The Impact of Ocean Dynamics on Atlantic Sea Surface Temperature Variability

Olivia Gozdz (ogozdz@gmu.edu) Dr. Martha Buckley and Dr. Tim DelSole

George Mason University

AMOC Conference

Woods Hole, Massachusetts April 2022

Background

Clement et al. (2015):

AMV can be reproduced in models without interactive ocean dynamics

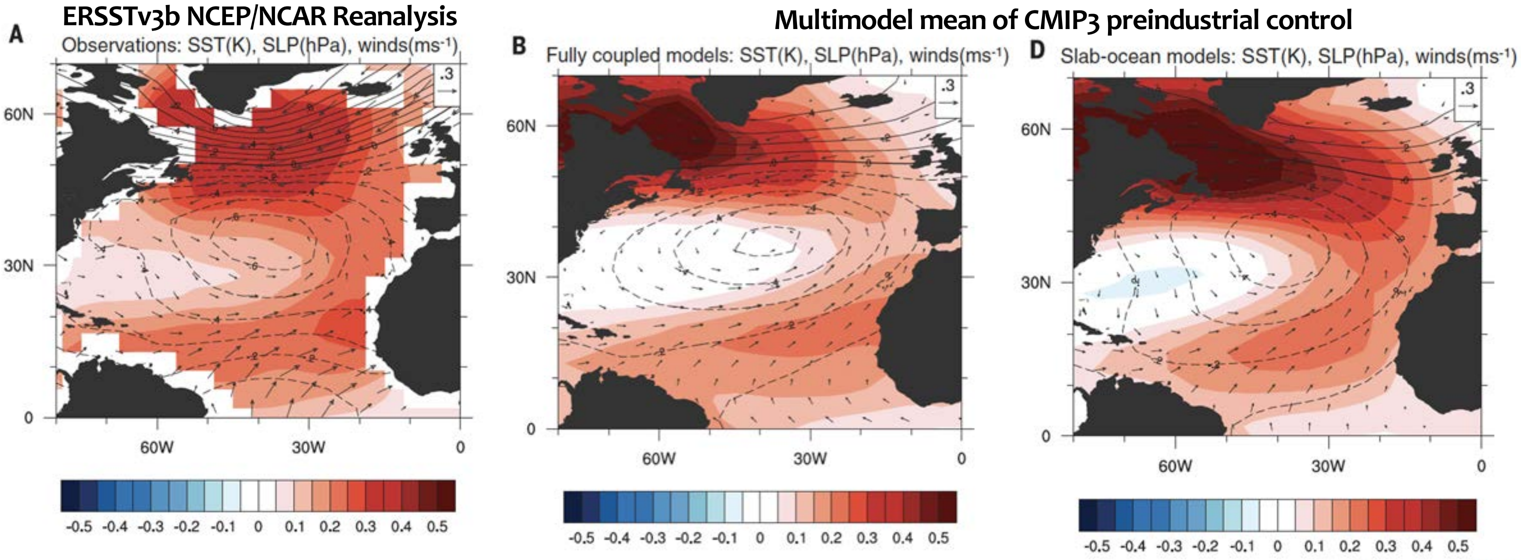


Figure: Spatial patterns of SST (colors), SLP (contours) and surface winds (vectors) associated with the AMV from (A) observations and (B, C) preindustrial control runs of CMIP3 (B) fully coupled models and (C) slab ocean models.

- However, it this has been debated… (Zhang et al. 2016, O'Reilly et al. 2016, etc.)

Data: CESM LENS (Community Earth System Model 1.2, Kay et al. 2015)

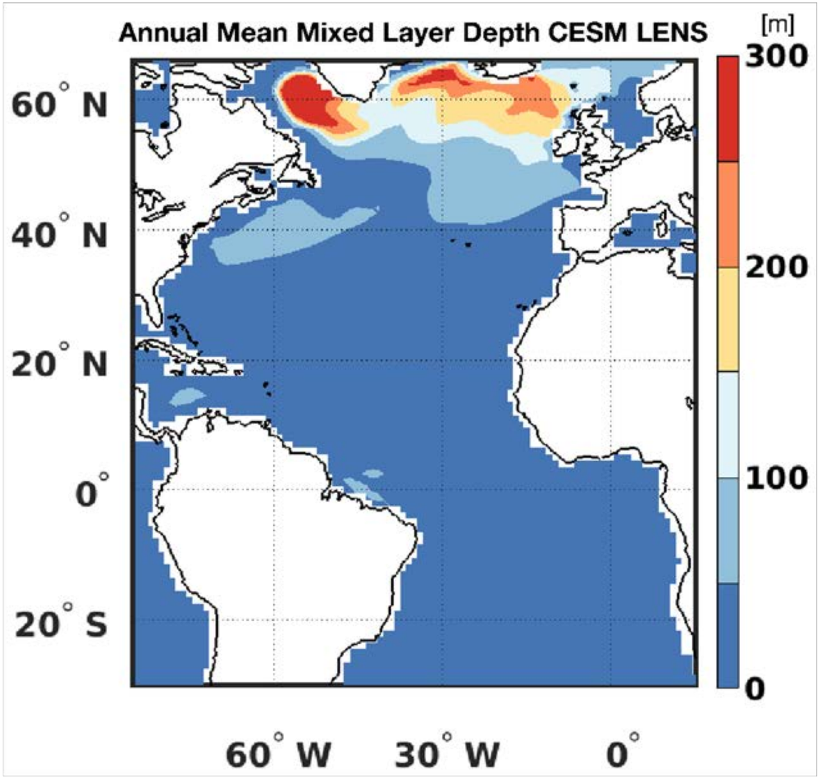
- Preindustrial control runs
- 900 year monthly time series

<u>Fully Coupled Model (FCM):</u>

- Historical CESM1 simulations shows model fidelity in the Atlantic basin (Danabasoglu et al. 2012b)
- The observed AMV pattern is generally captured (Zhang and Wang 2013)

<u>Slab Ocean Model (SOM):</u>

- A coupled model with the same atmosphere and ice model as FCM, but the ocean replaced by a motionless slab
- Interacts thermodynamically with the atmosphere
- No time variable currents, temperature advection, diffusion, etc.
- Attempts to reproduce FCM SST climatology
- Slab layer is set to annual mean MLD from the FCM



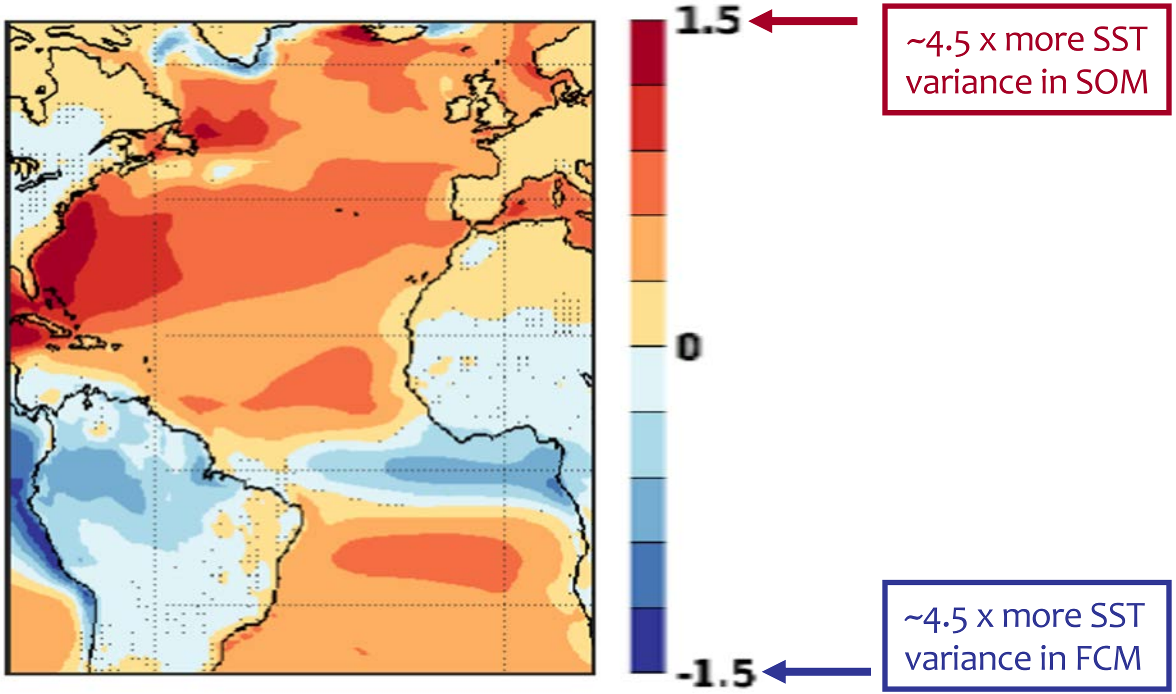
Does Atlantic SST differ between models with and without interactive ocean dynamics?

Does North Atlantic SST Variability differ between the SOM and FCM?

- SOM has higher Atlantic SST variance than FCM, except in the tropical Atlantic (corroborated by Murphy et al. 2021)

Log Ratios of Surface Temperature Variance

Monthly SOM/FCM



We now quantify these SST differences is a more rigorous way…

Approach: Covariance Discriminant Analysis (CDA)

This method finds a linear combination of variables that maximizes a ratio of variances

<u>We are optimizing a ratio of SST variance in the SOM to the FCM</u>

$$\lambda = \frac{\text{var(SOM)}}{\text{var(FCM)}}$$

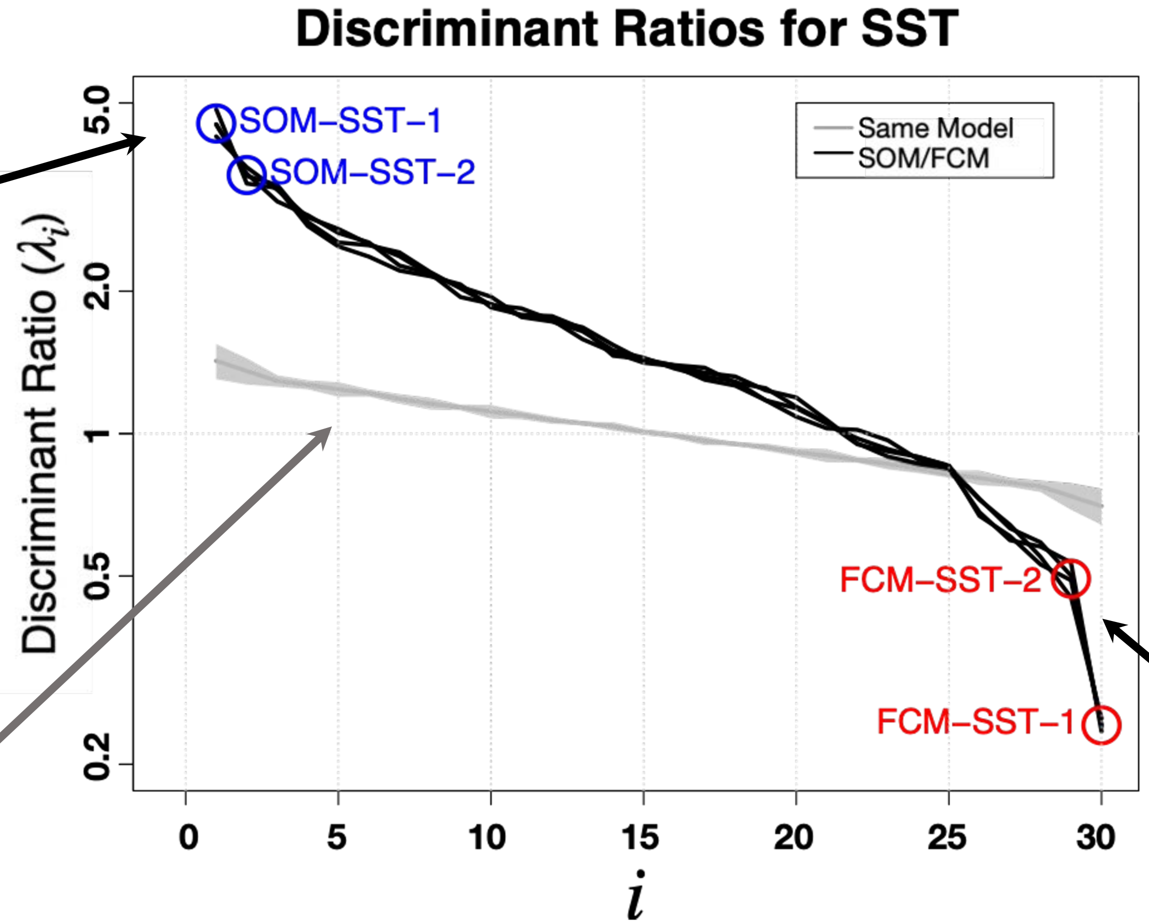
From CDA we get:

1) An ordering of variance ratios = discriminant ratios (λ)
2) Time series = variate
3) Spatial patterns = loading vectors

CDA Results: Ordering of Variance Ratios for Atlantic SST

We reject the null hypothesis of equal SST variance between the SOM and FCM

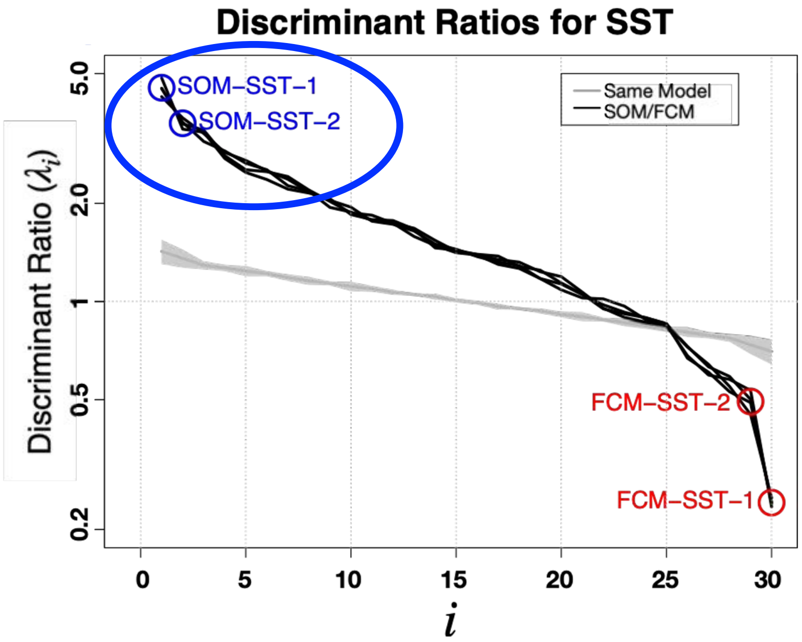
SOM/FCM > ~ 1 · components where SOM contains more variance than FCM



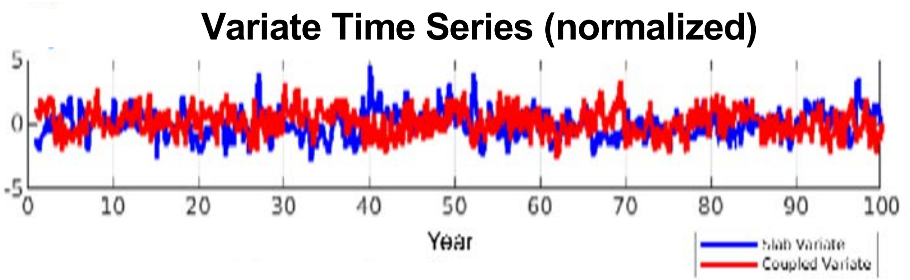
Null Hypothesis of equal SST variance

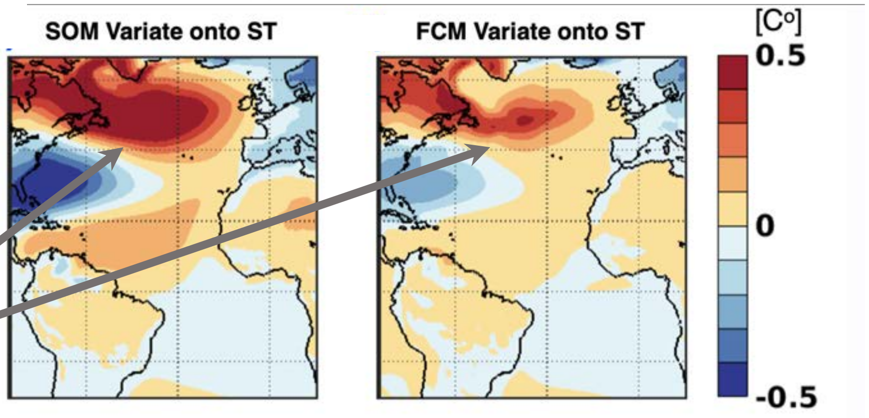
SOM/FCM< ~1 · components where FCM contains more variance than SOM

Which SST patterns have more variance in the SOM?



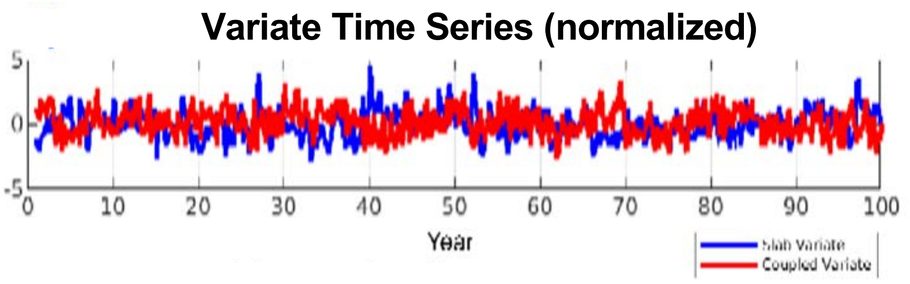
SOM-SST-1: Component with more variance in Slab Ocean Model



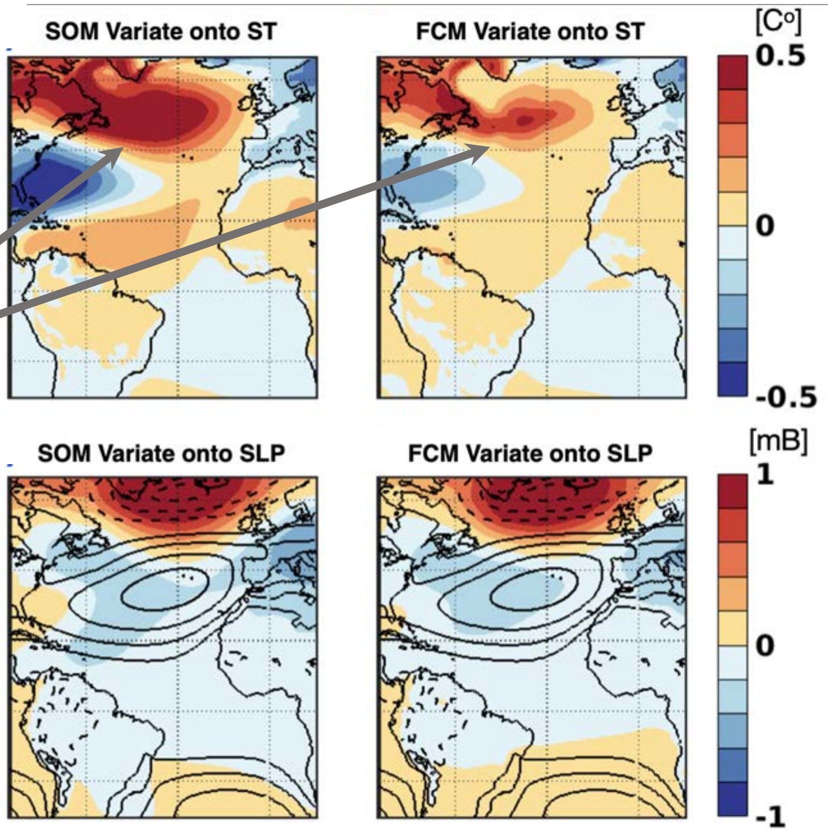


- **NAO Tripole Pattern has higher SST variance in the SOM (λ ~ 4.5)**

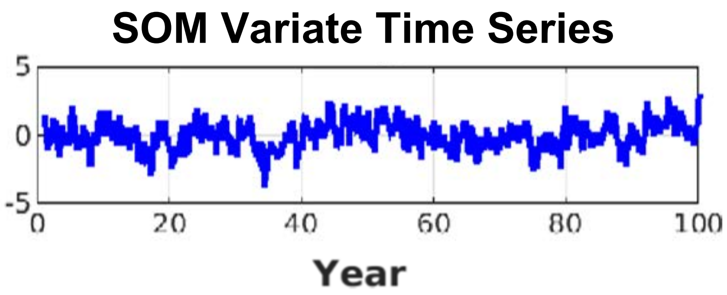
SOM-SST-1: Component with more variance in Slab Ocean Model



- **NAO Tripole Pattern has higher SST variance in the SOM ($\lambda \sim 4.5$)**
- Associated SLP patterns in FCM and SOM are nearly identical
- SST has a stronger response to NAO in SOM than FCM

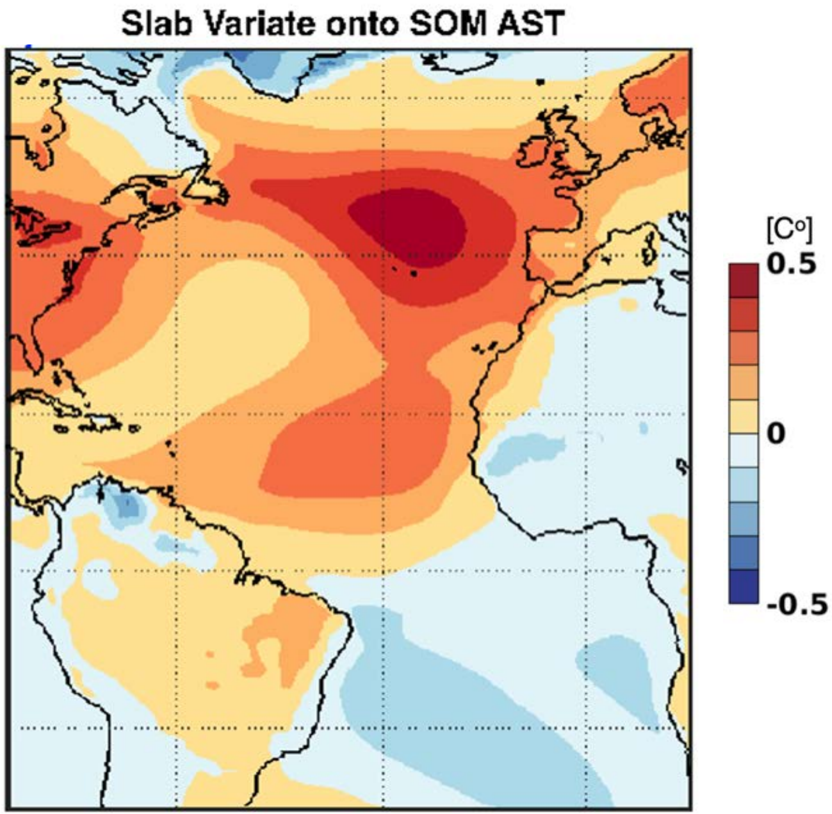


SOM-SST-2: Component with more variance in Slab Ocean Model

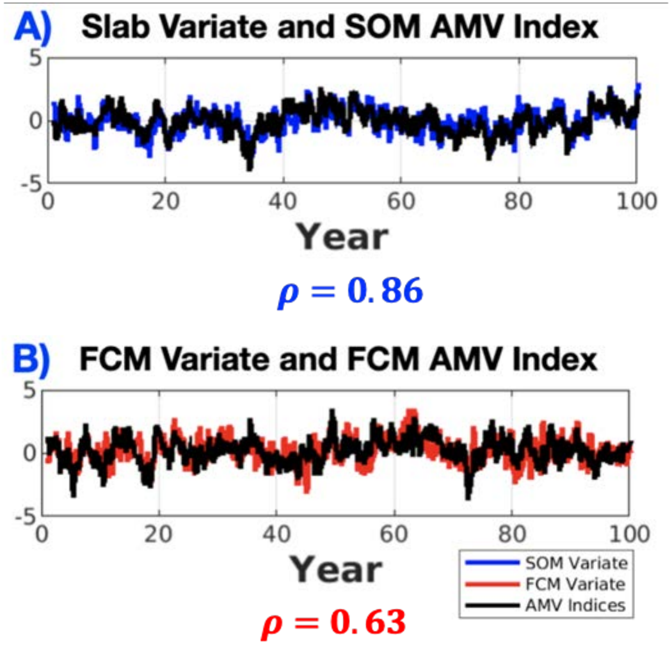


- **Horse-shoe like SST anomaly has more variance in the SOM** (λ=3.4)

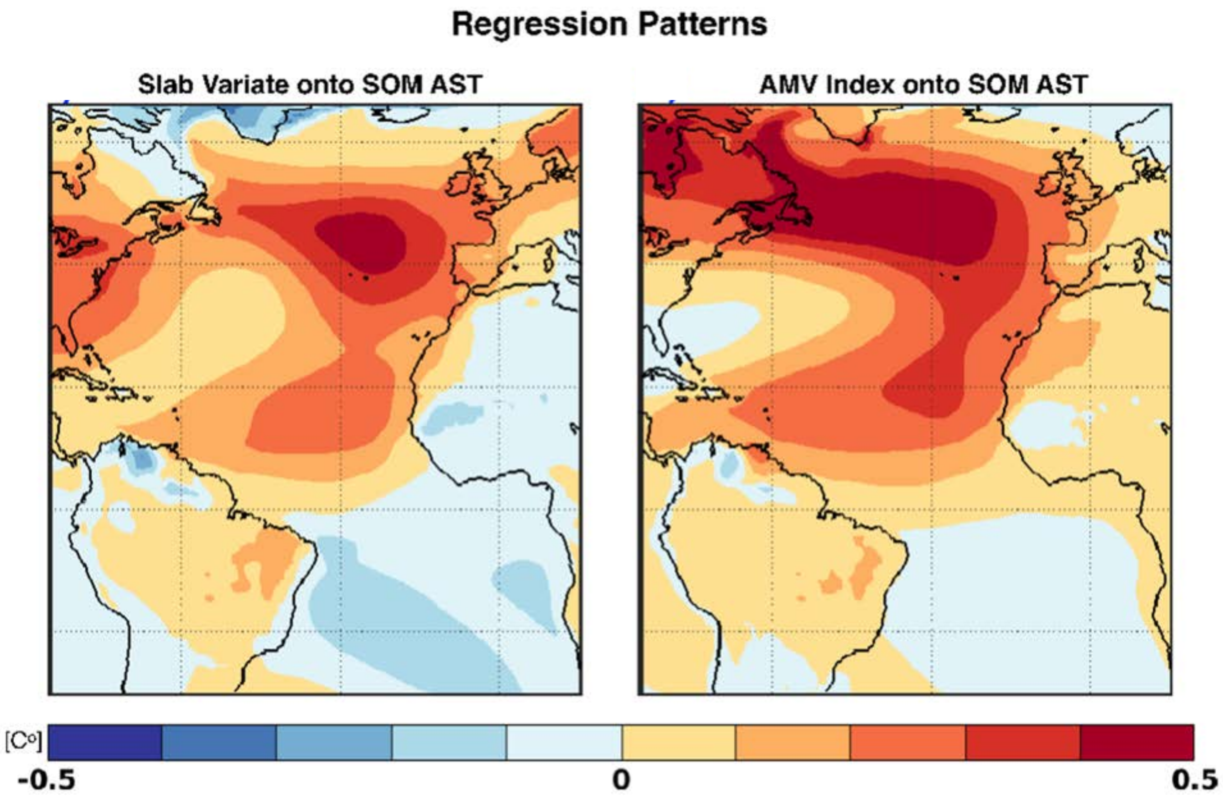
Regression Pattern



SOM-SST-2: Component with more variance in Slab Ocean Model

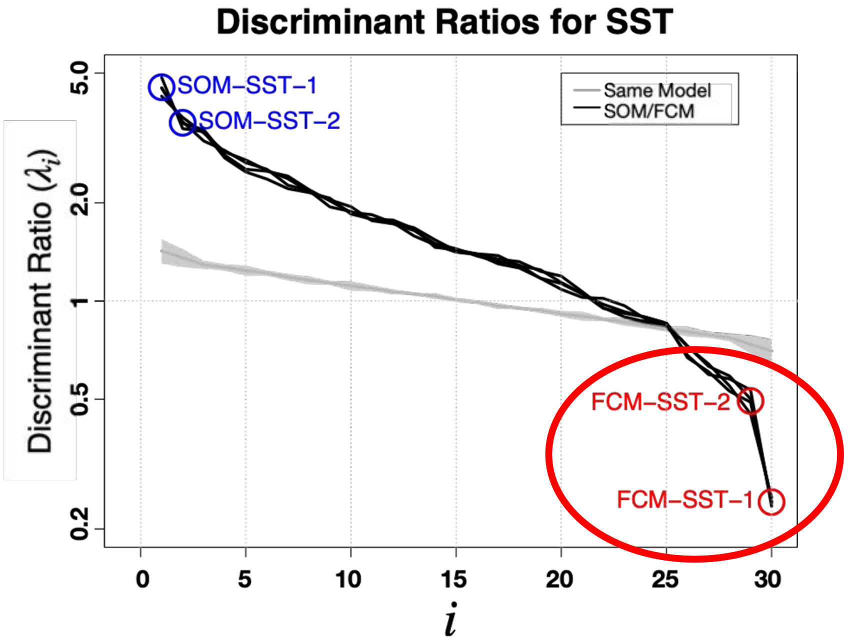


- **AMV has more variance in the SOM** (λ=3.4)
- SOM-SST-2 variates are highly correlated with the AMV

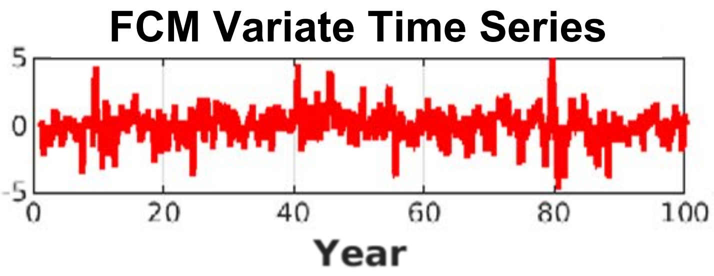


AMV Index: regionally averaged Atlantic SST from 0-60N

Which SST patterns have more variance in the FCM?

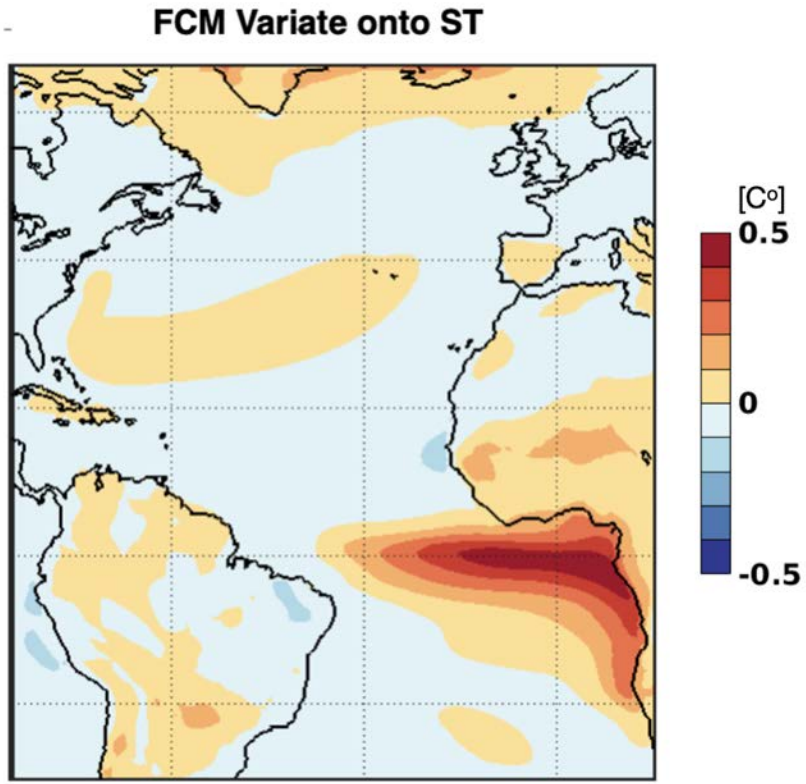


FCM-SST-1: Component with more variance in Fully Coupled Model

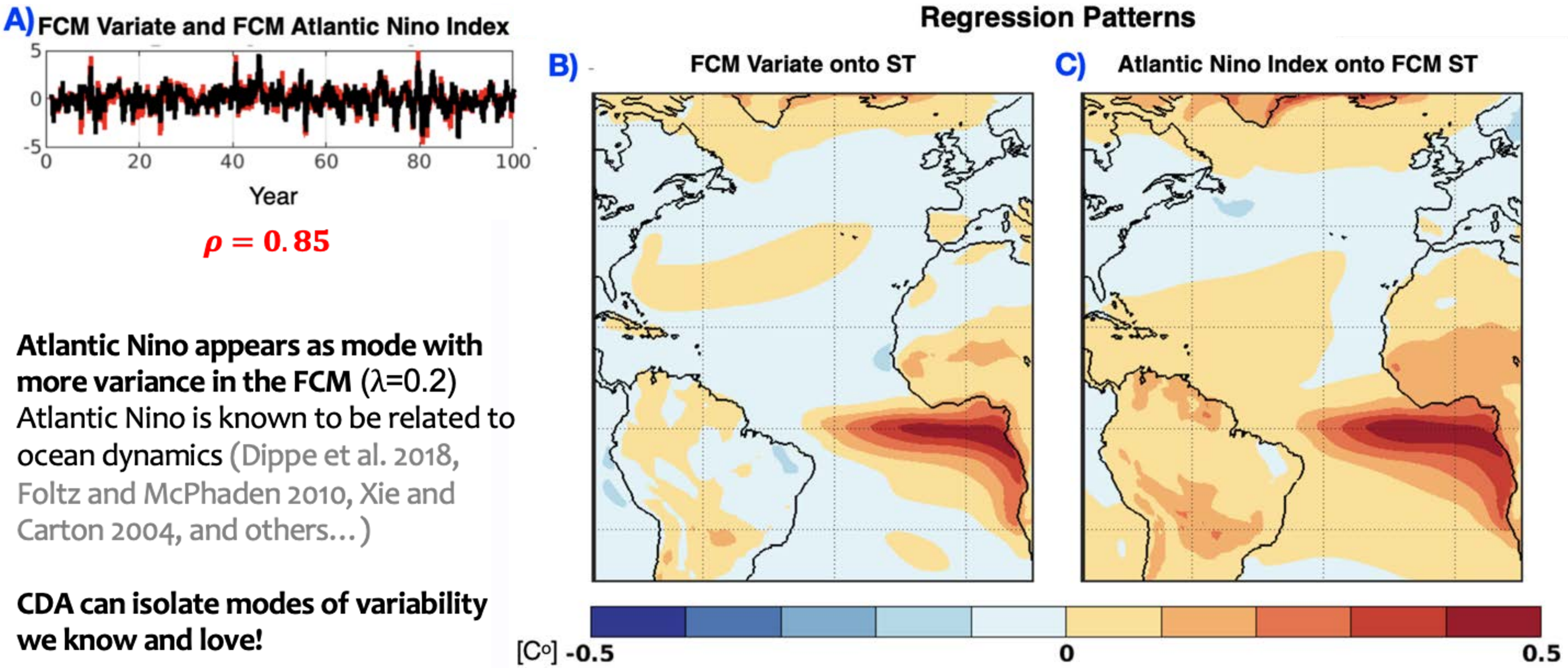


- **Equatorial SST anomaly appears as mode with more variance in the FCM** (λ=0.2)

Regression Pattern



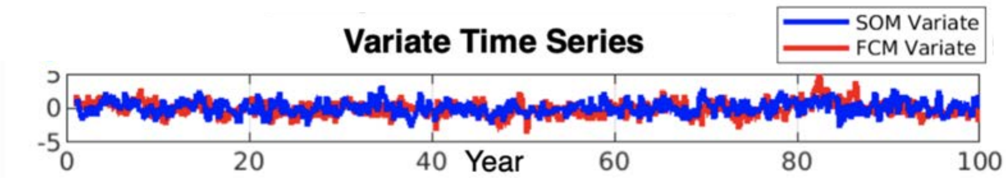
FCM-SST-1: Component with more variance in Fully Coupled Model



- **Atlantic Nino appears as mode with more variance in the FCM** (λ=0.2)
- Atlantic Nino is known to be related to ocean dynamics (Dippe et al. 2018, Foltz and McPhaden 2010, Xie and Carton 2004, and others…)

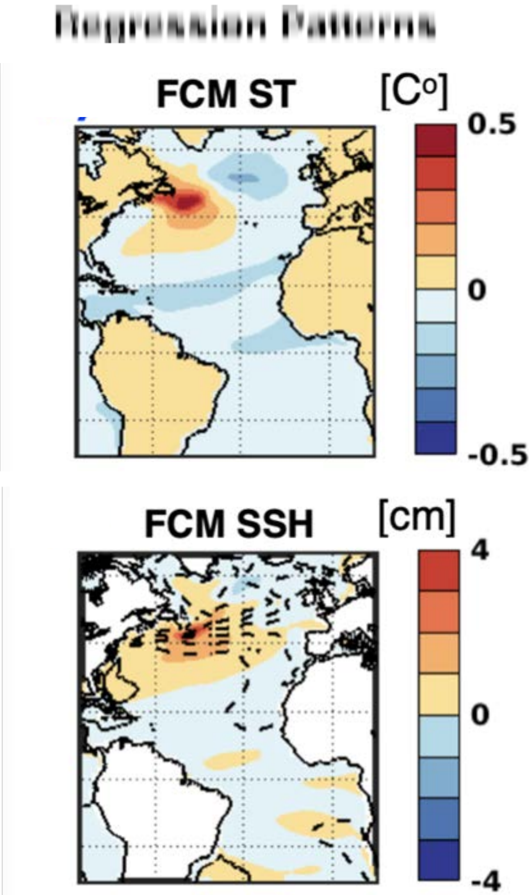
- **CDA can isolate modes of variability we know and love!**

FCM-SST-2: Component with more variance in Fully Coupled Model



- **Subpolar SST mode has more variance in FCM** (λ=0.5)
- Differences are concentrated on the Subpolar North Atlantic, specifically the Transition Zone (Buckley & Marshall 2016)
- Confirms the importance of ocean dynamics in setting SST in this region (Delworth et al. 2017; Buckley and Marshall 2016).

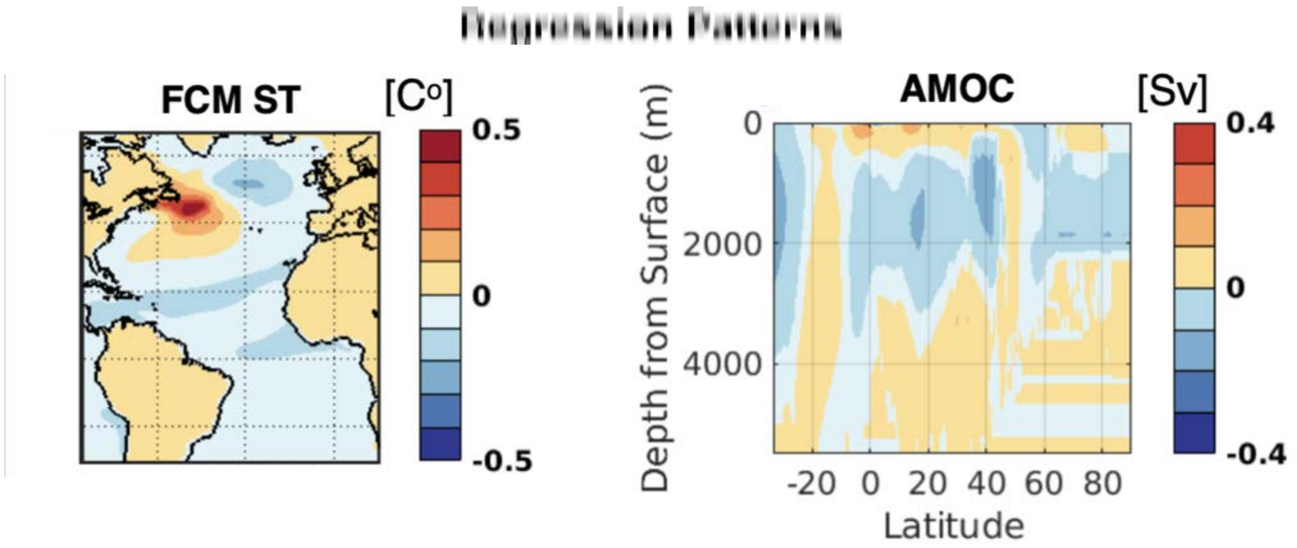
- Max SSH anomaly occurs along the path of the North Atlantic Current
- Accounts for ~2/3 of Annual SSH variance
- Likely related to variations on Gulf Stream path



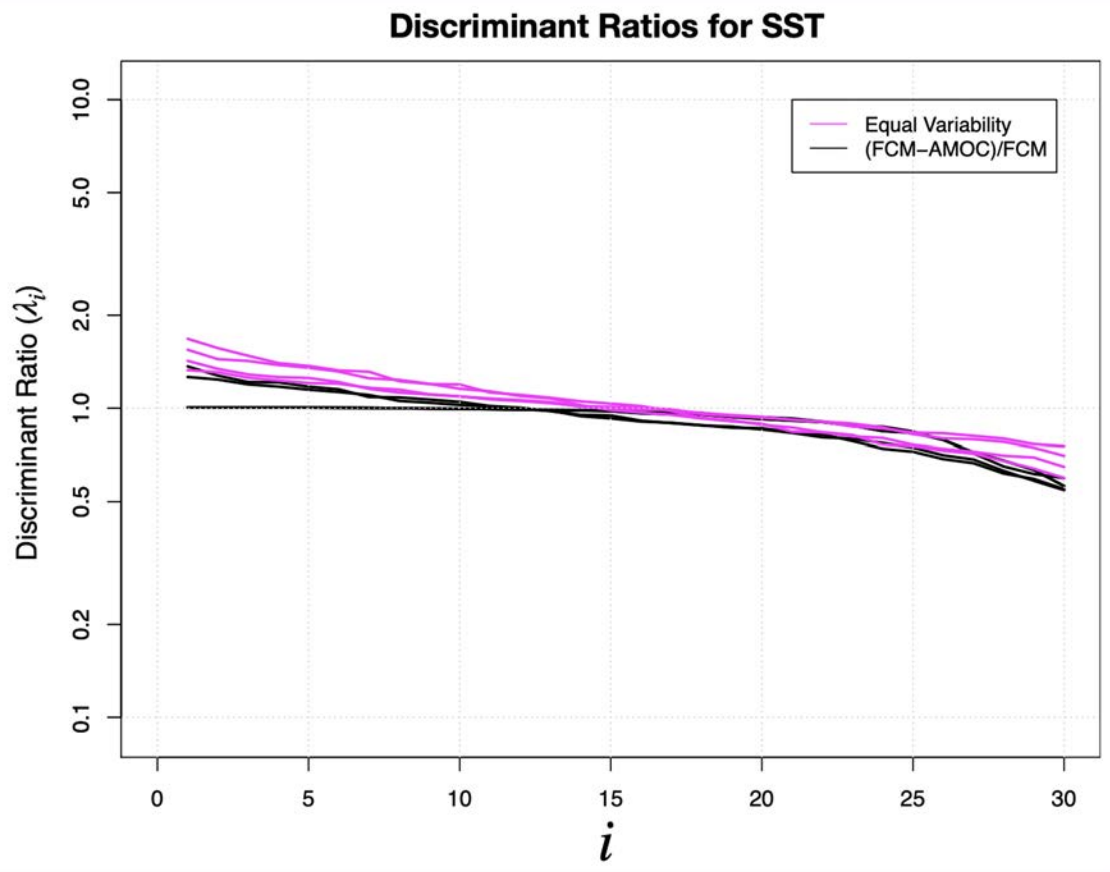
FCM-SST-2: A role for the AMOC?

Why do we think this?

- Warming hole
- AMOC is thought to be important in the Subpolar North Atlantic



Could the AMOC be forcing SST variations?



The AMOC does not significantly influence Atlantic SST variability in CESM LENS

Conclusions

1. **Does Atlantic SST differ between models with and without interactive ocean dynamics?**

 Yes, significantly!

2. ***What SST patterns differ* in models with and without interactive ocean dynamics?**

Modes where ocean dynamics decreases SST variance (SOM has higher variance than FCM)

SOM-SST-1: SST response to the NAO

- NAO Tripole Pattern has higher variance in SOM

SOM-SST-2: AMV

- Suggests AMV is driven by stochastic atmospheric forcing (Clement et al., 2015)

- Lack of oceanic damping in SOM may increase magnitude of SST variance in the SOM (Murphy et al., 2021)

Modes where ocean dynamics increases SST variance (FCM has higher variance than SOM)

FCM-SST-1: Atlantic Nino

FCM-SST-2: Subpolar SST

- Related to strong SSH signatures & strong reemergence signature

- Differences in SST variability do not appear to be related to AMOC