Investigation of the drivers of sea surface salinity and North Atlantic climate variability using a stochastic model

Glenn Liu[1], Young-Oh Kwon[2], Claude Frankignoul[2]

Climate Variablity and Change Working Group

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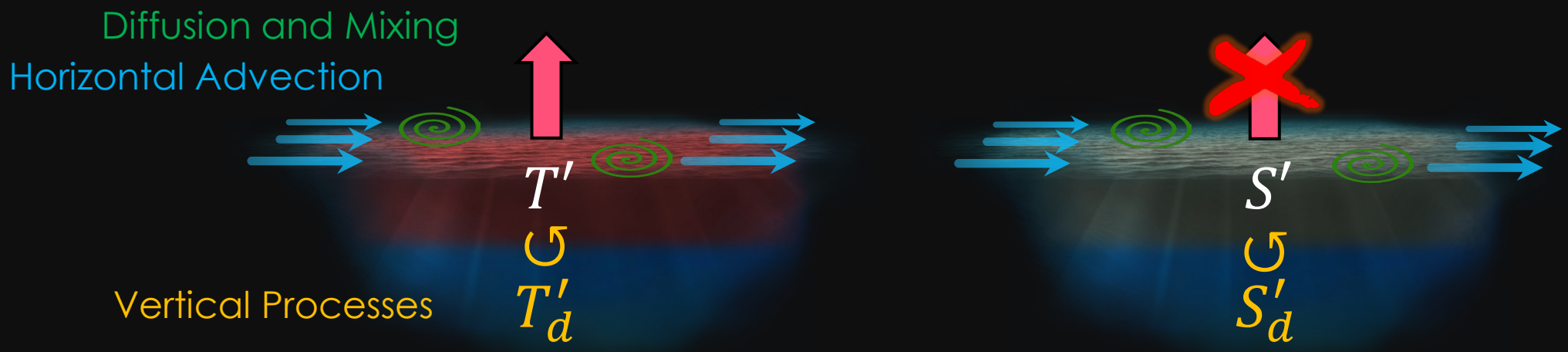
[1]MIT-WHOI Joint Program, [2]Woods Hole Oceanographic Institution

glennliu@mit.edu

Salinity Variability and Ocean Dynamics



Q: How do specific ocean processes impact salinity variability?

Can this tell us anything about North Atlantic Climate?

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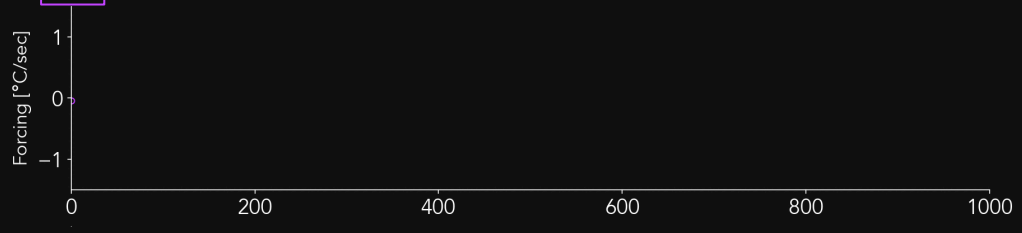
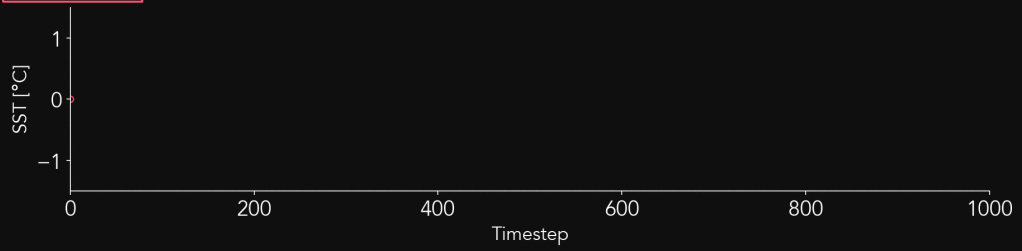
Stochastic Model Theory *(Frankignoul and Hasselmann 1977)*

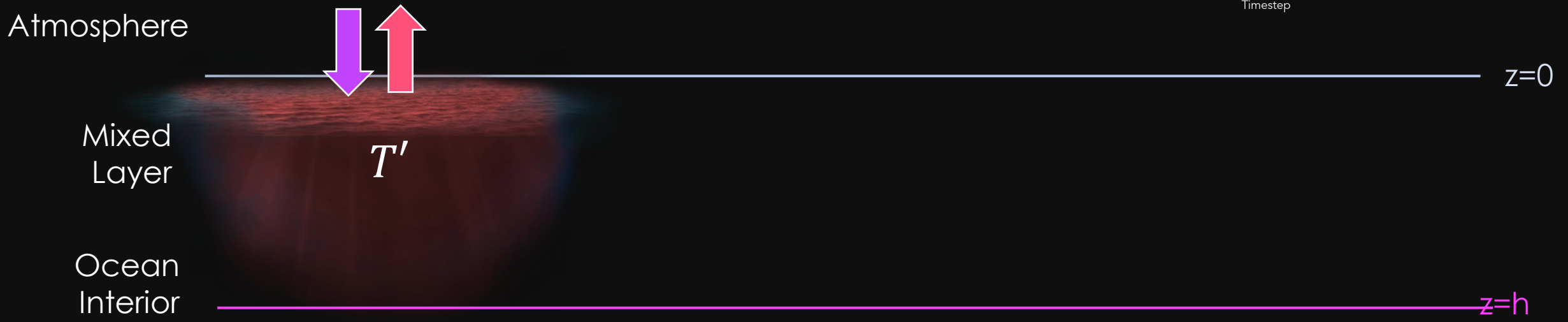
$$\frac{\partial T'}{\partial t} = \underbrace{\frac{F'}{\rho C_p h}}_{\text{stochastic atmospheric forcing}} - \underbrace{\frac{\lambda^a}{\rho C_p h} T'}_{\text{heat flux damping}}$$

F' Atmosphere, "Weather Noise"



$-\lambda^a T'$ Ocean, "Passive Response"





Winter (Year 1) Summer (Year 1) Winter (Year 2)

glennliu@mit.edu

Entrainment and Re-emergence

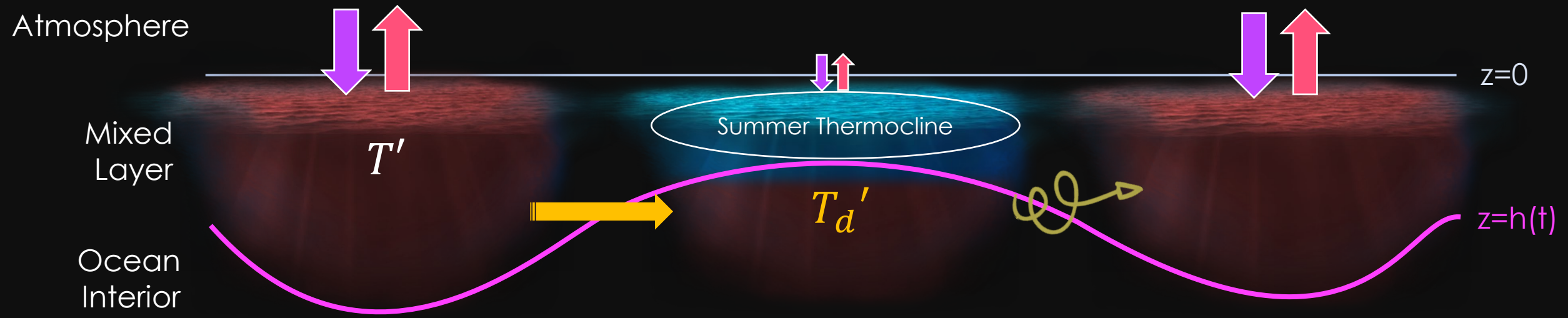
$$\frac{\partial T'}{\partial t} = \frac{F'}{\rho C_p h} - \frac{\lambda^a}{\rho C_p h} T' - \frac{1}{h} w_e (T' - T_d')$$

stochastic atmospheric forcing

heat flux damping

entrainment velocity

SST' below mixed layer



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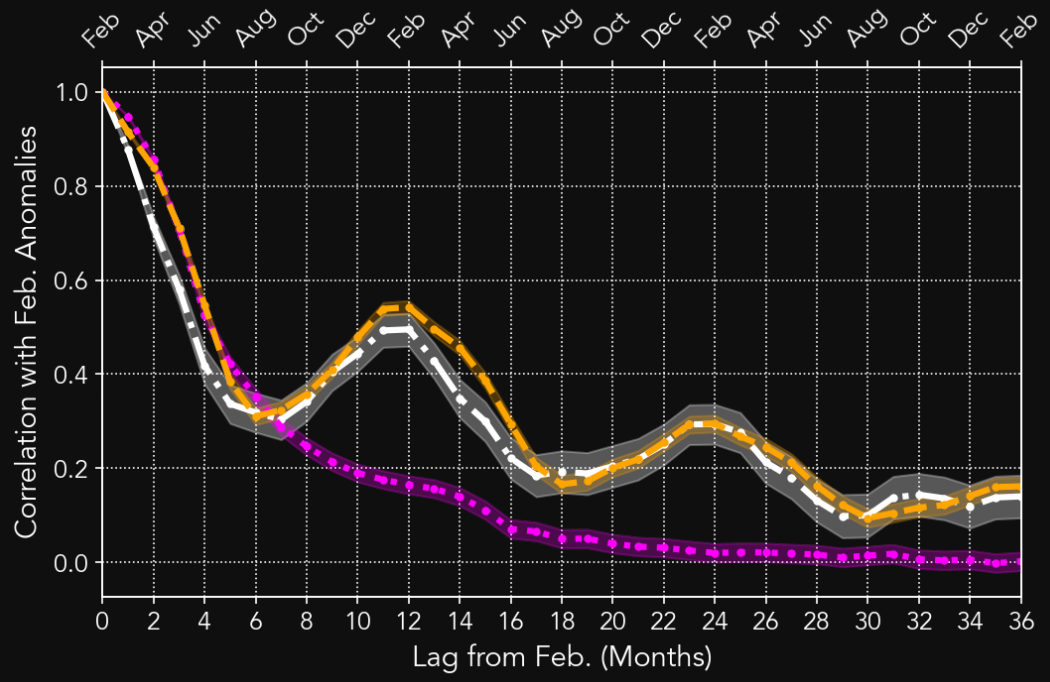
Entrainment and Re-emergence

stochastic atmospheric forcing | heat flux damping | entrainment velocity | SST' below mixed layer

$$\frac{\partial T'}{\partial t} = \frac{F'}{\rho C_p h} - \frac{\lambda^a}{\rho C_p h} T' - \frac{1}{h} w_e (T' - T_d')$$

The **entraining stochastic model** successfully captured aspects of SST behavior at key locations in the **Community Earth System Model 1** (Liu et al. 2023)



glennliu@mit.edu

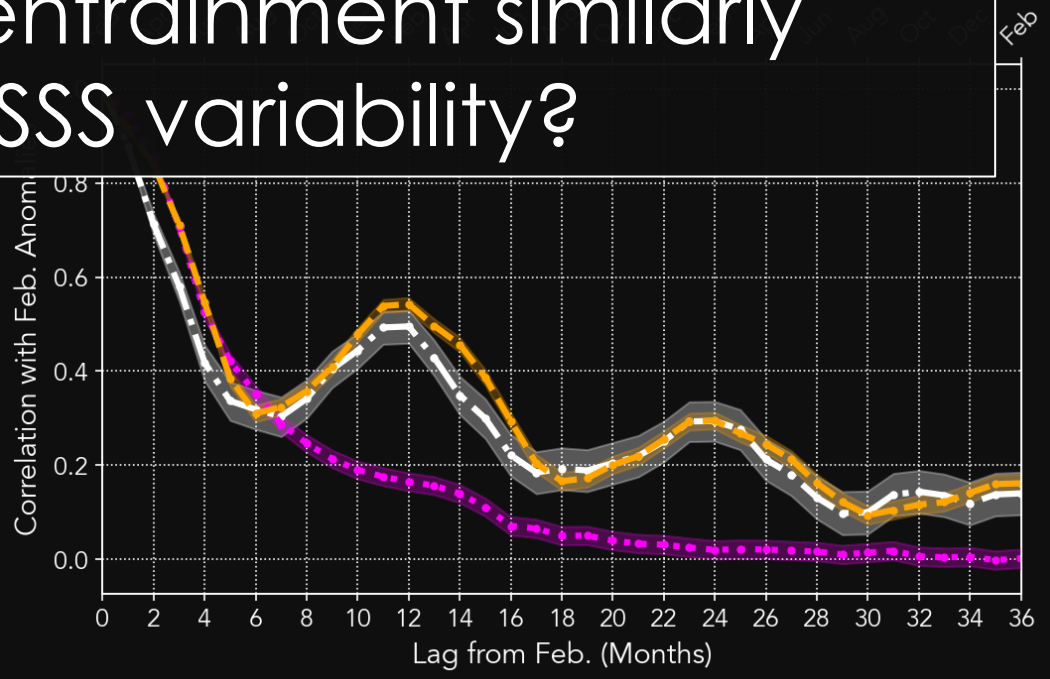
Entrainment and Re-emergence

stochastic atmospheric forcing | heat flux damping | entrainment velocity | SST' below mixed layer

$$\frac{\partial T'}{\partial t} = \frac{F'}{\rho C_p h} - \frac{\lambda^a}{\rho C_p h} T' - \frac{1}{h} w_e (T' - T_d')$$

Q: Is local vertical entrainment similarly important for SSS variability?

The **entraining stochastic model** successfully captured aspects of SST behavior at key locations in the **Community Earth System Model 1** (Liu et al. 2023)



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stochastic atmospheric forcing

heat flux damping

entrainment velocity

SST' below mixed layer

$$\frac{\partial T'}{\partial t} = \frac{F'}{\rho C_p h} - \frac{\lambda^a}{\rho C_p h} T' - \frac{1}{h} w_e (T' - T_d')$$

Stochastic evaporation and precipitation

$$\frac{\partial S'}{\partial t} = \frac{\bar{S}(E' - P')}{\rho h} - \frac{1}{h} w_e (S' - S_d')$$

Entrained Value

Detrained Value

$$S_d' = \lambda^d S_{d,0}$$

Subsurface

Estimate parameters and compare with the 42-member CESM1 Large Ensemble, 1920-2005

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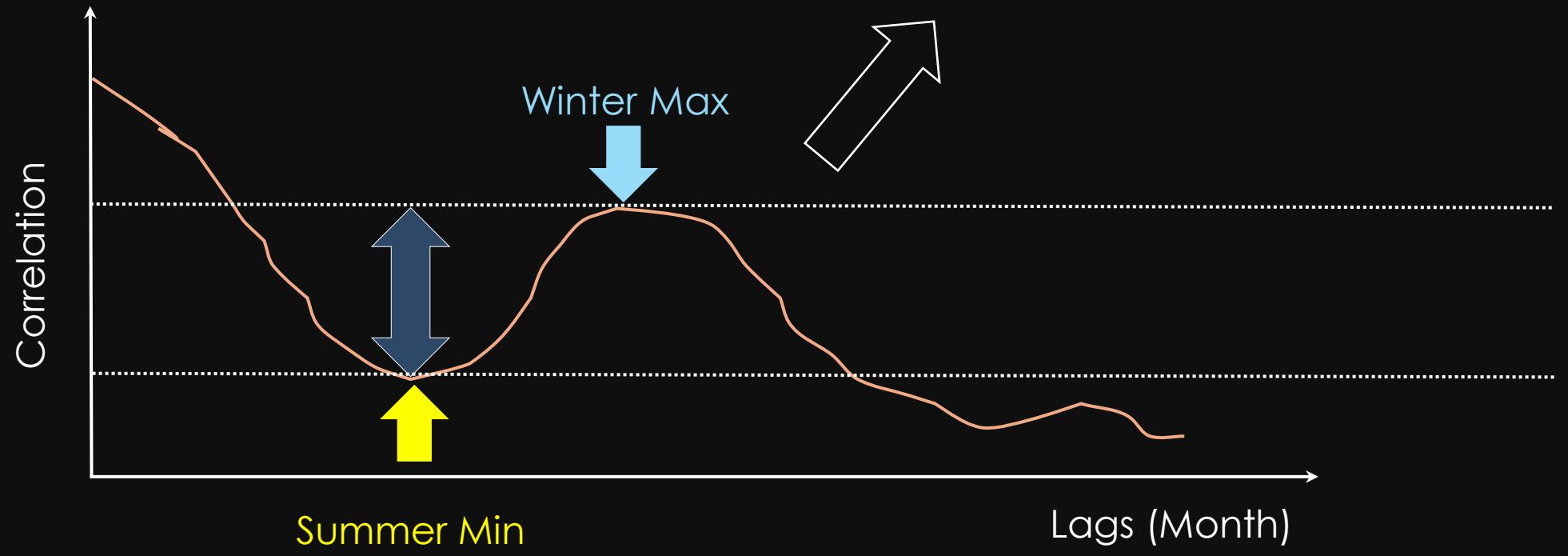
Re-emergence and Persistence

$$REI = Corr_{Winter} - Corr_{Summer}$$



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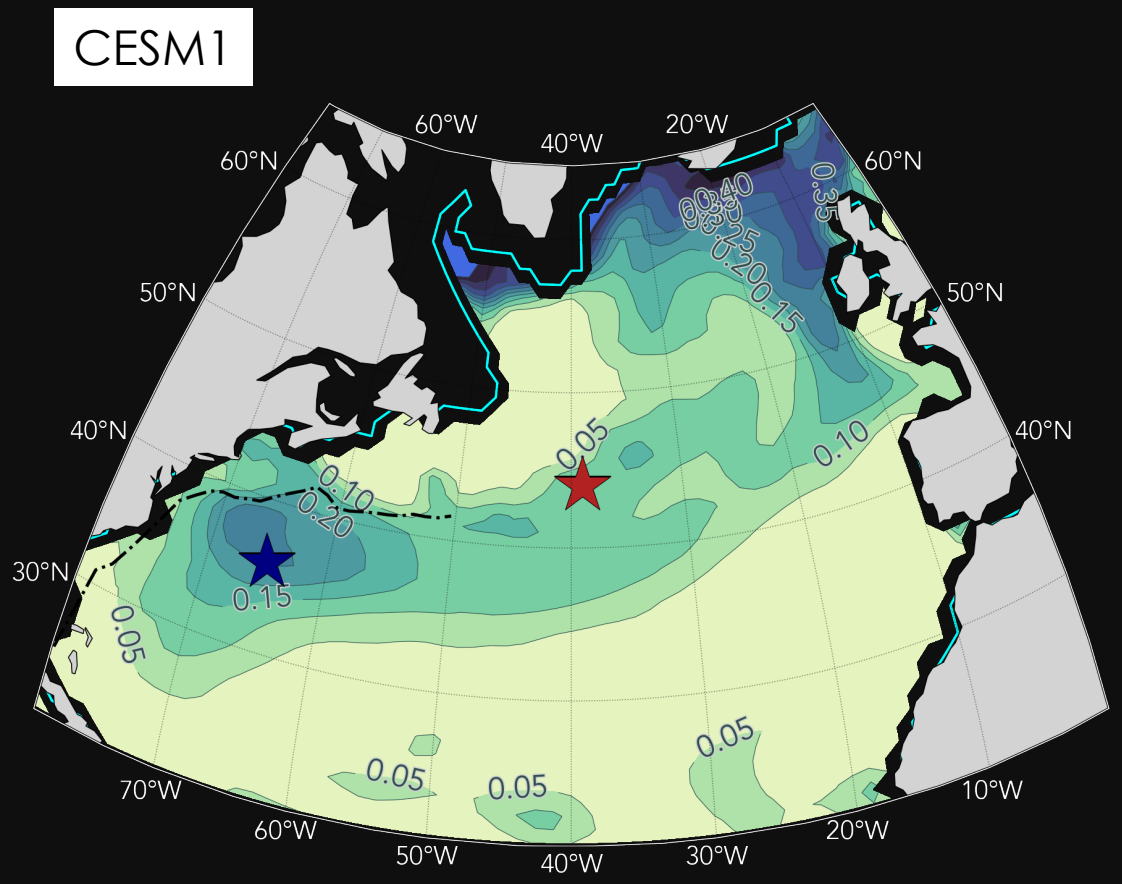
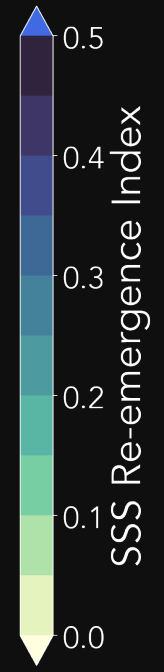
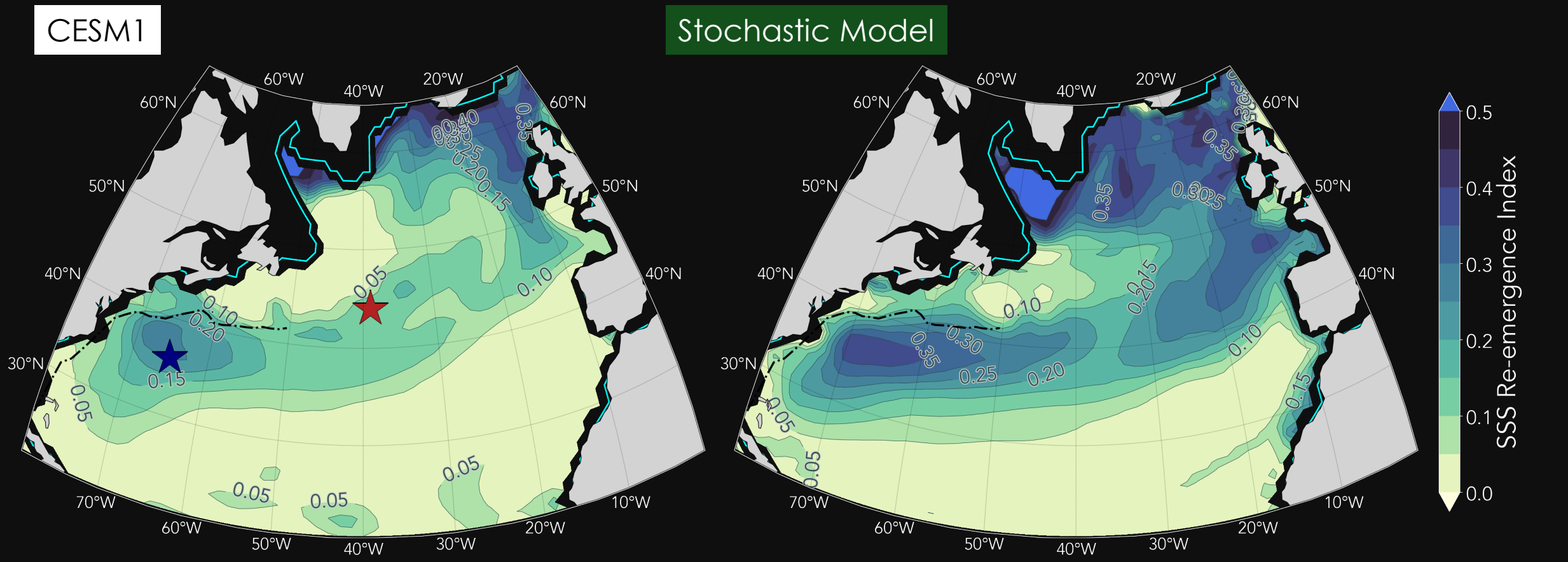
SSS Re-emergence patterns in CESM1





We then integrate the stochastic model for 10,000 years at each point in the North Atlantic…

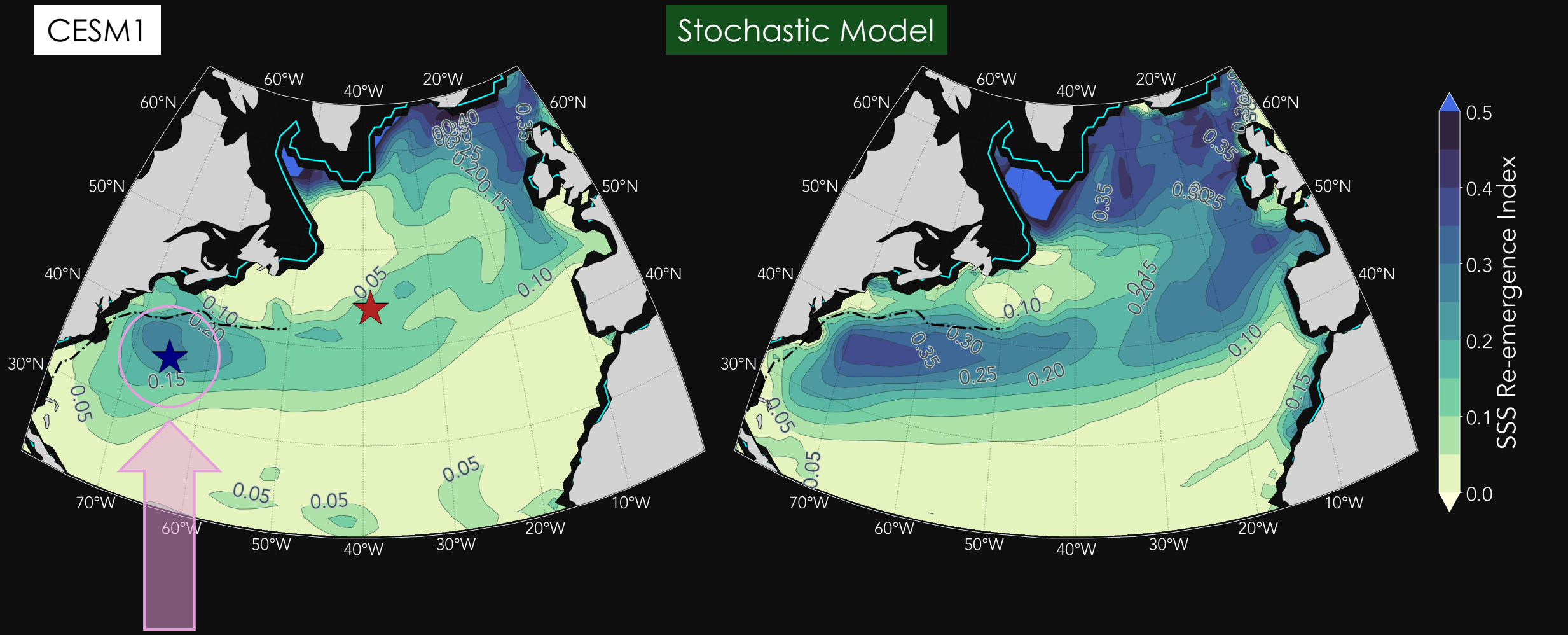
SSS Re-emergence patterns in CESM1



Even without horizontal dynamics, the stochastic model captures the amplitude and pattern of wintertime SSS re-emergence

glennliu@mit.edu

SSS Re-emergence patterns in CESM1



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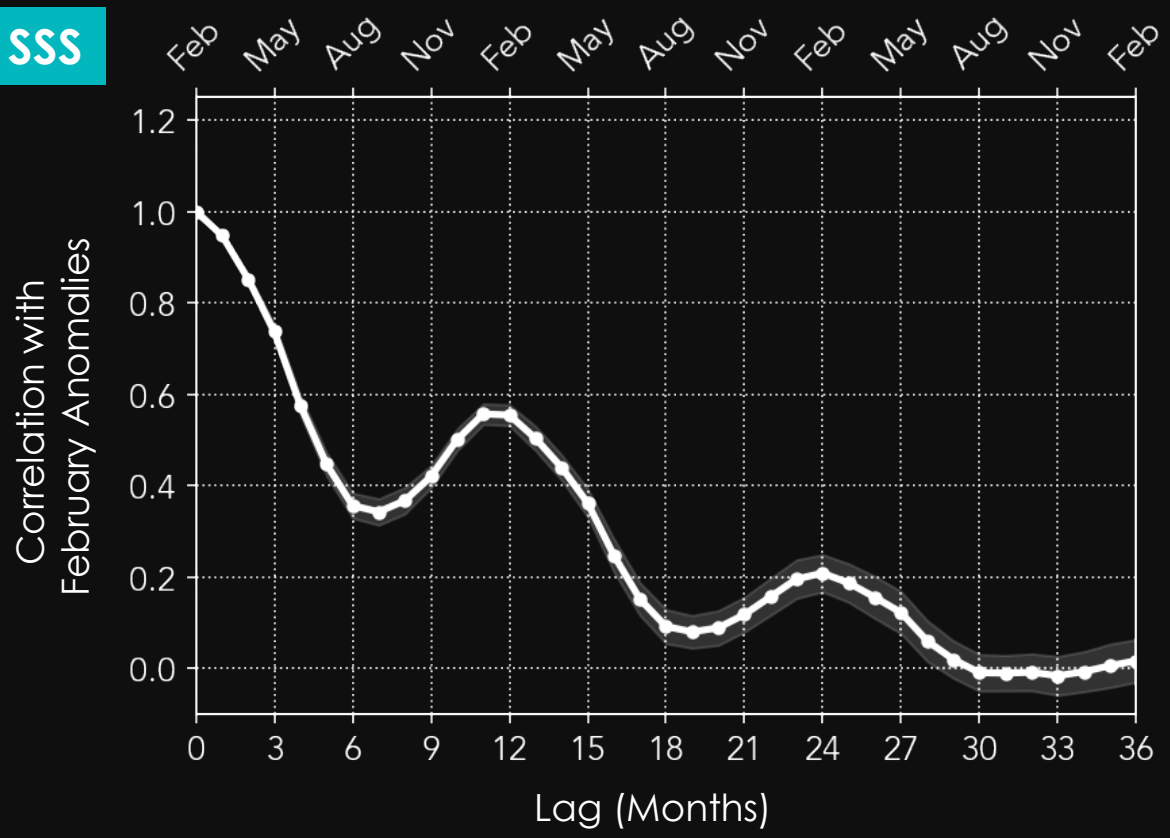
Wintertime SSS Persistence

CESM1

SSS



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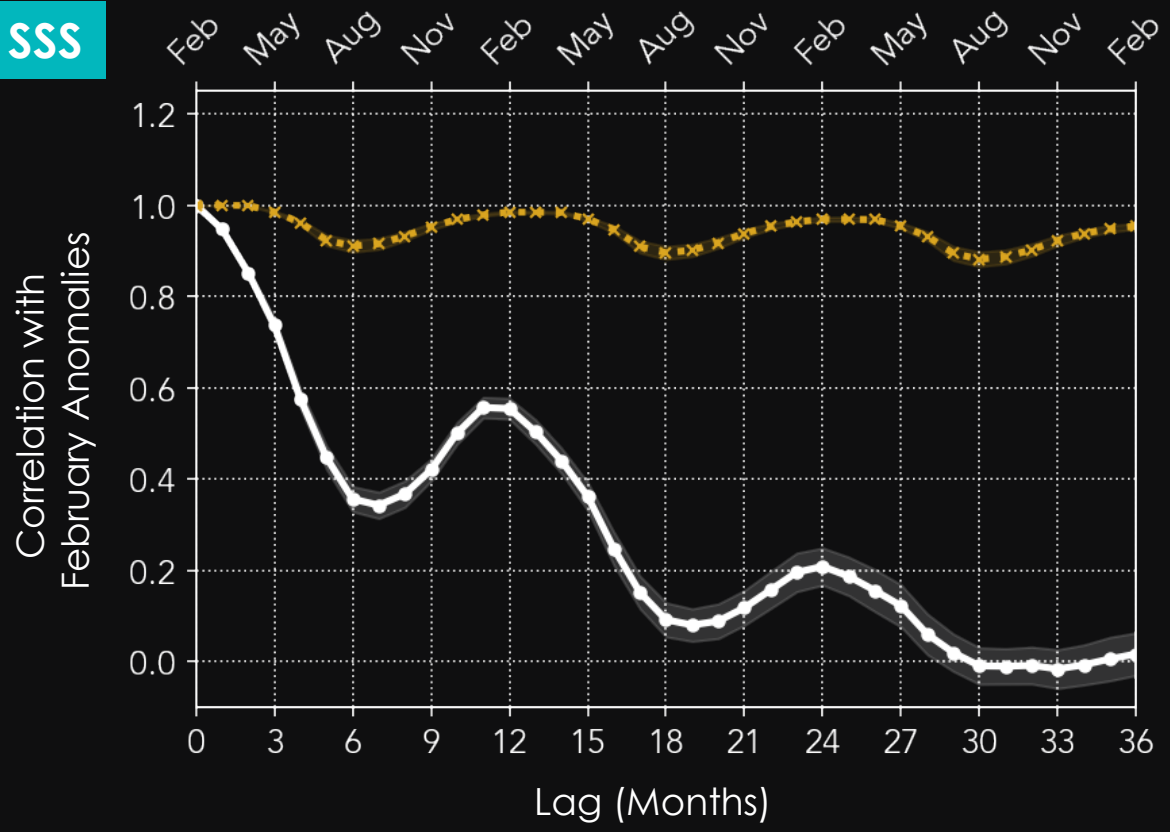
Wintertime SSS Persistence

CESM1
Stochastic Model

SSS

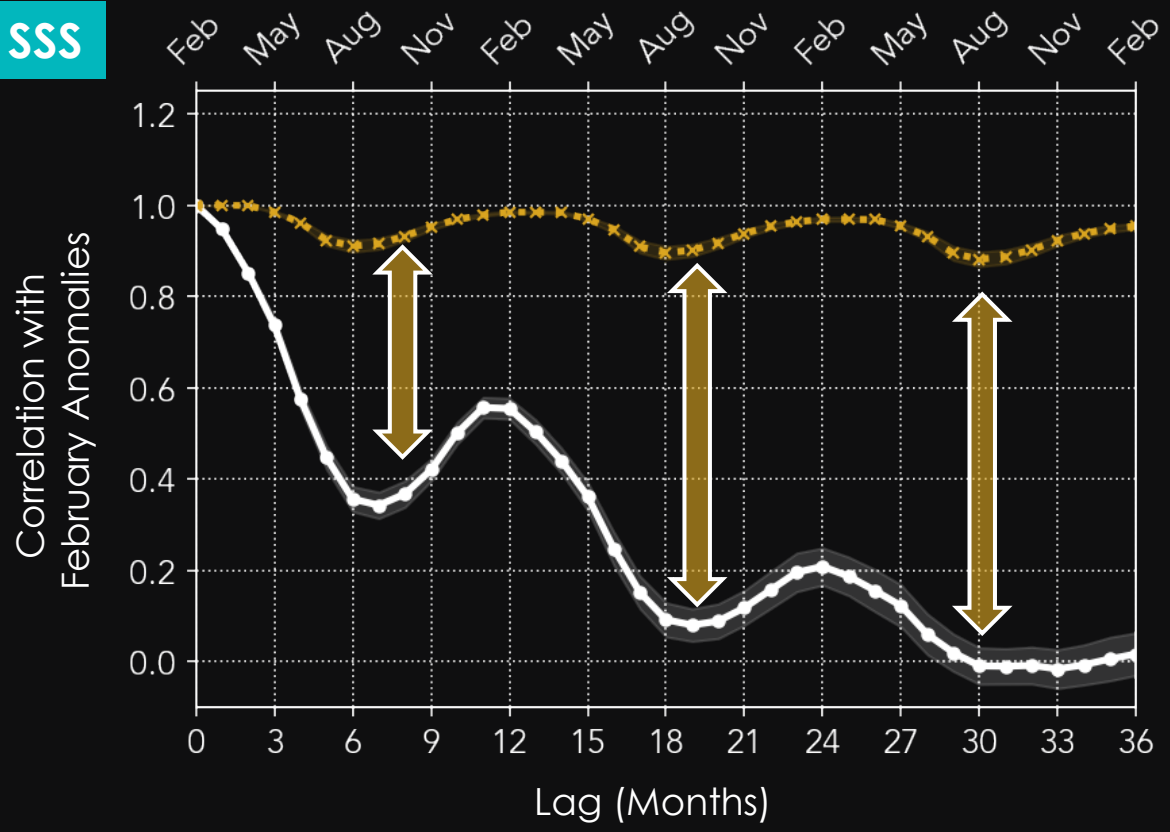


glennliu@mit.edu

Wintertime SSS Persistence

CESM1
Stochastic Model

SSS



With entrainment damping alone, SSS is too persistent

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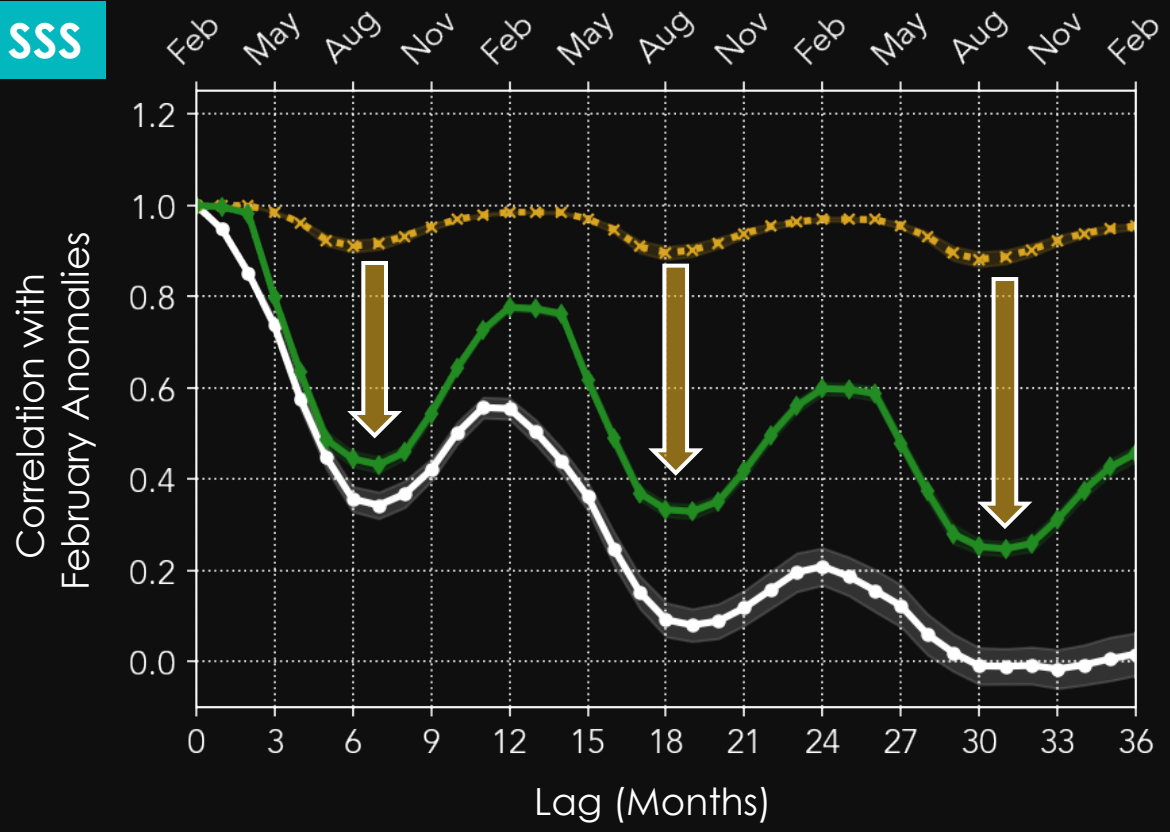
Wintertime SSS Persistence

CESM1
Stochastic Model
Stochastic Model (Subsurface Damping)

SSS



Addition of subsurface damping substantially improves representation of SSS persistence

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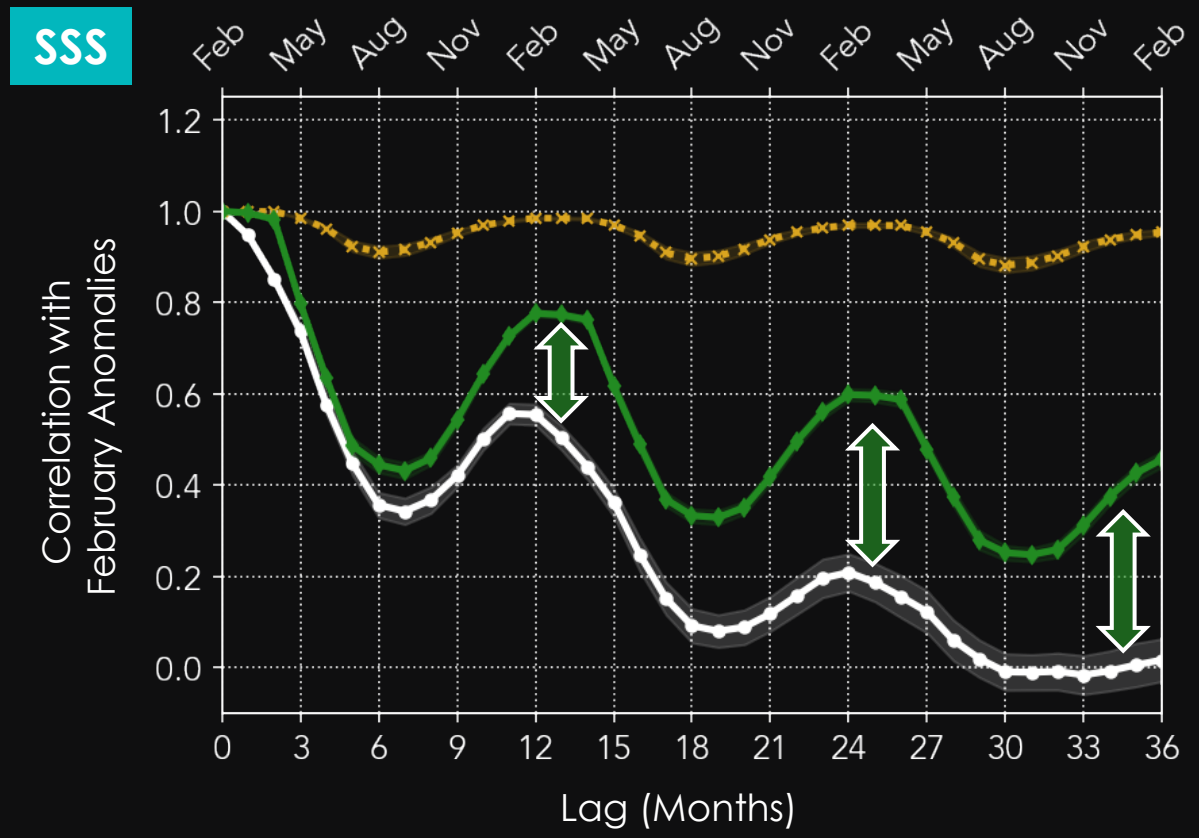
Wintertime SSS Persistence

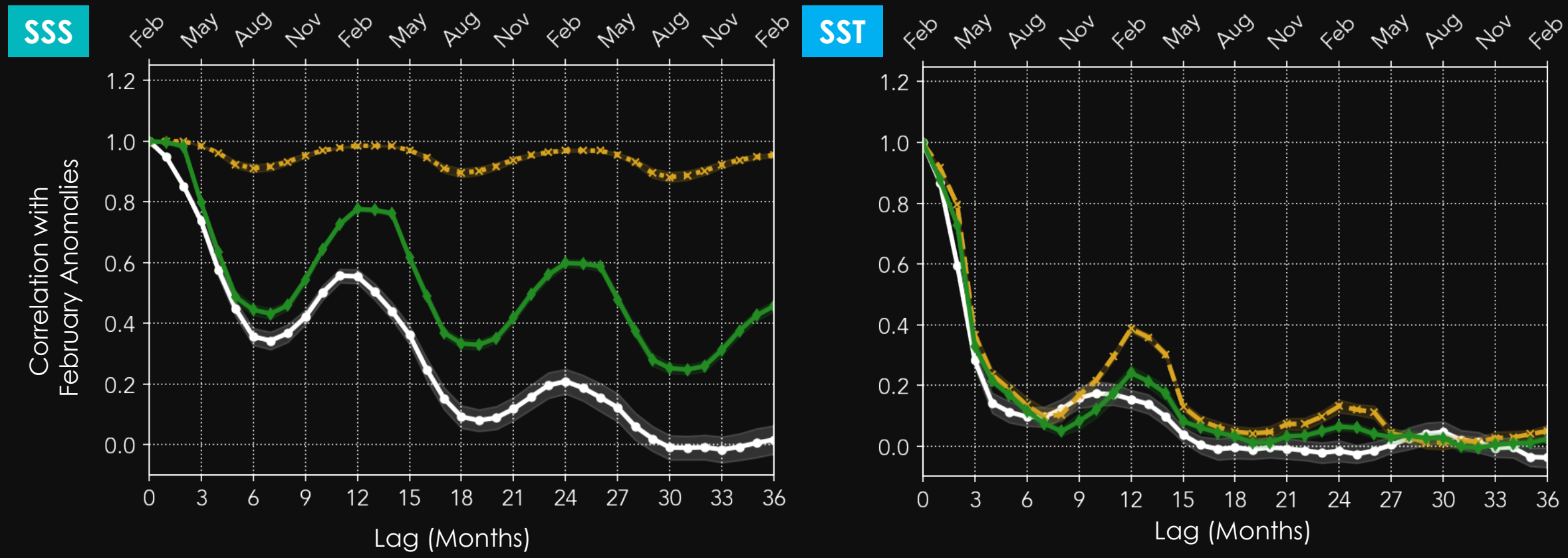
CESM1
Stochastic Model
Stochastic Model (Subsurface Damping)



However, missing horizontal/vertical ocean dynamics are needed to correctly capture SSS persistence on longer timescales

glennliu@mit.edu

SSS versus SST Persistence

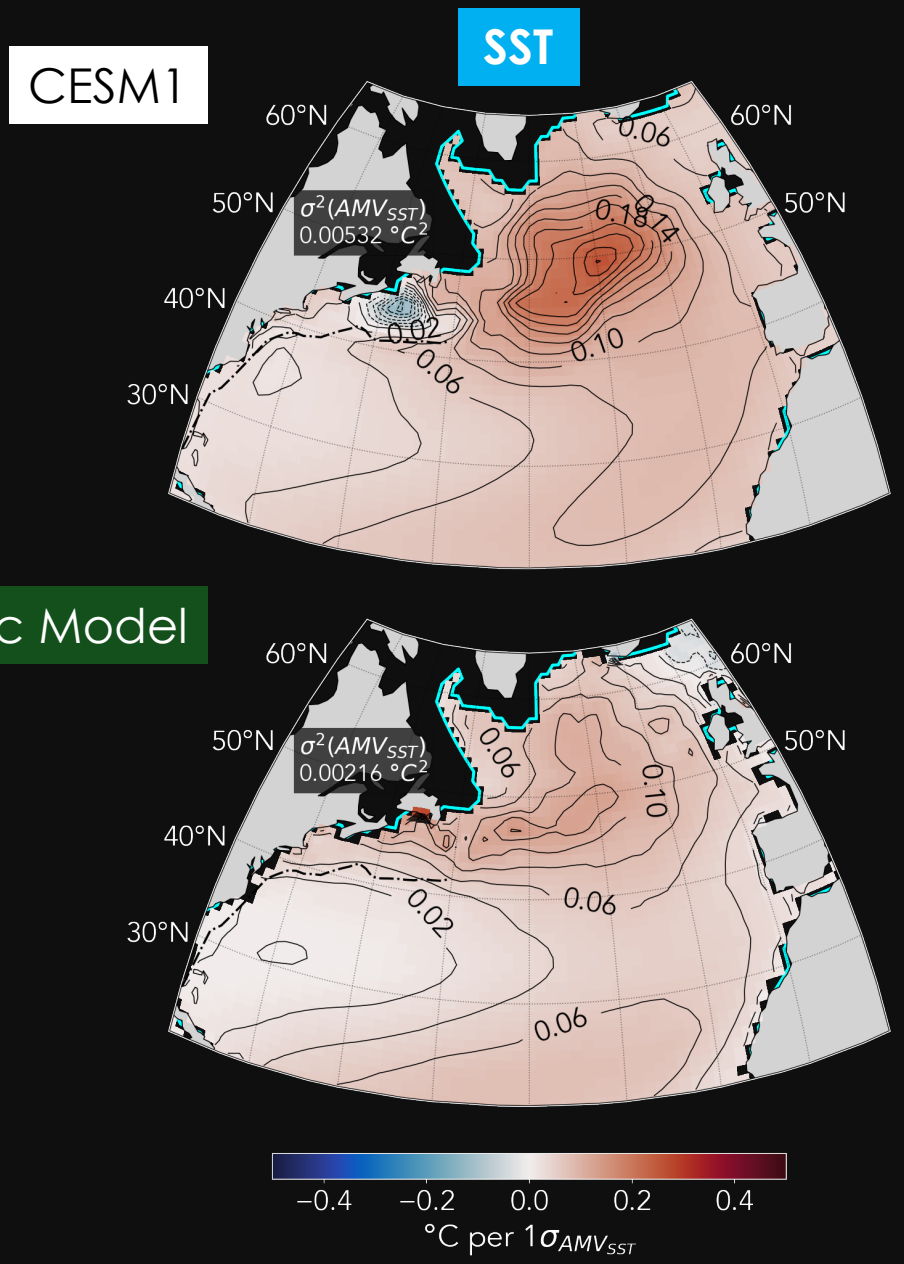


Unlike SSS, SST persistence is well captured by the stochastic model *without* additional horizontal or vertical ocean dynamics beyond entrainment

glennliu@mit.edu

Patterns of Multidecadal Variability

The stochastic model SST has only **~40%** of the variance of CESM1



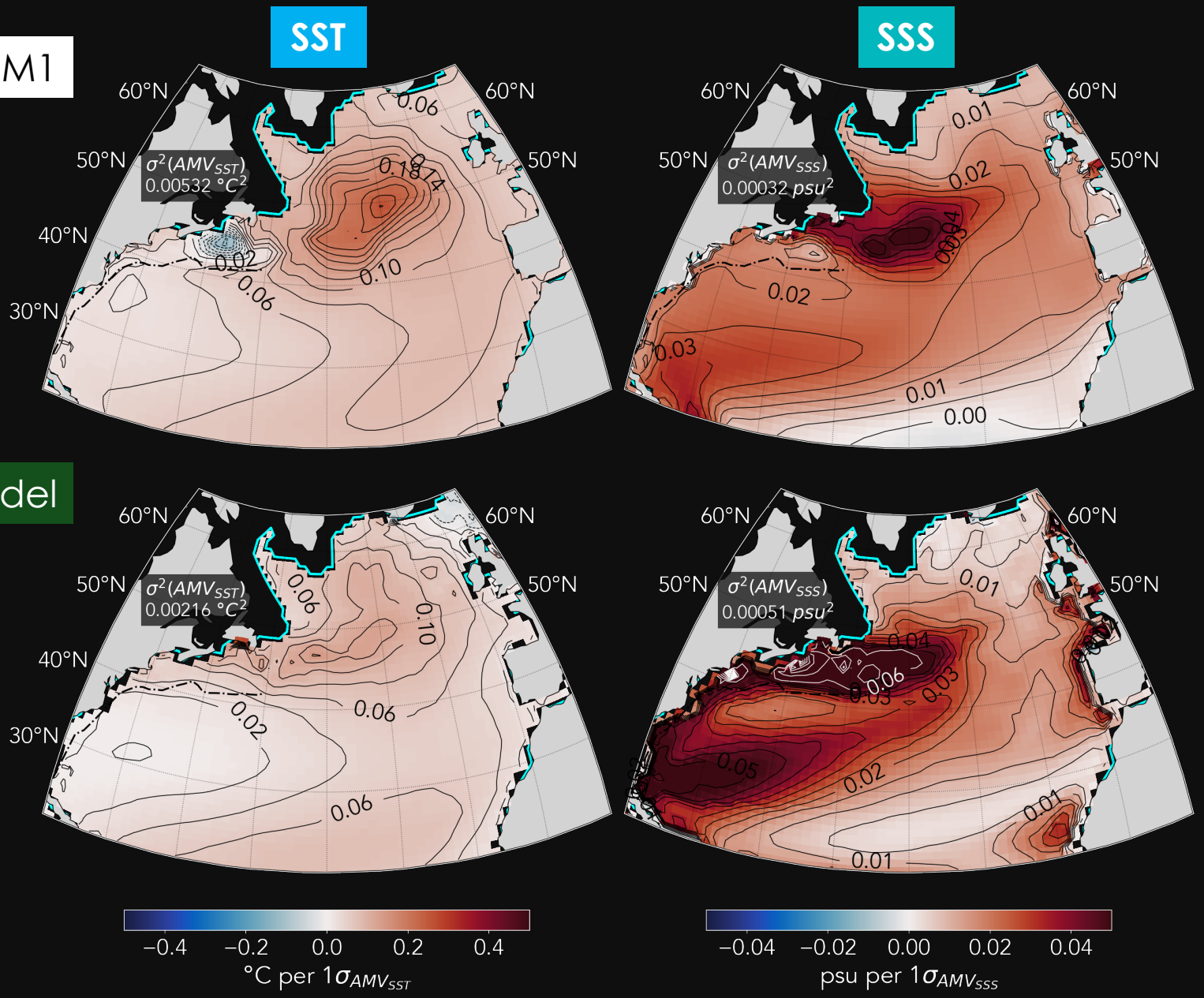
Patterns of Multidecadal Variability

CESM1

The stochastic model SST has only **~40%** of the variance of CESM1

Stochastic Model

SSS in the stochastic model has **~1.6x** the variance of CESM1



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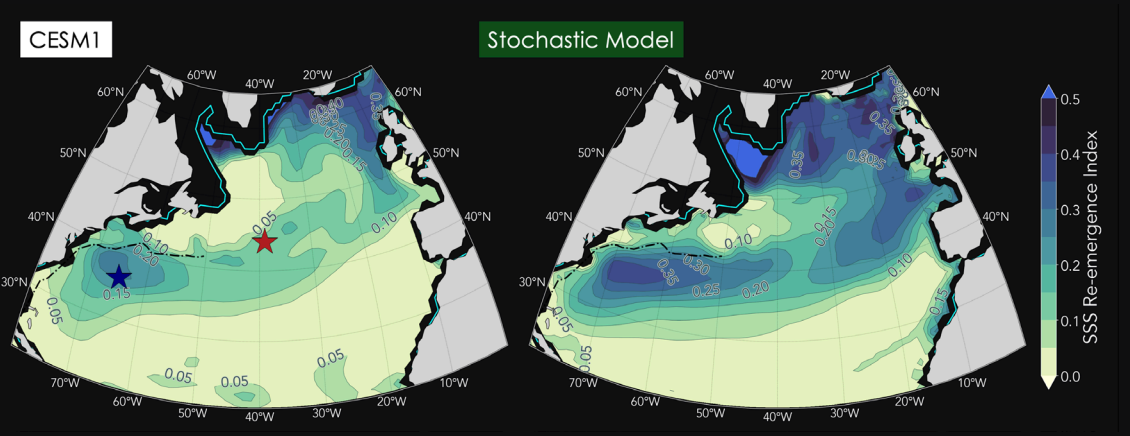
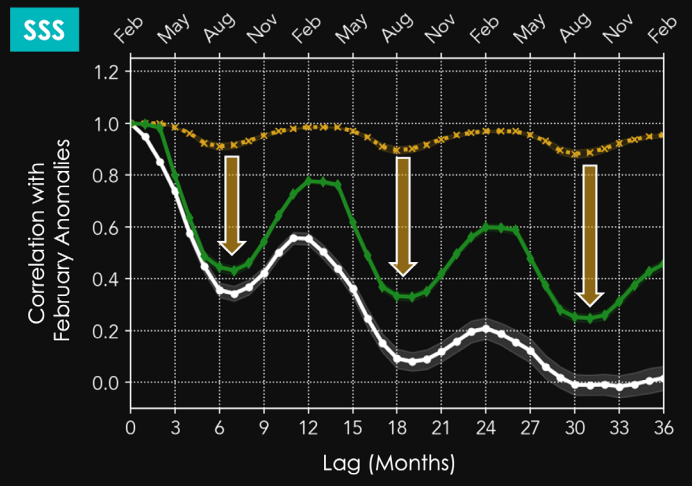
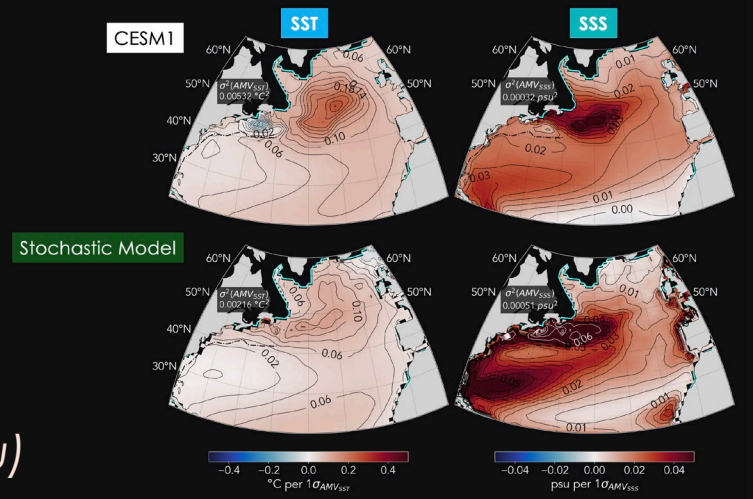
Main Takeaways

A stochastic model with vertical entrainment captures SSS persistence and its seasonal progression





Subsurface damping improves representation of SST/SSS behavior especially for SSS persistence



Ocean processes impact SST and SSS differently

- *Damping* SSS persistence and low-frequency variance
- *Enhancing* low-frequency SST

Thanks for Listening! Questions? (glennliu@mit.edu)