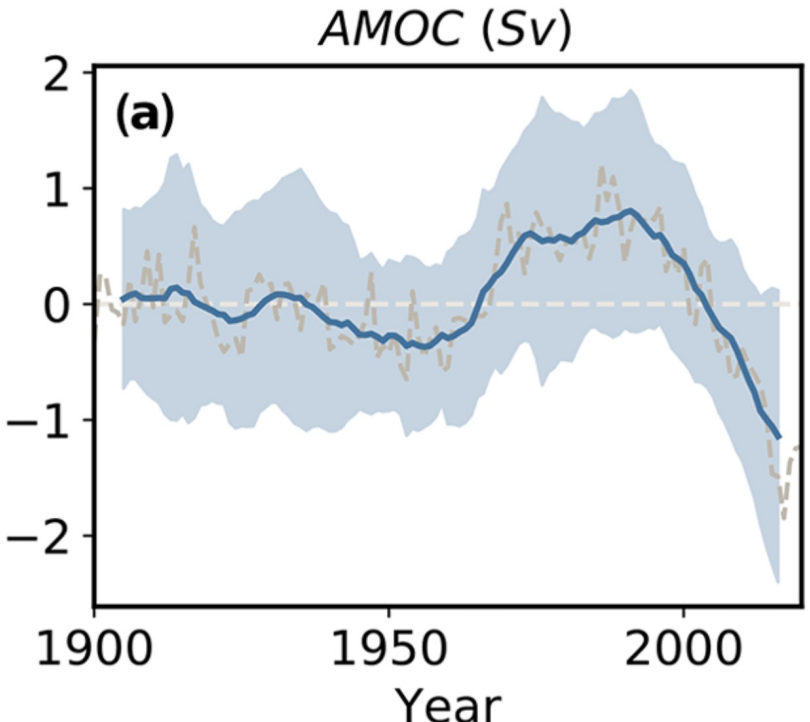




We are resimulating the historical climate change using a new ocean model hierarchy developed in Hsu et al. (2022).

Final discussion2 Fingerprint of the AMOC?





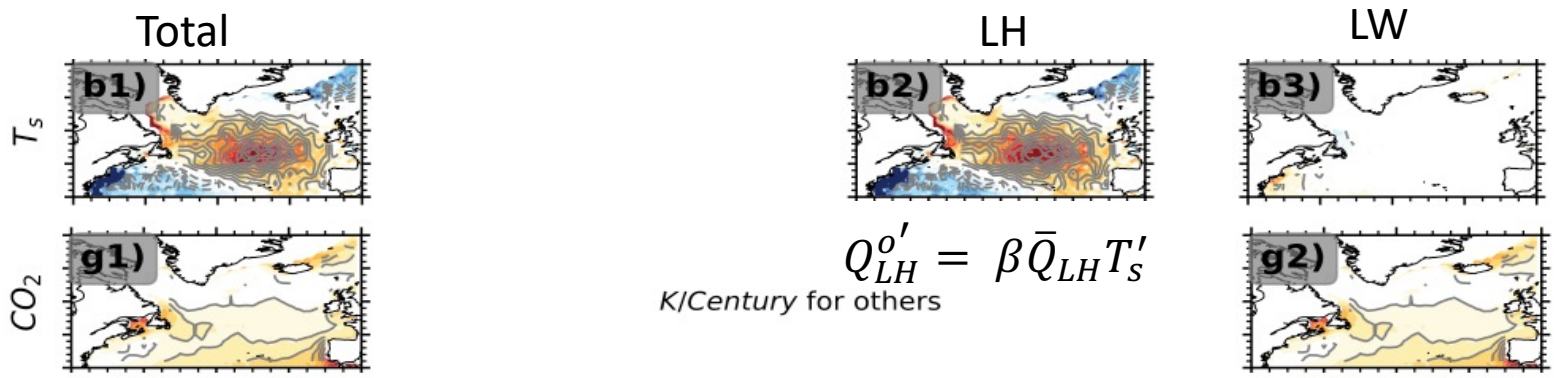
- **Strong CO2 forcing**

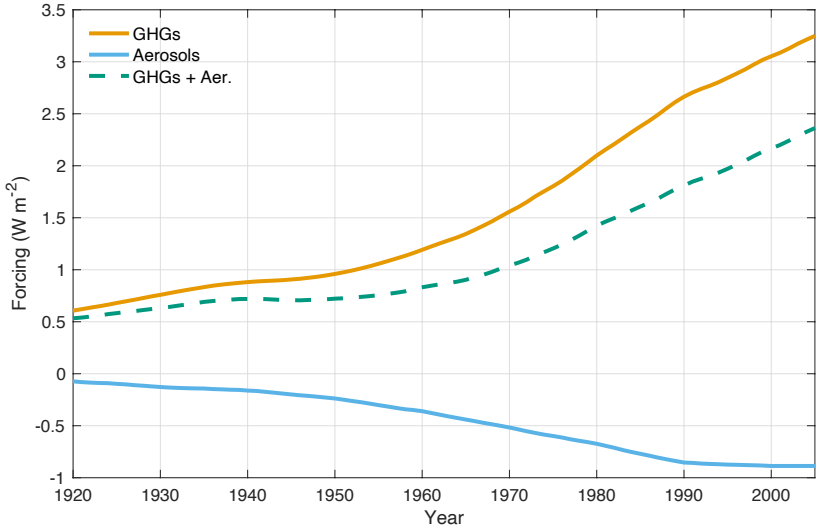
- **Real world aerosols lead to an overall intensifying AMOC in the past century**

Hassan et al. 2021 ACP

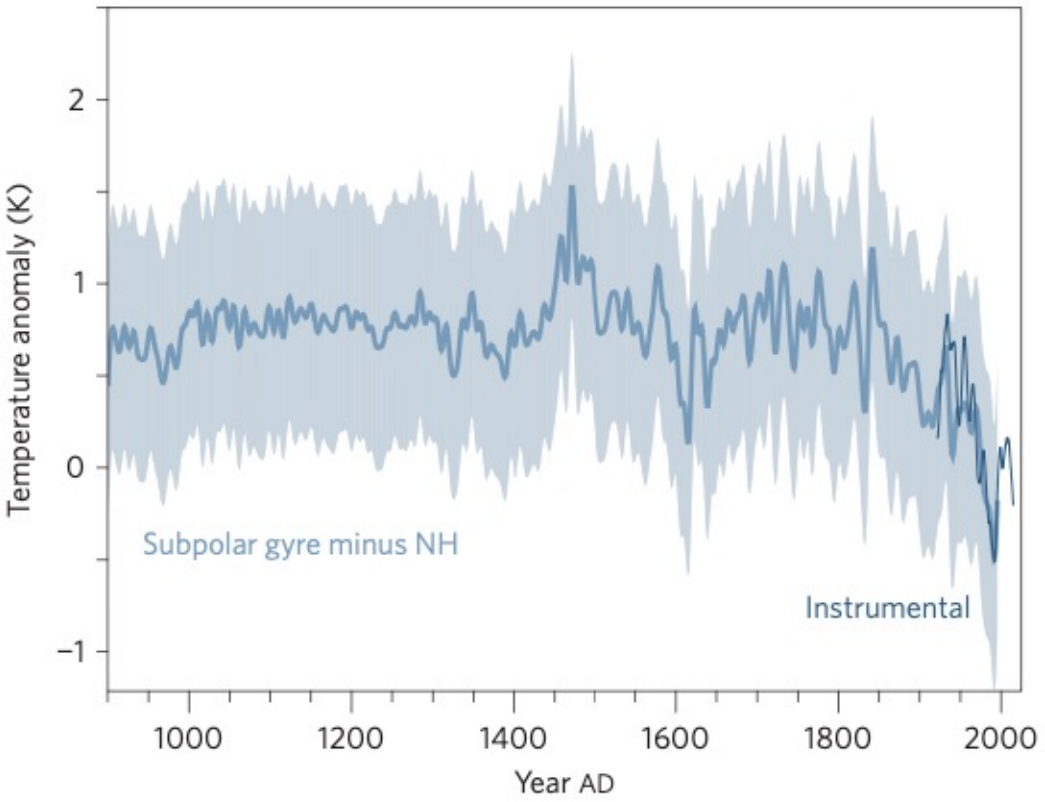
Backup

Q2: The role of CO2 and SST





- Ts as negative feedback
- CO_2 warming, aerosol cooling



- AMOC slowdown in 20th century

Rahmstorf et al. 2015 Nature climate change