



# “Causal Mechanisms of Freshwater Content Change in the Beaufort Sea”



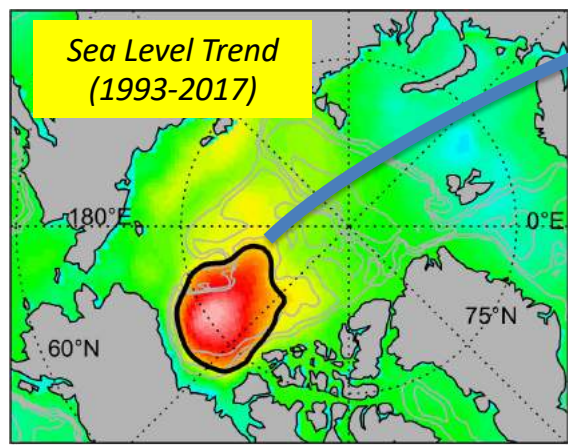
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Jet Propulsion Laboratory, California Institute of Technology

Ocean Salinity Conference 2022  
June 6-9, 2022

Fukumori, I., O. Wang, and I. Fenty, 2021: Causal Mechanisms of Sea-level and Freshwater Content Change in the Beaufort Sea. *J. Phys. Oceanogr.*, **51**, 3217–3234, <https://doi.org/10.1175/jpo-d-21-0069.1>.

# Changes in the Beaufort Sea (1/3)

Sea level has risen dramatically in the Beaufort Sea, accompanied by an increase in freshwater content, heightening the prospect of a major climate anomaly (e.g., *Great Salinity Anomaly* of the 1970s).



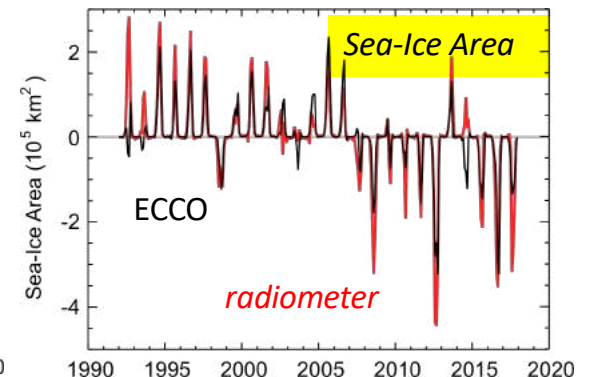
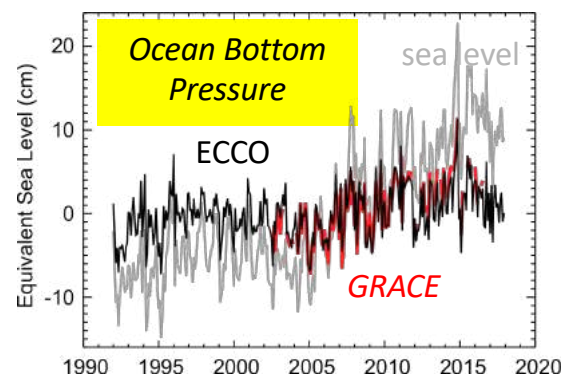
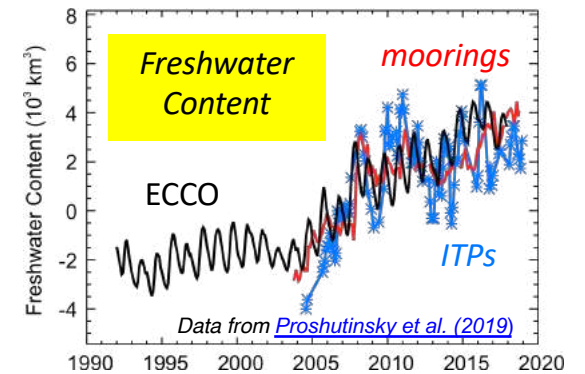
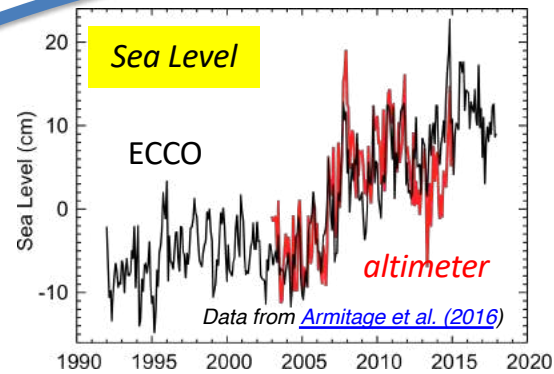
-15 -10 -5 0 5 10 15 (mm/yr)

ECCO ocean & sea-ice model  
(Version 4 release 4)

<https://www.ecco-group.org/>

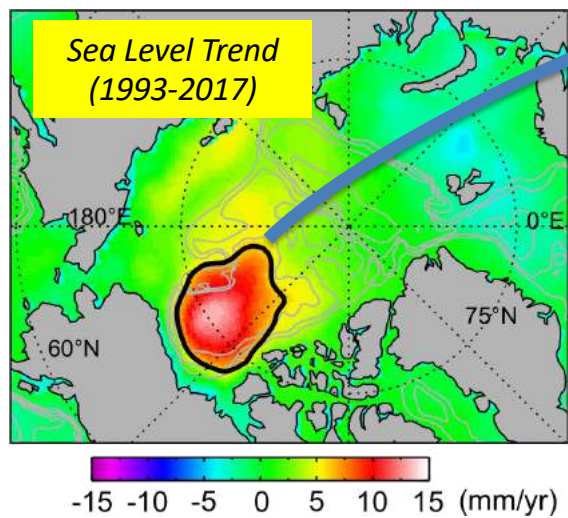


Time-series of "Gyre"-mean quantities



# Changes in the Beaufort Sea (2/3)

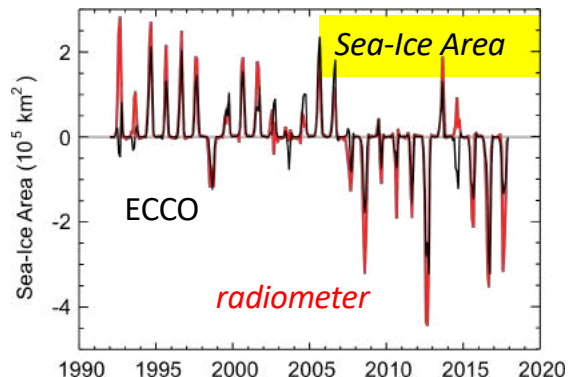
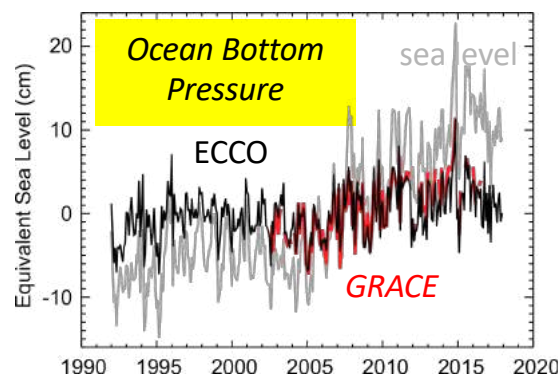
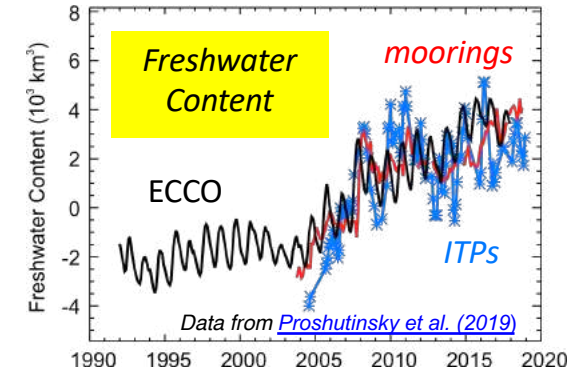
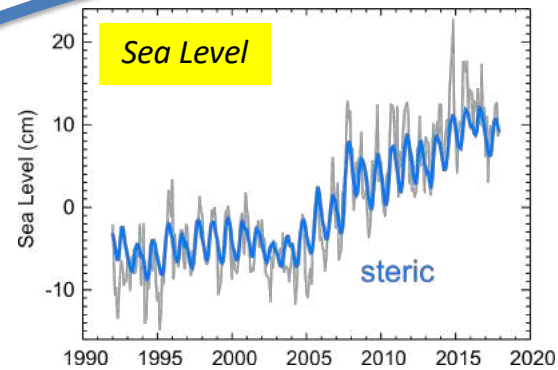
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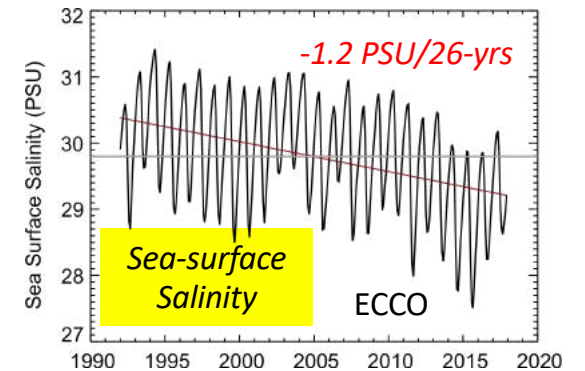
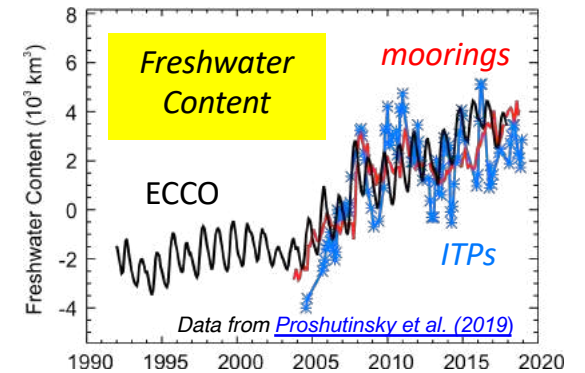
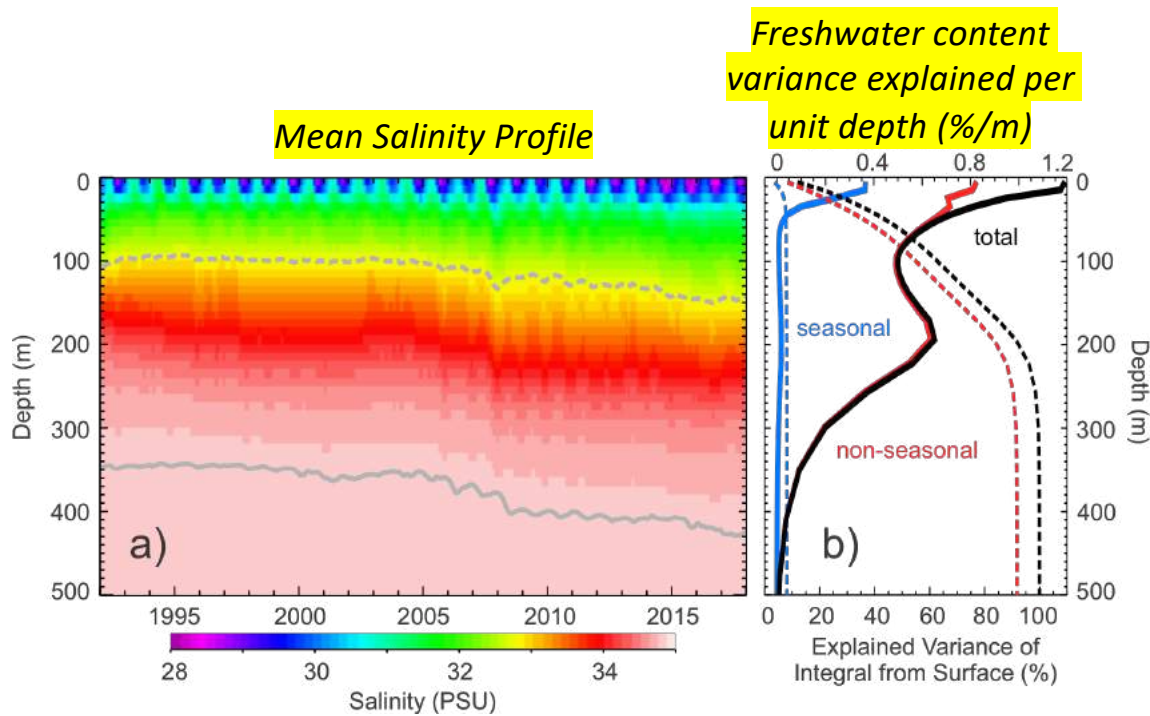
Time-series of "Gyre"-mean quantities



# Changes in the Beaufort Sea (3/3)

Sea level has risen dramatically in the Beaufort Sea, accompanied by an increase in freshwater content, heightening the prospect of a major climate anomaly (e.g., *Great Salinity Anomaly* of the 1970s).

Time-series of "Gyre"-mean quantities



# Wind & Sea-Ice Melt are responsible for the change

## Adjoint Gradient Decomposition & Reconstruction

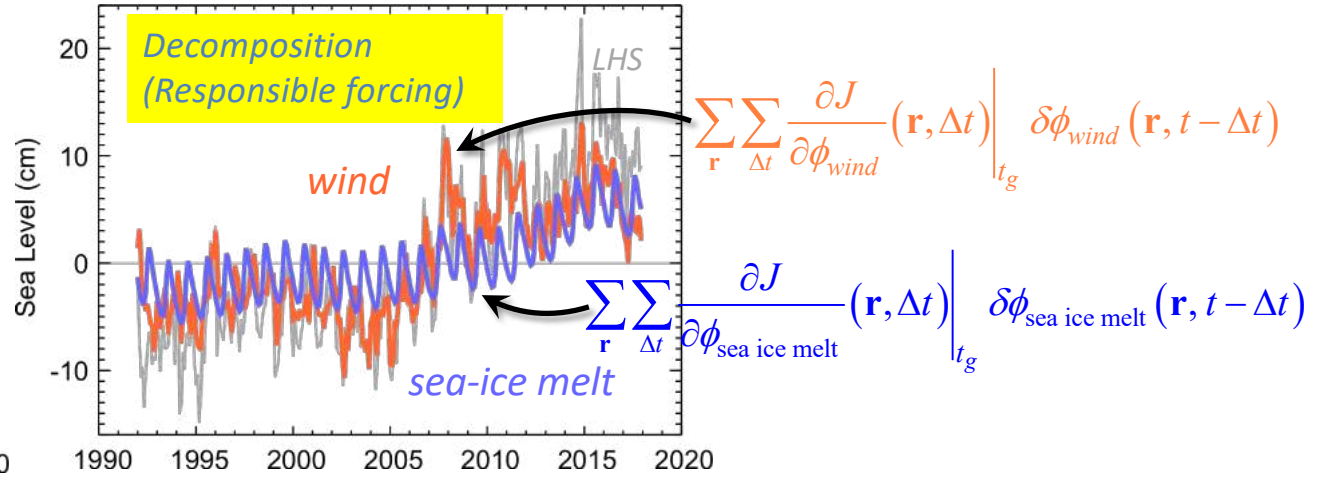
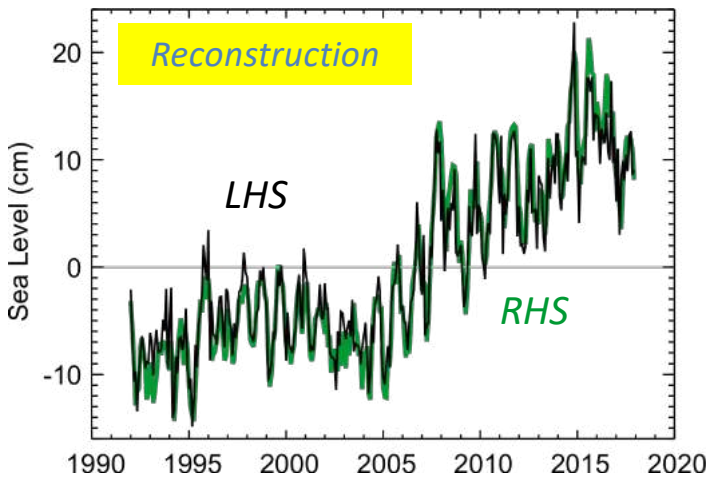
Beaufort Sea mean sea level @ time  $t$

$$J(t) \approx \sum_i \sum_r \sum_{\Delta t} \left. \frac{\partial J}{\partial \phi_i}(\mathbf{r}, \Delta t) \right|_{t_g} \delta \phi_i(\mathbf{r}, t - \Delta t)$$

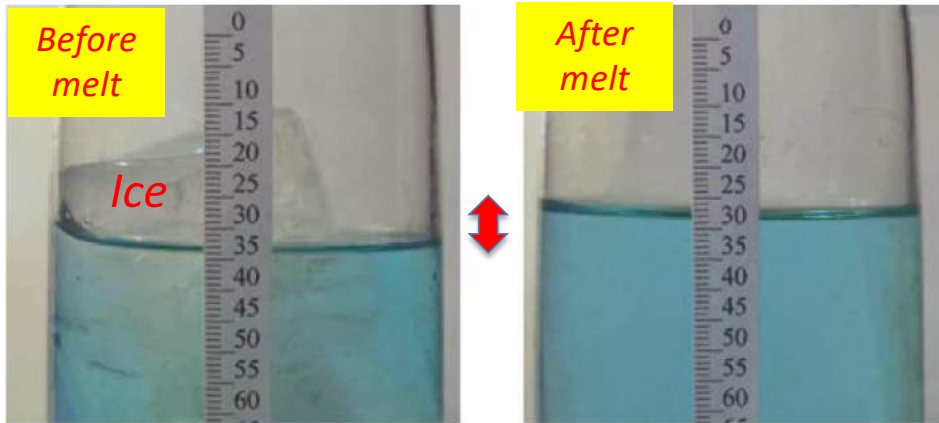
Sensitivity (adjoint gradient) @ location  $r$  and temporal lag  $\Delta t$

forcing  $i$  @ location  $r$  & time  $t - \Delta t$

### Beaufort Sea Mean Sea Level

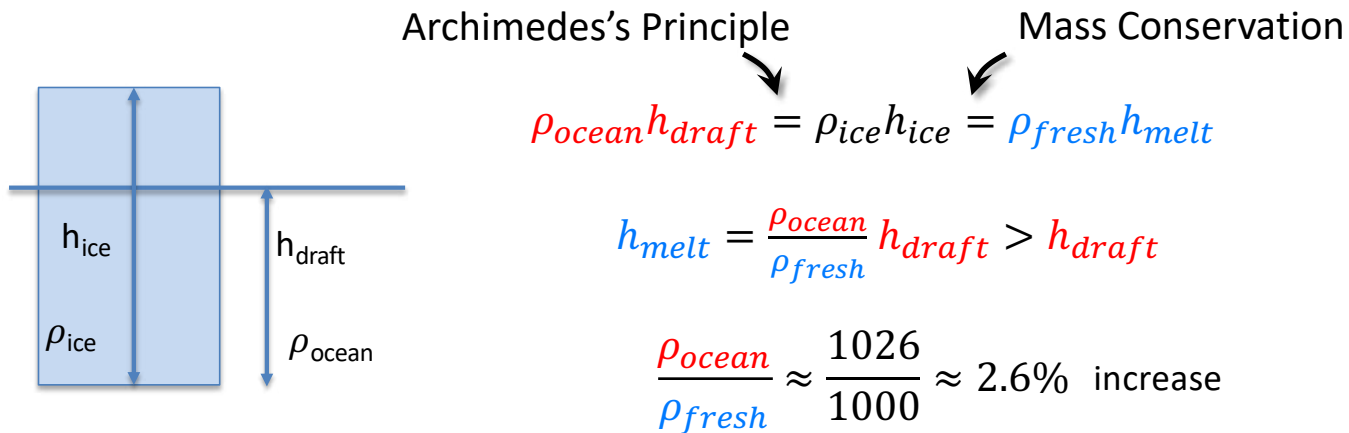


# Sea-Level Rise by Sea-Ice Melt



Noerdlinger & Brower (2007)

Sea-level rises when sea-ice melts because melt-water is lighter than sea-water which Archimedes's Principle does not account for.



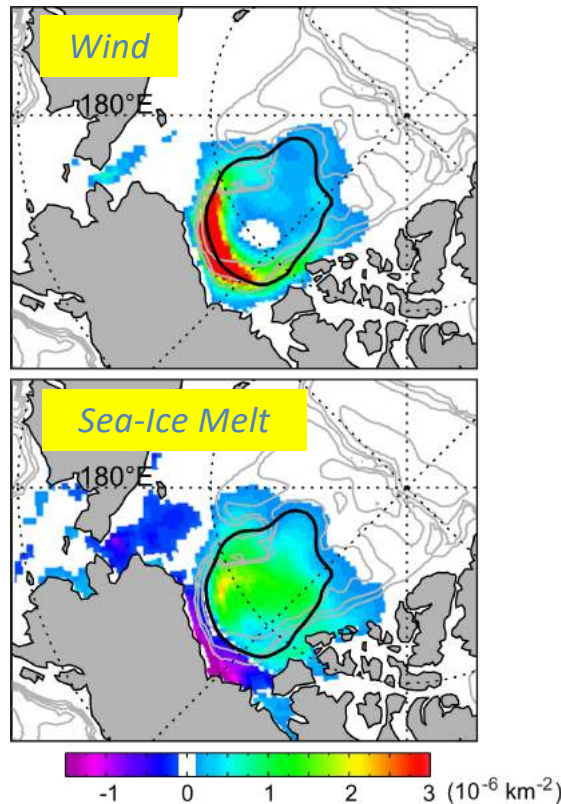
# Where and When do wind and sea-ice melt matter?

Wind-driven Ekman transport from surrounding area and sea-ice melt within the Gyre are responsible for the steric change.

Explained Variance per area

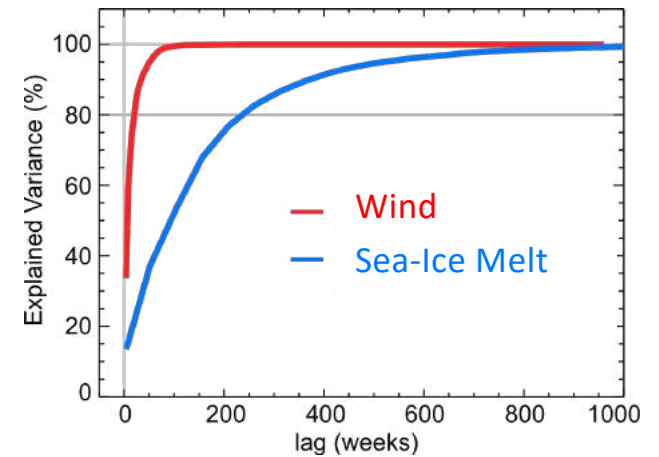
$$E_i(\mathbf{r}) \equiv \frac{1}{dS(\mathbf{r})} \times$$

$$\left[ \frac{\text{var} \left\{ J_{halosteric}(t) - \sum \frac{\partial J}{\partial \phi_i}(\mathbf{r}, \Delta t) \Big|_{t_g} \delta \phi_i(\mathbf{r}, t - \Delta t) \right\}}{\text{var} \{ J_{halosteric}(t) \}} \right]$$

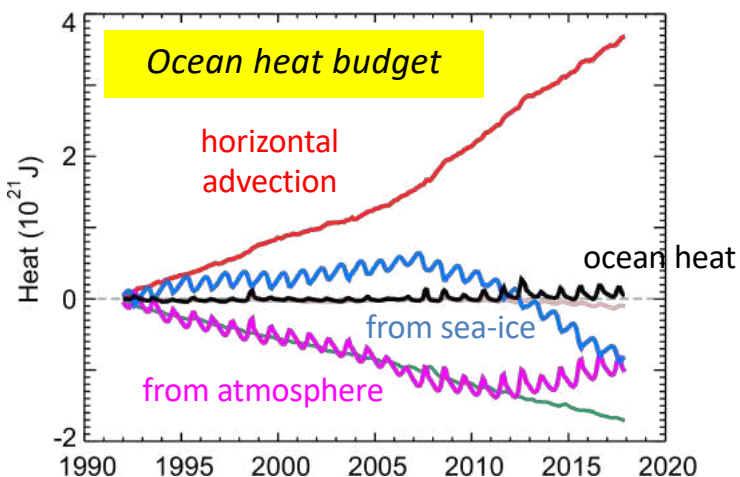
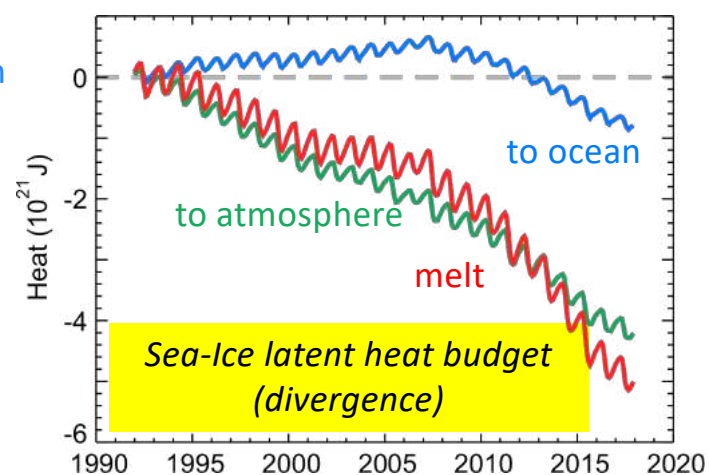
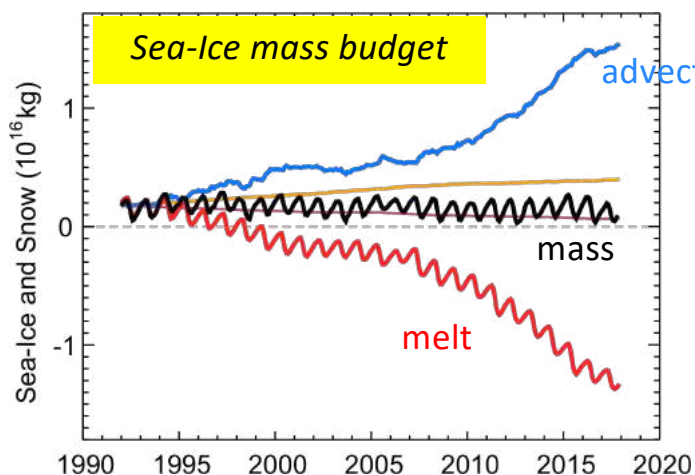


Wind effect only lasts a few months but effect of sea-ice melt lasts years.

Explained Variance (cumulative) vs lag



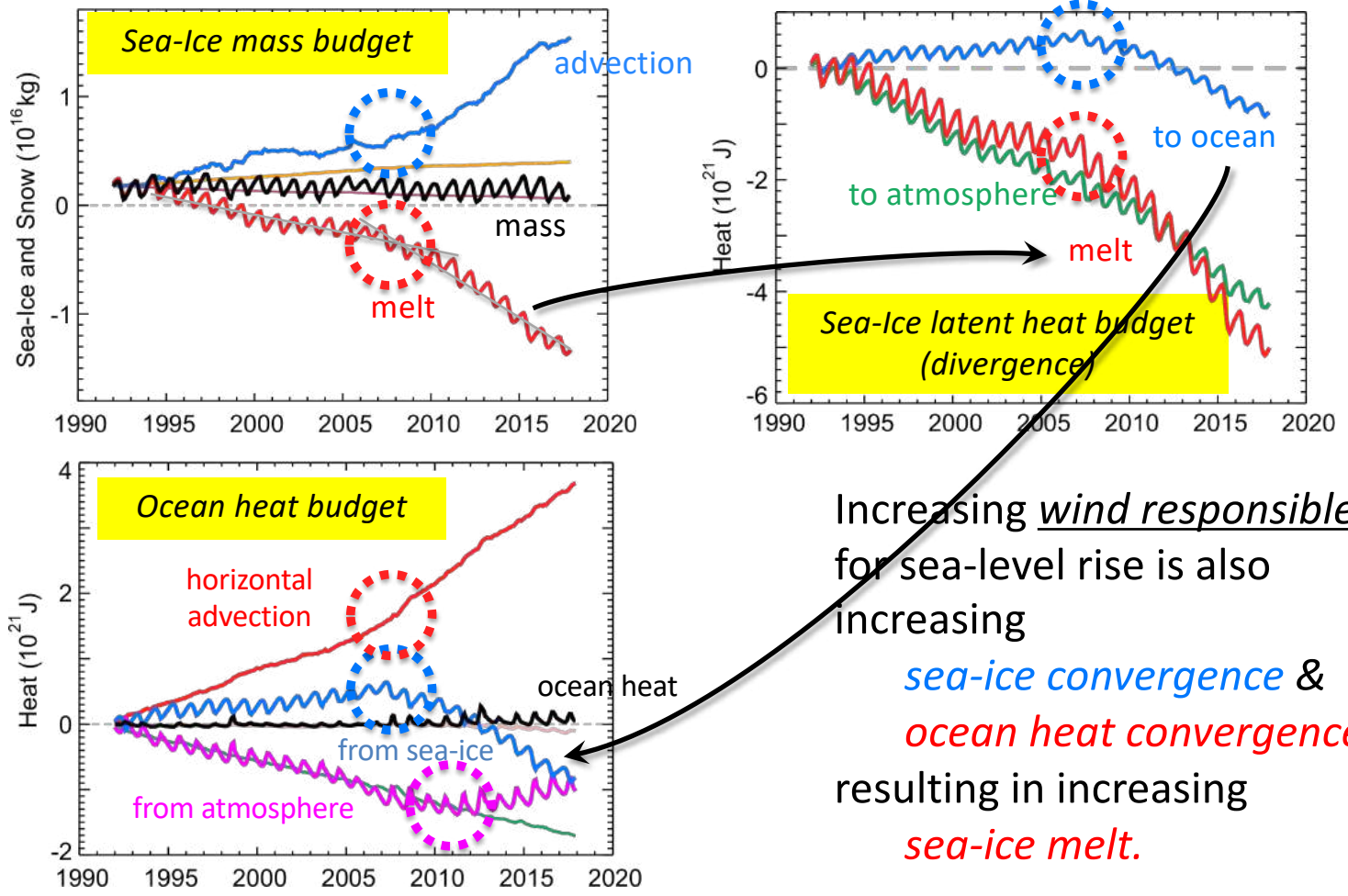
# Why is sea-ice melt increasing in the Beaufort Sea?



Increasing wind responsible for sea-level rise is also increasing  
*sea-ice convergence* &  
*ocean heat convergence*  
 resulting in increasing  
*sea-ice melt.*



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# Summary

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Causal mechanism of Beaufort Sea's freshwater content change;

- 1) Seasonal change reflects **sea-ice melt**,
- 2) Inter-annual variations are caused by **wind-driven** Ekman transport,
- 3) At decadal time-scale, **sea-ice melt** becomes as important as direct **wind-driven** Ekman change,
- 4) The **sea-ice melt** at decadal time-scale is itself also **wind-driven**.