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Arctic Ocean Heat Budget
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BROWN
Jet Propulsion Laboratory
California Institute of Technology
ECCO SUMMER SCHOOL
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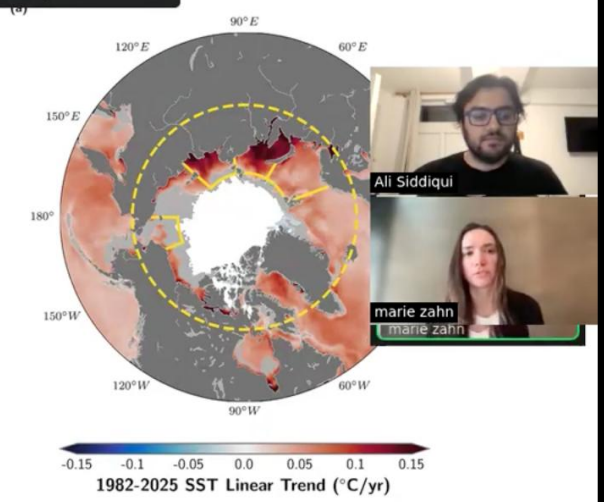
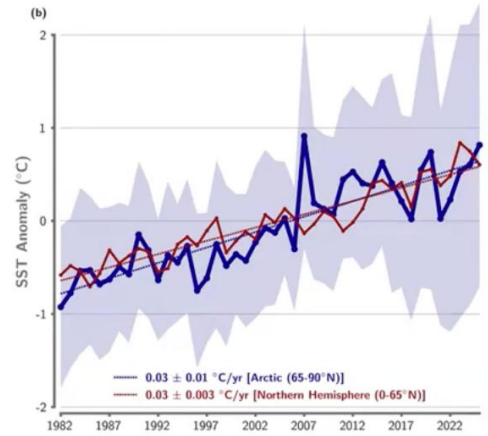
Motivation: Why Does Arctic OHC Matter?

- **Arctic Amplification**
  - Warming >3x faster than the global mean, but warming is not regionally uniform
  - Ocean plays important role in accelerated warming through ice-albedo and ocean-atmosphere feedbacks
- **Sea Ice Decline**
  - ~50% loss in SIE since 1979
  - OHC variability is essential for explaining observed and projected ice loss trajectories
- **Atlantic & Pacific Water Intrusions**
  - Warm water masses entering the Arctic basin (“Atlantification”, Pacific Water inflow through Bering Strait) are increasing in temperature and depth penetration
- **Salinity Stratification Impacts**
  - Changes in upper OHC are closely tied to freshwater fluxes (e.g., ice melt and runoff), which enhance stratification, modulate vertical heat exchange, and influence sea ice





Timmermans & Labe (2025)

Objectives

1. **Resolution Sensitivity**

   To quantify the effect of model resolution on the Arctic Ocean heat budget, from coarse to eddy-permitting scales.

2. **Regional Heat Budget & Sea Ice Coupling**

   To characterize regional Arctic OHC variability and its relationship to sea ice across seasonal to interannual timescales.

Key Scientific Questions

1. **How do Arctic heat budget terms vary across ECCO resolutions (llc90 → llc270 → llc1080)?**
   a. What is the effect of downscaling to the eddy-permitting llc1080 solution?

2. **How do heat budget terms vary regionally across the Arctic Ocean?**
   a. How does ocean heat content in the upper mixed layer interact with sea ice thermodynamics?
   b. How does OHC vary on seasonal to interannual timescales?

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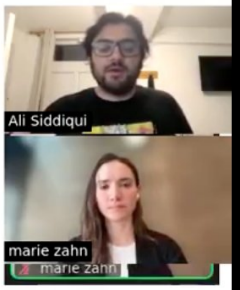
Why the need to do this?



- Evaluate effects of downscaling as these models are becoming more prevalent in our community with increasing computational capacity and push to high-res
- Provide a basis for model evaluation, and calibration of future Arctic modeling efforts.
- Extend previous estimates of Arctic heat, freshwater content and transports along with **sea ice volume** to **2024** (*Nguyen et al. 2021, Tsubouchi et al. 2018, Haine et al. 2015, Rossby et al. 2018, Woodgate et al. 2018, Schauer et al. 2009, Curry et al. 2011, Smedsrud et al 2010, and many more*)

Three models, three configurations

Model	**ECCOv4r6 llc90**	**ECCOv5r1 llc270**	**SASSIE ECCO llc1080**
Temporal Coverage	1992-2024	1992-2024	2014-2020
Temporal Resolution	Monthly means	Monthly means	Daily means
Horizontal grid resolution (Arctic)	1° (~40 km)	1/3° (~14 km)	1/12° (~3.5 km)
Vertical levels	50	50	90
Mixing Parameterization	GM-Redi (not eddy-permitting)	GM-Redi (somewhat eddy-permitting)	KPP (eddy-permitting)
Solution	Adjoint-optimized	Adjoint-optimized	Free-running

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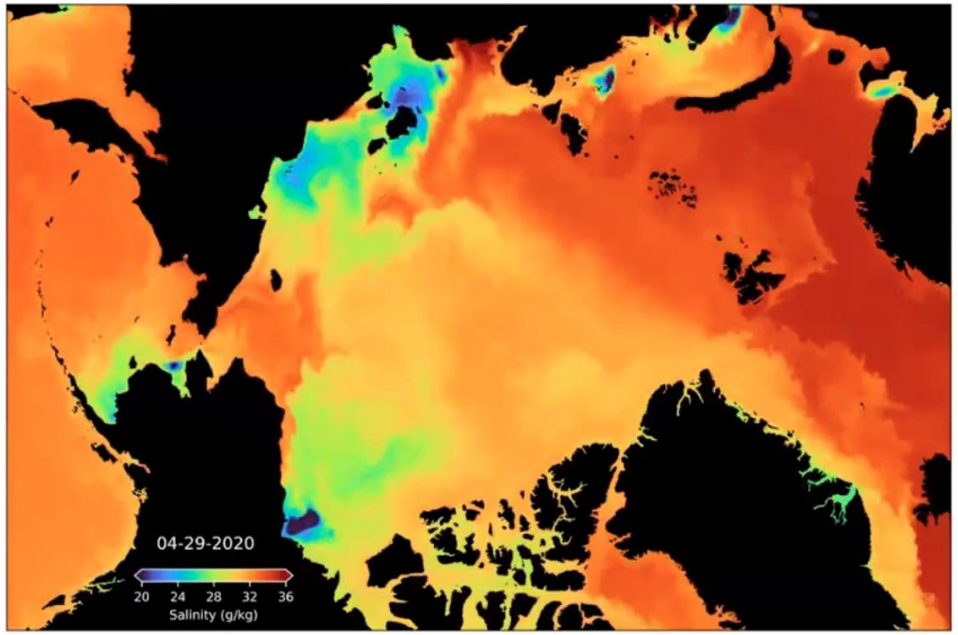
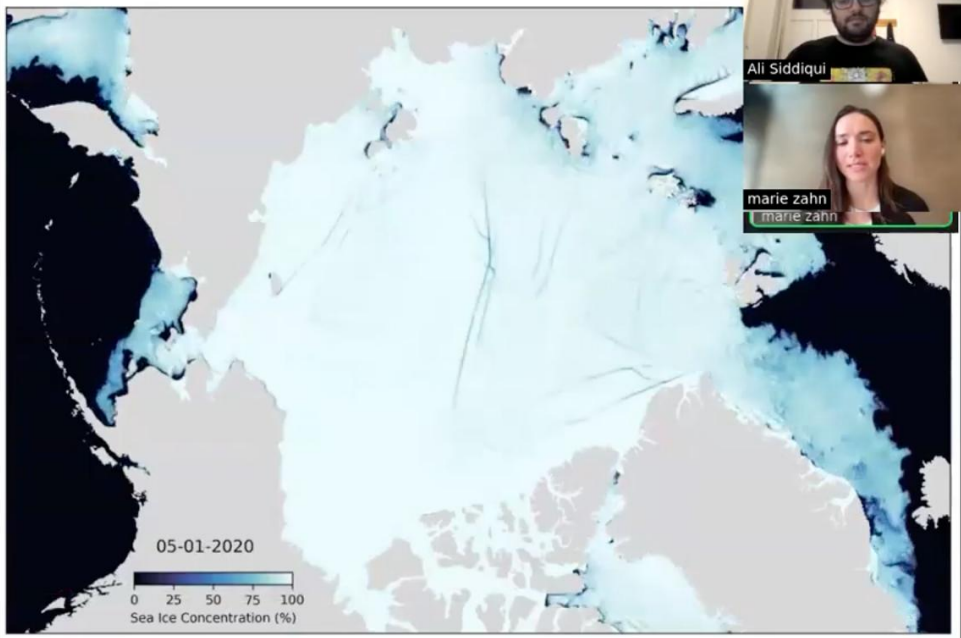
SASSIE ECCO Pan-Arctic High Res

Surface Salinity



Sea Ice Concentration



- Model generated for the NASA SASSIE (Salinity and Stratification at the Sea Ice Edge) campaign
- Produced by downscaling llc270 to 1/12° (llc1080)
- Fields consolidated onto single pan-Arctic curvilinear grid face from the 5 faces of ECCO model output

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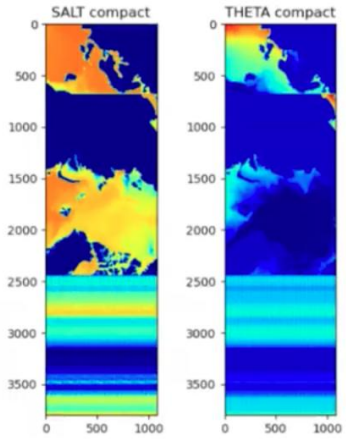
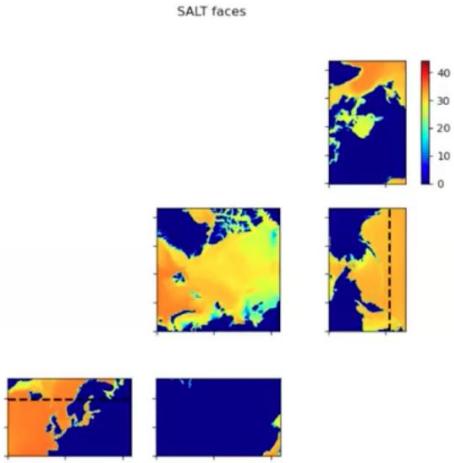
SASSIE ECCO Model Development

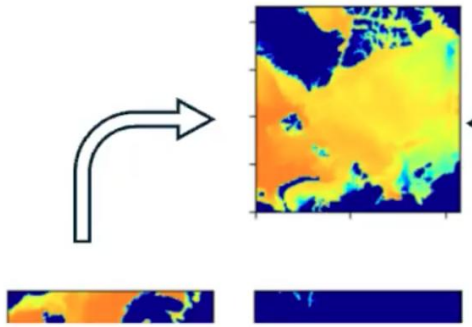
1. Read in binary files



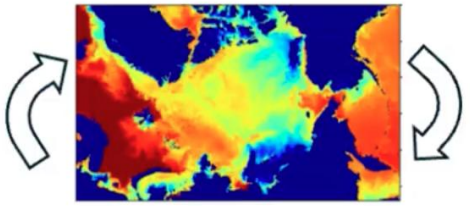
2. Convert to faces

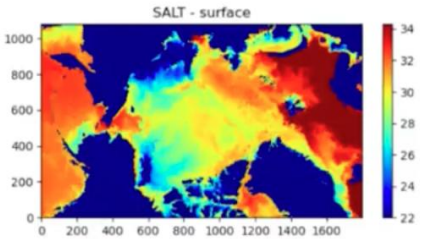


3. Extract part of faces 1 and 4, then join with Arctic tile

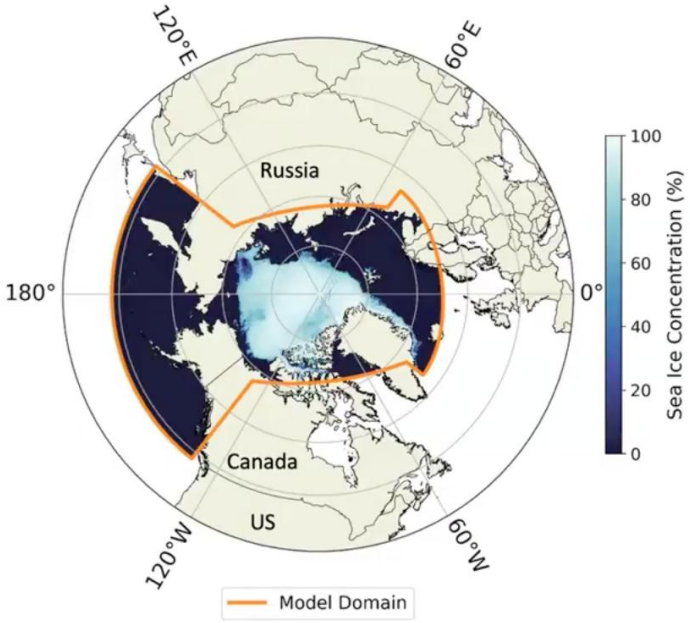


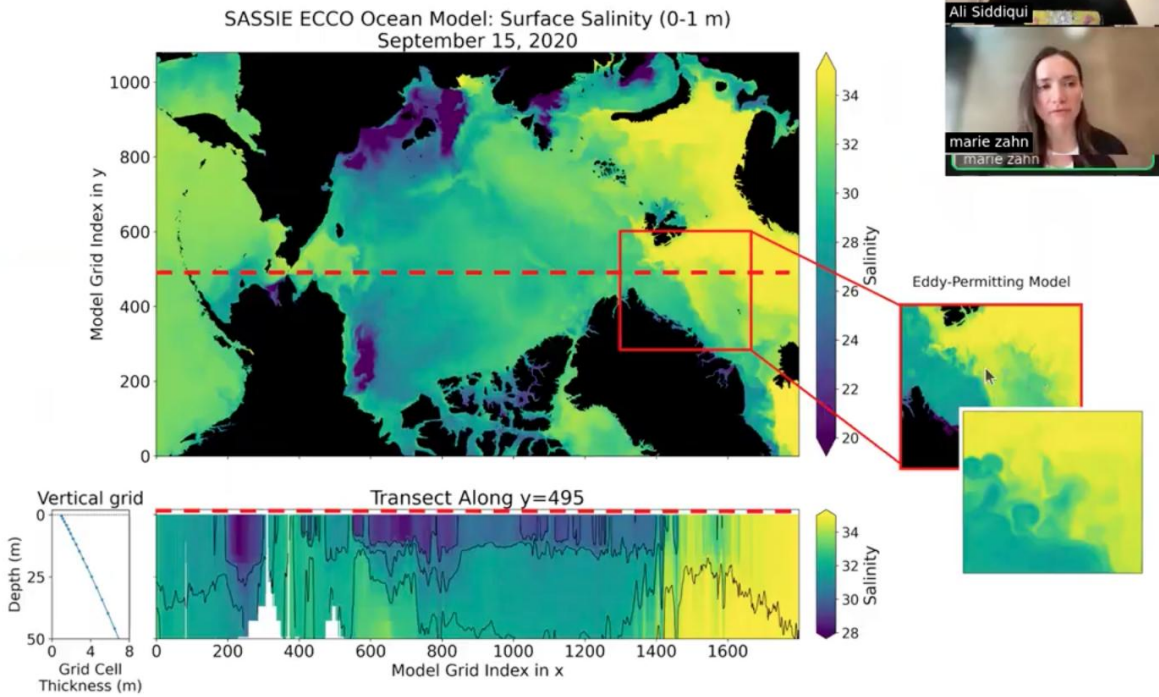
4. Rotate 180 degrees and apply land mask





SASSIE ECCO Pan-Arctic High Resolution Model



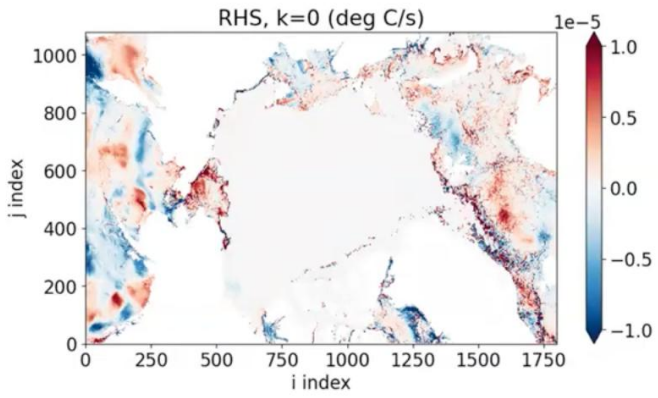


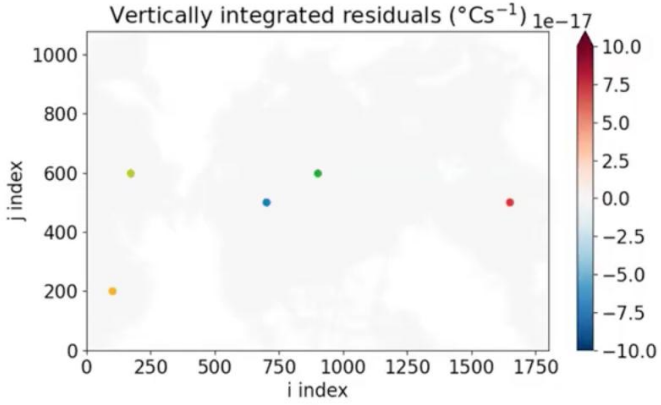
SASSIE ECCO Ocean Heat Budget Closure

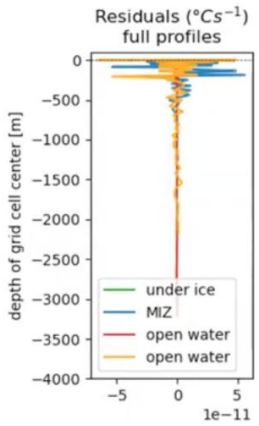
- Heat budget is closed!
- The total tendency is the sum of the tendencies from advective heat convergence, diffusive heat convergence, and total forcing.

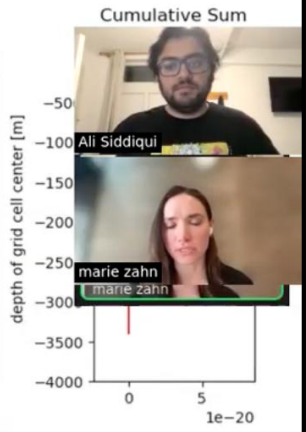
$$\underbrace{\frac{\partial(\theta)}{\partial t}}_{G^{\theta}_{\text{total}}} = \underbrace{-\nabla_{z^*} \cdot (\theta\, \mathbf{v}_{res}) - \frac{\partial(\theta\, w_{res})}{\partial z^*}}_{G^{\theta}_{\text{advection}}} \underbrace{-(\nabla \cdot \mathbf{F}^{\theta}_{\text{diff}})}_{G^{\theta}_{\text{diffusion}}} + \underbrace{F^{\theta}_{\text{forc}}}_{G^{\theta}_{\text{forcing}}}$$

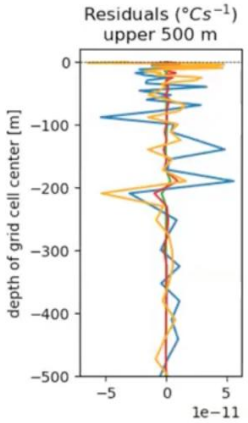
- Evaluated heat budget for one day daily mean, two snapshots
- The residual is essentially zero everywhere

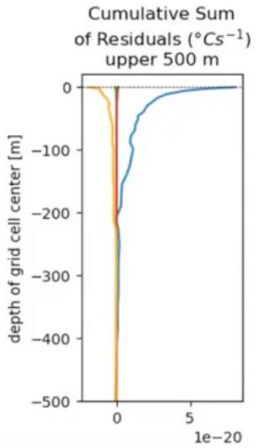












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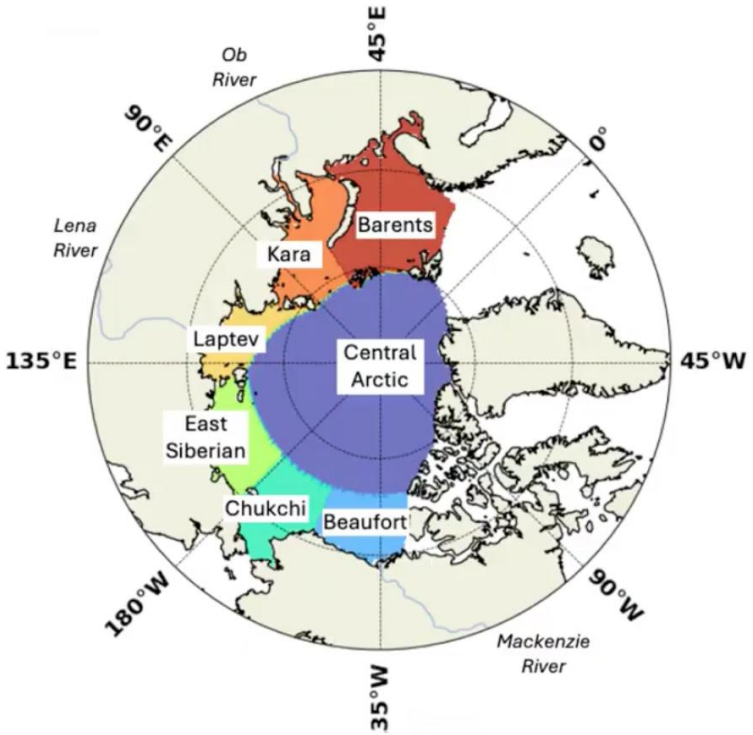
Starting with standard NSIDC masks

Masking out regions



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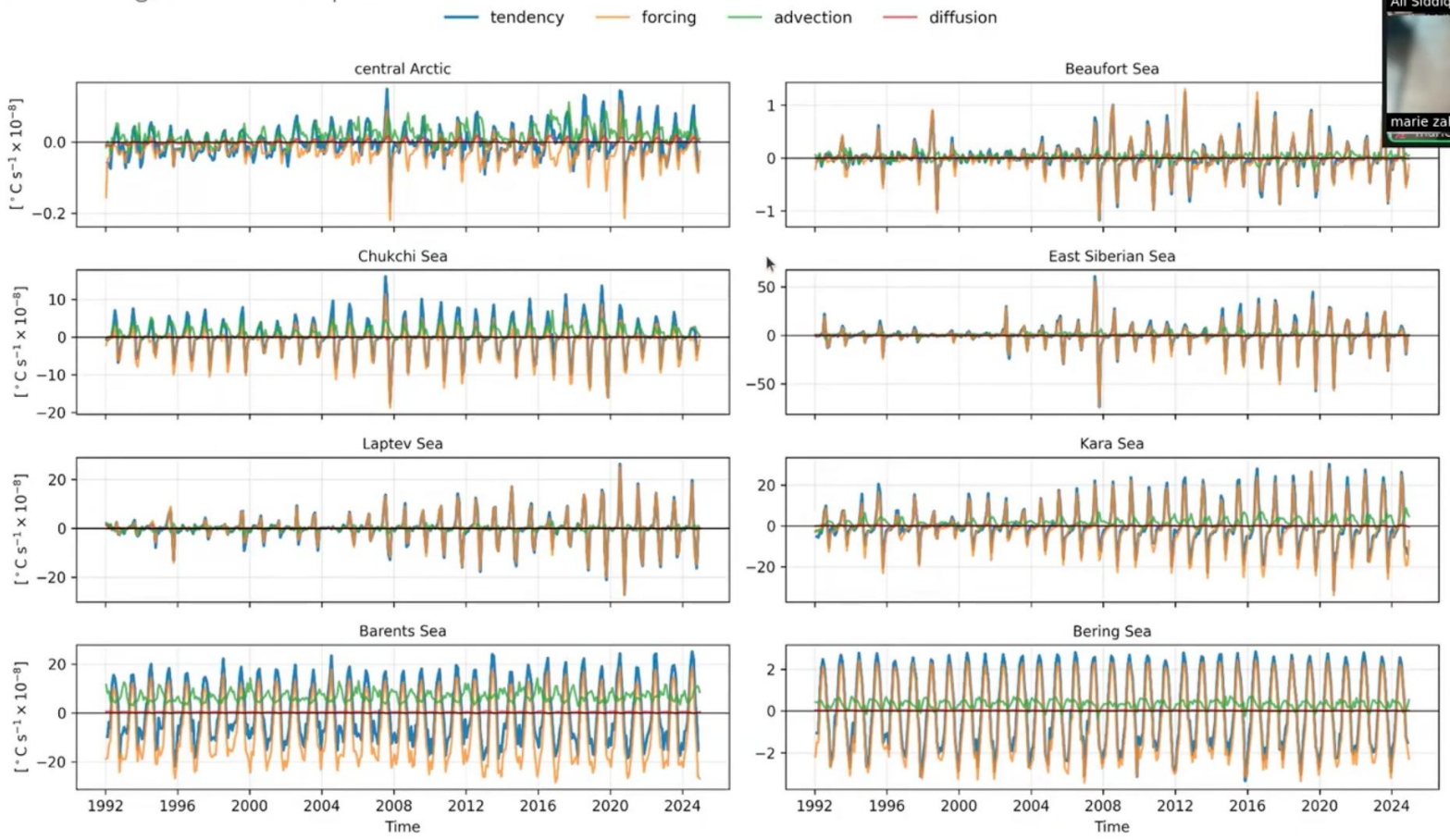
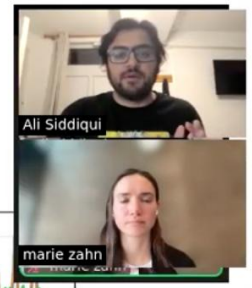
Preliminary Results: Heat budget in the LLC90 simulation

Tendencies averaged over full depth





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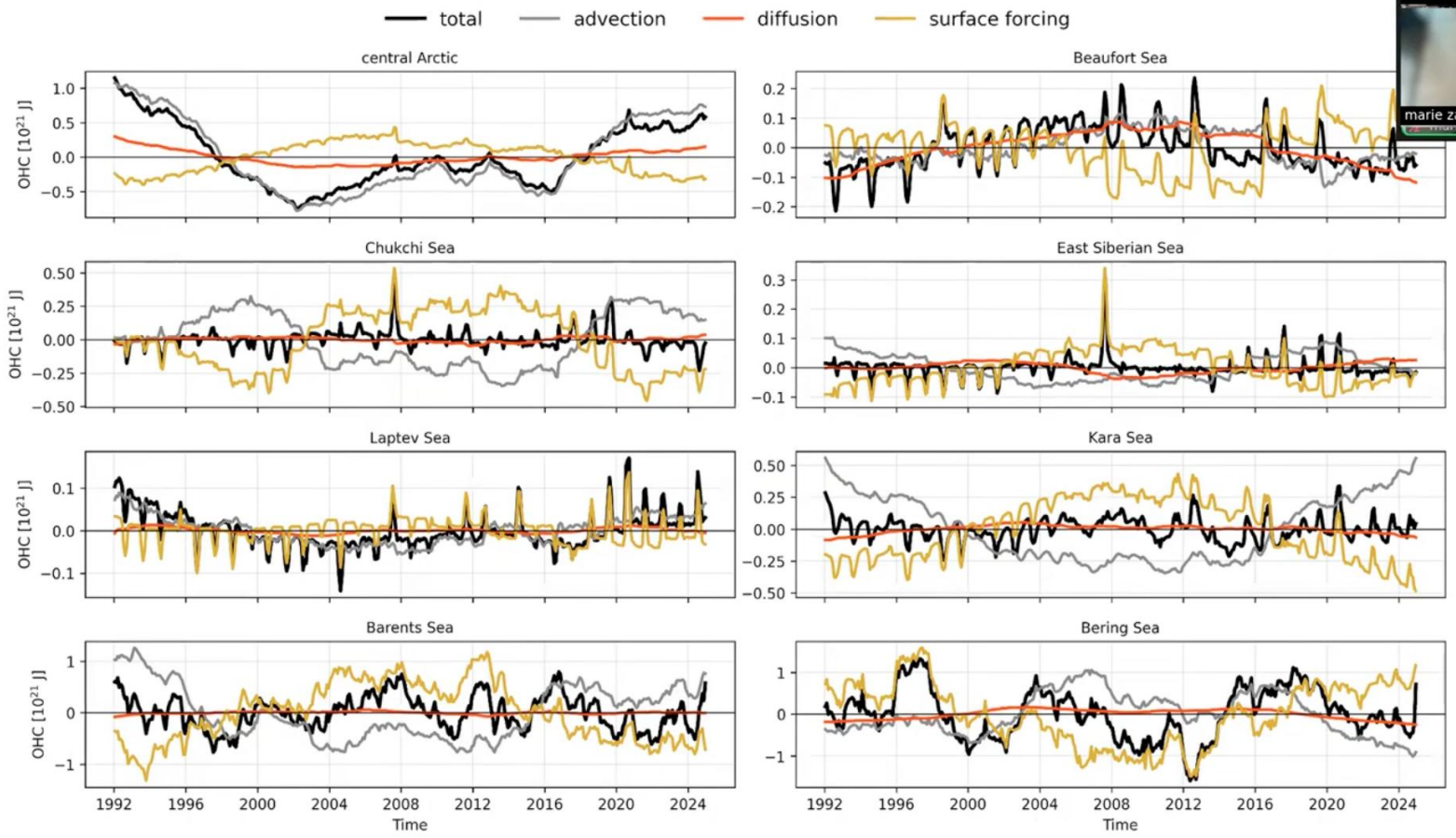
Preliminary Results: Heat budget in the LLC90 simulation

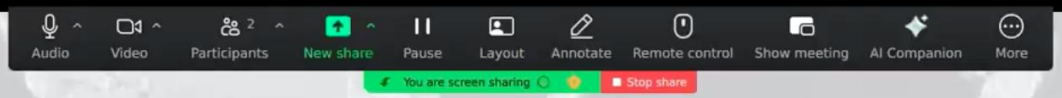
Ocean heat content anomalies, full depth

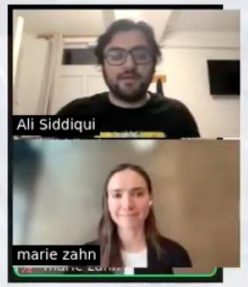


Ongoing/Proposed work

- Quantify heat transport across regional boundaries and gateway sections
- Reynolds decomposition of the transport terms
- Analyze freshwater and sea ice volume budgets
- Build and share a Jupyter notebook for sea ice volume budget

Thank you!





Ideas, suggestions, feedback welcome!

Lets collaborate!

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