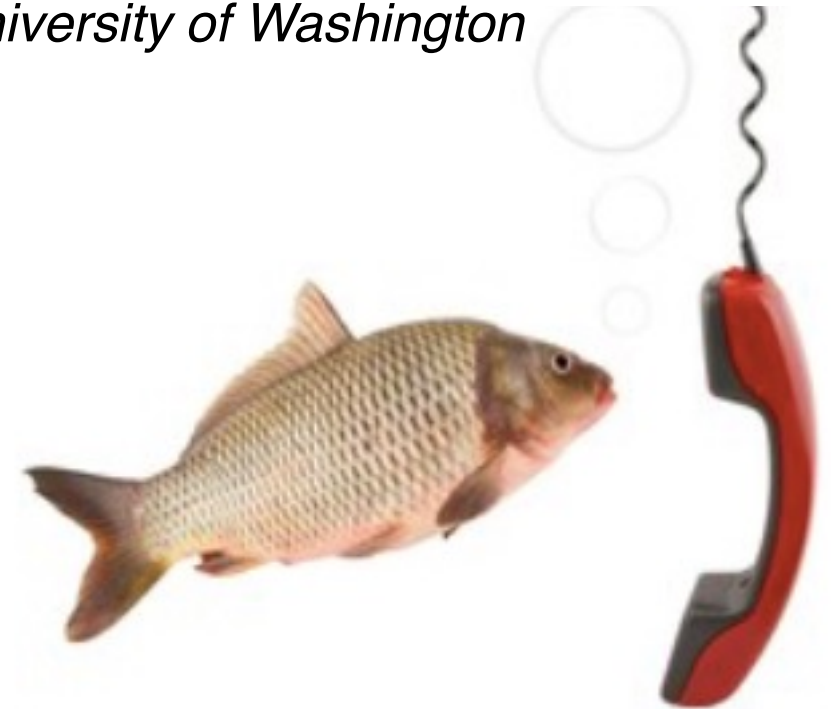


# Does the **subsurface** Arctic Ocean know what's happening at the **surface**?

**Michael Steele** & collaborators

*Polar Science Center, Applied Physics Lab, University of Washington  
Seattle, WA USA*



# Does the **subsurface** Arctic Ocean know what's happening at the **surface**?

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Seattle, WA USA*



**Wenli Zhong**  
*Ocean U of China*



# Does the **subsurface** Arctic Ocean know what's happening at the **surface**?

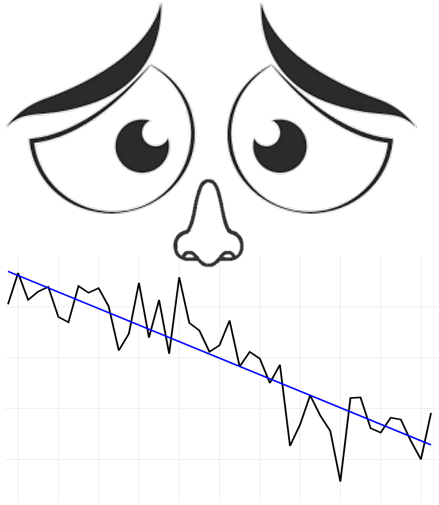
**Michael Steele** & collaborators

*Polar Science Center, Applied Physics Lab, University of Washington  
Seattle, WA USA*

**Upper ~ 300 m**



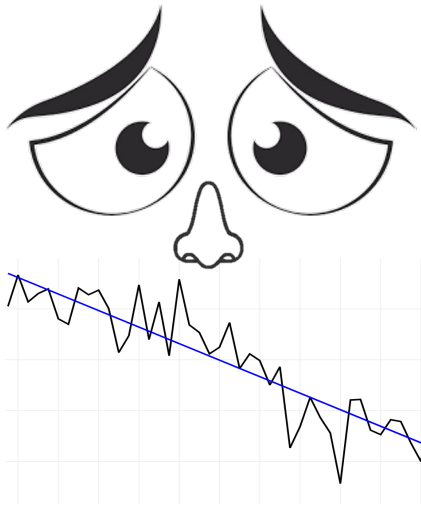
# Ice Retreat



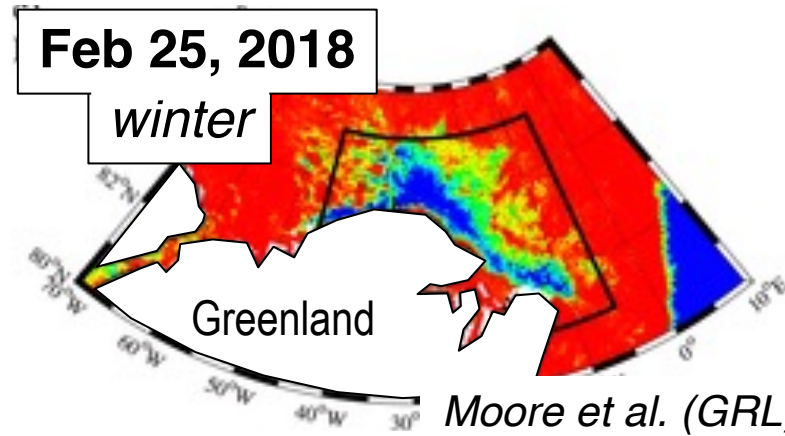
Sept. Arctic Sea Ice Extent  
(1979-2021, NSIDC)



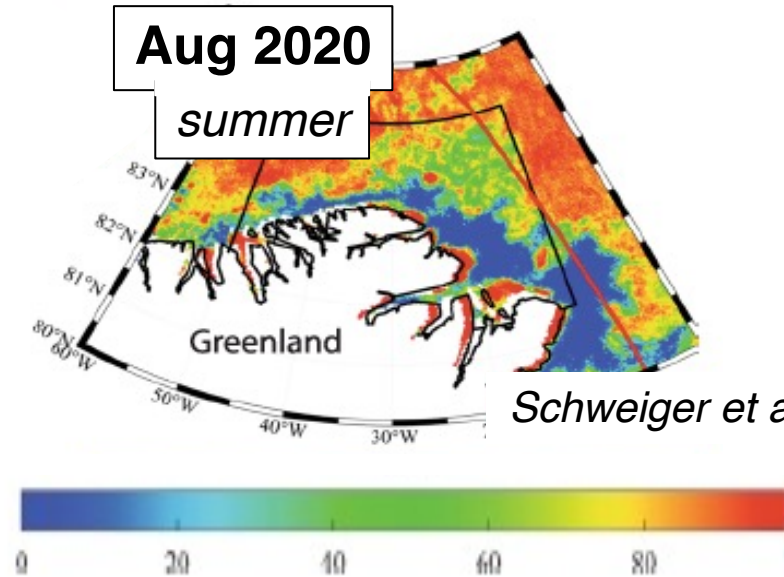
# Ice Retreat



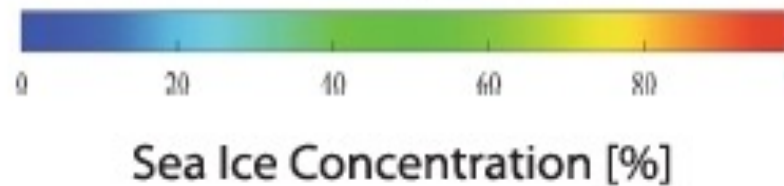
Sept. Arctic Sea Ice Extent  
(1979-2021, NSIDC)



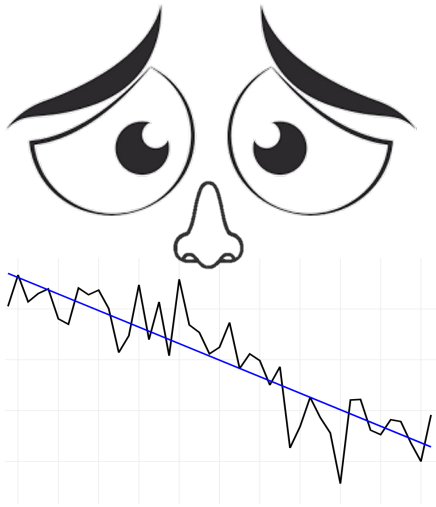
**Ice loss even  
north of Greenland!**



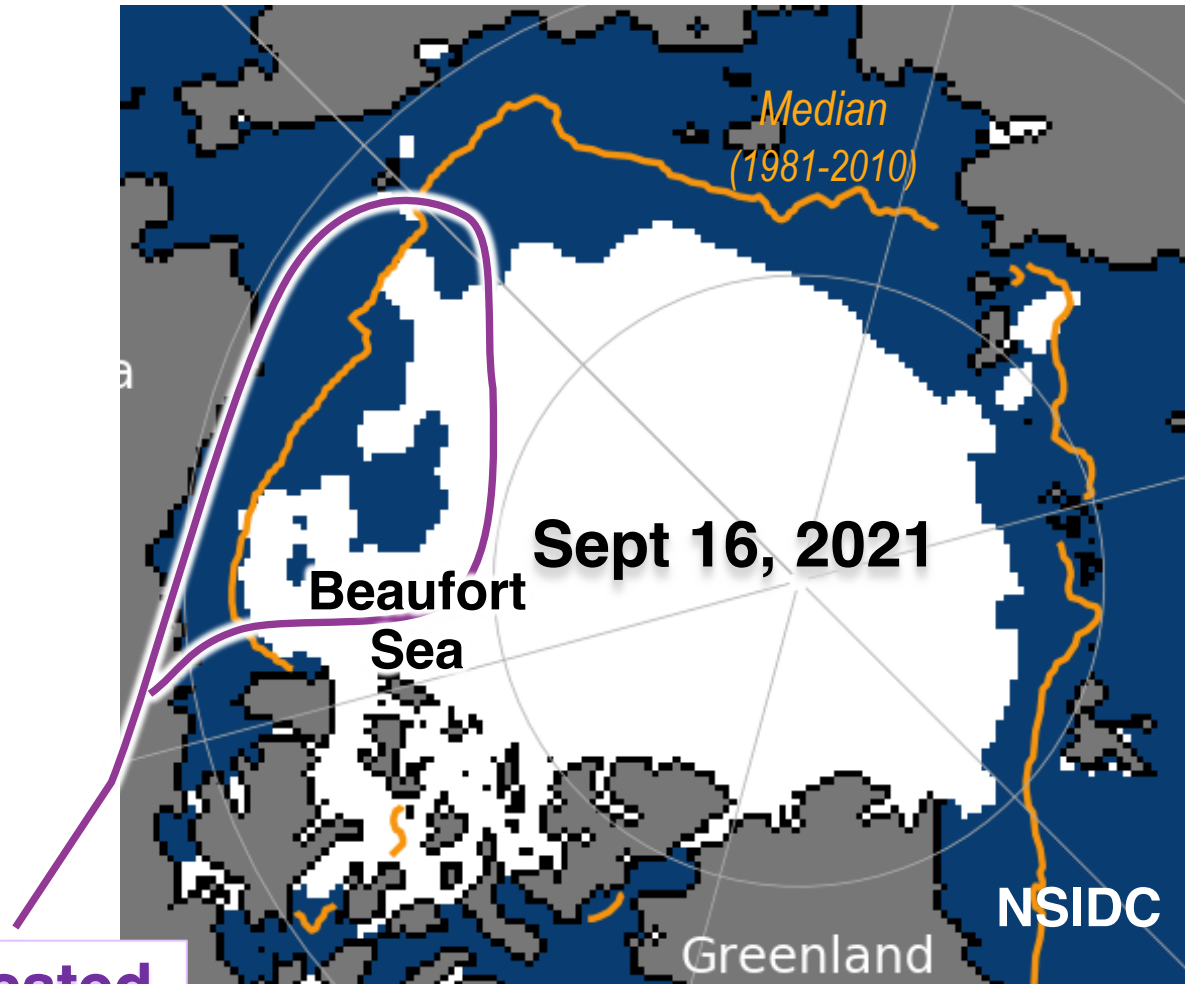
later today:  
**Axel Schweiger's talk**



# Ice Change



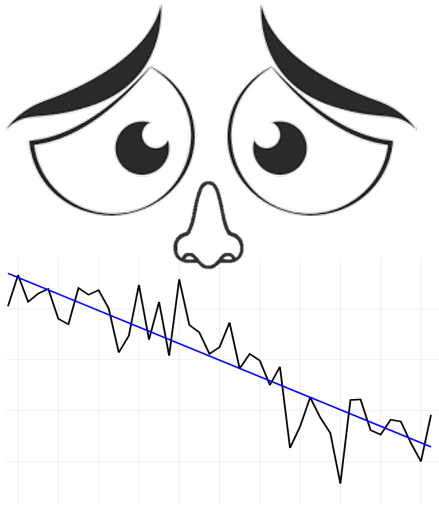
Sept. Arctic Sea Ice Extent  
(1979-2021, NSIDC)



Complicated  
2D geometry!

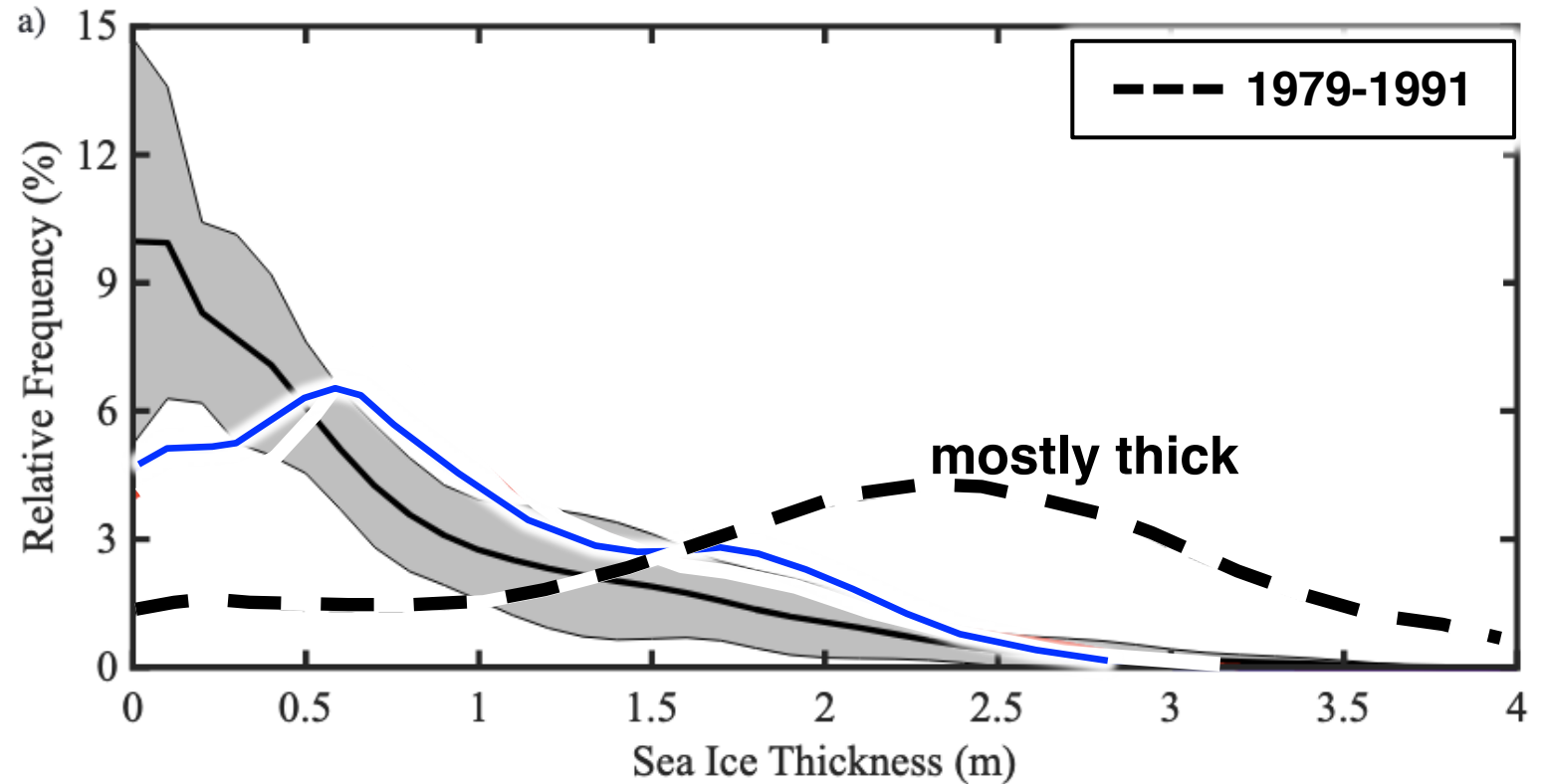


# Ice Change



Sept. Arctic Sea Ice Extent  
(1979-2021, NSIDC)

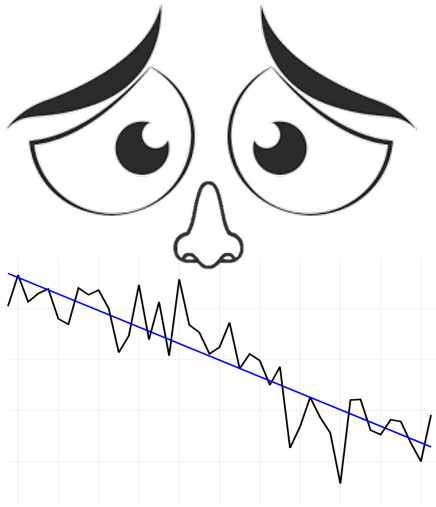
## Beaufort summer (JAS) sea ice thickness distribution (PIOMAS)



Moore et al. (Nature CE&E, 2022, in review)

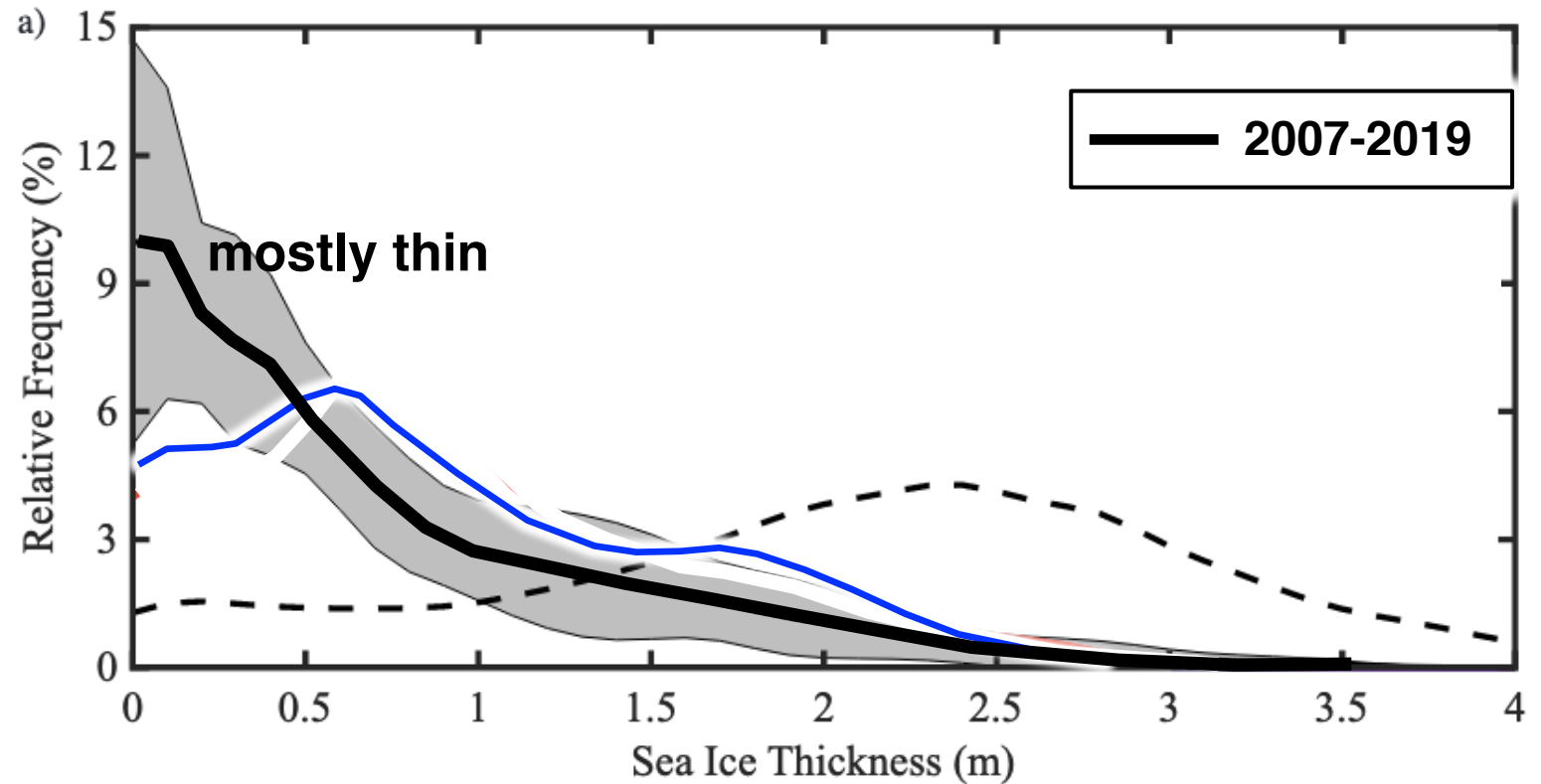


# Ice Change



Sept. Arctic Sea Ice Extent  
(1979-2021, NSIDC)

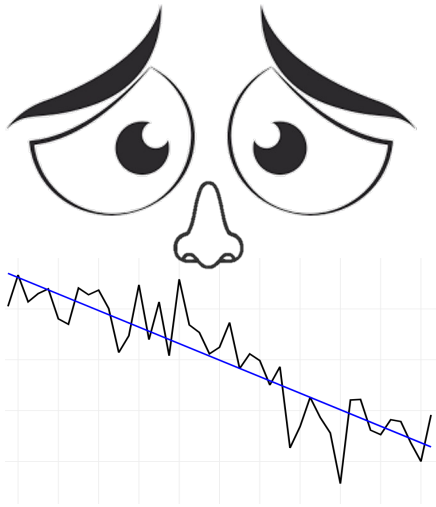
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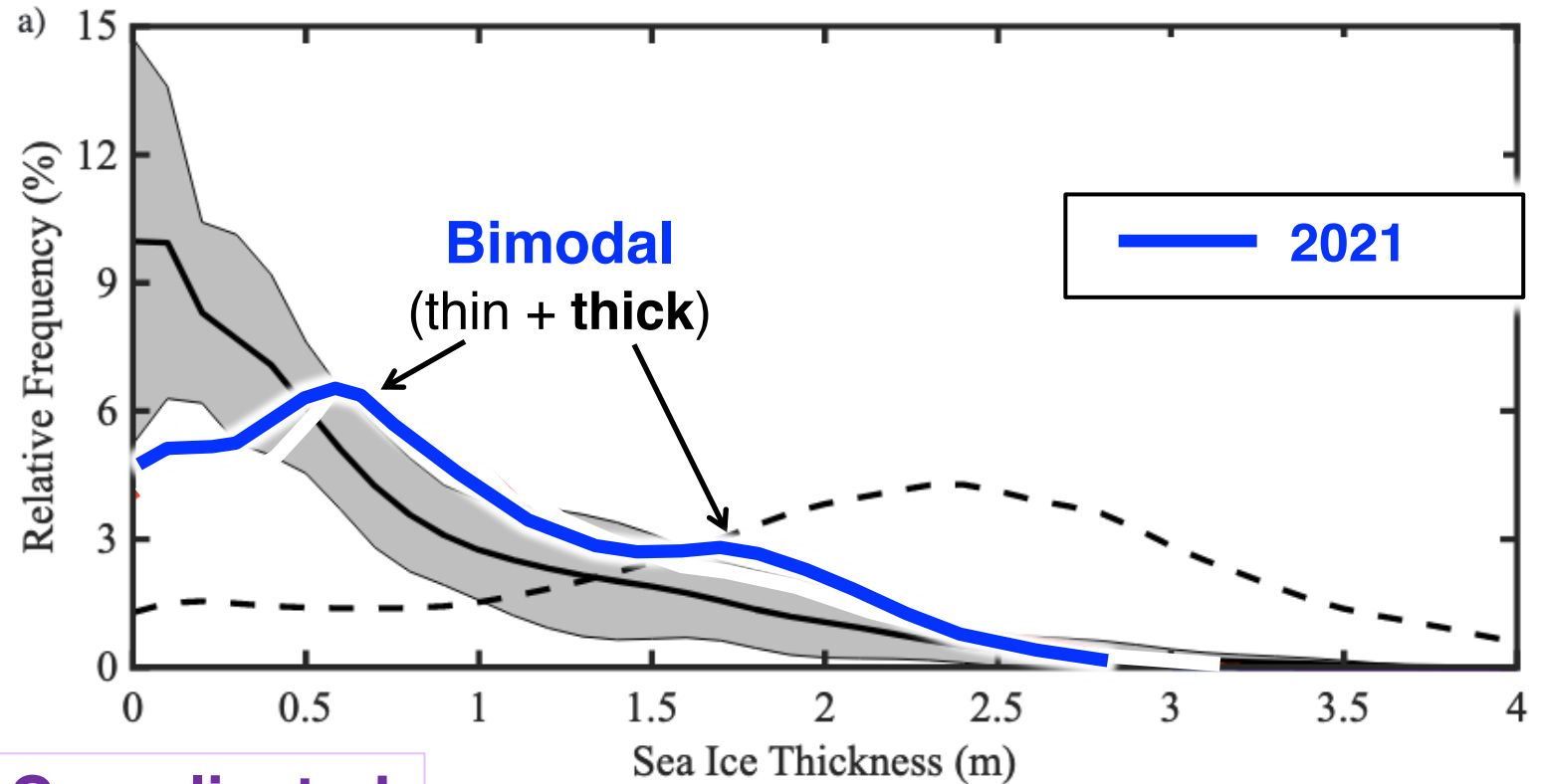


# Ice Change



Sept. Arctic Sea Ice Extent  
(1979-2021, NSIDC)

## Beaufort summer (JAS) sea ice thickness distribution (PIOMAS)



Complicated  
3D geometry!

Moore et al. (Nature CE&E, 2022, in review)

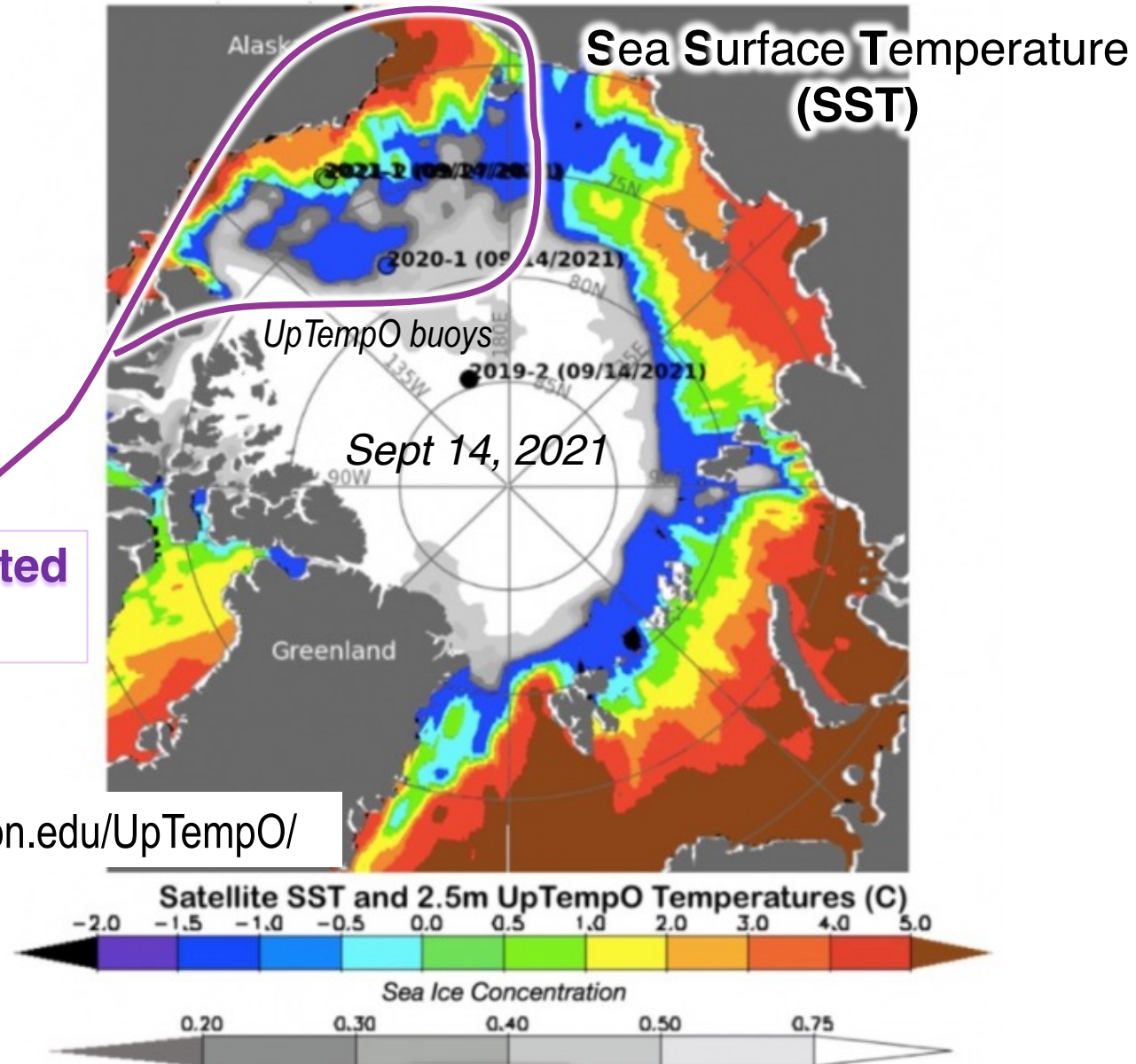
# Ocean surface warming



Complicated  
2D geometry!

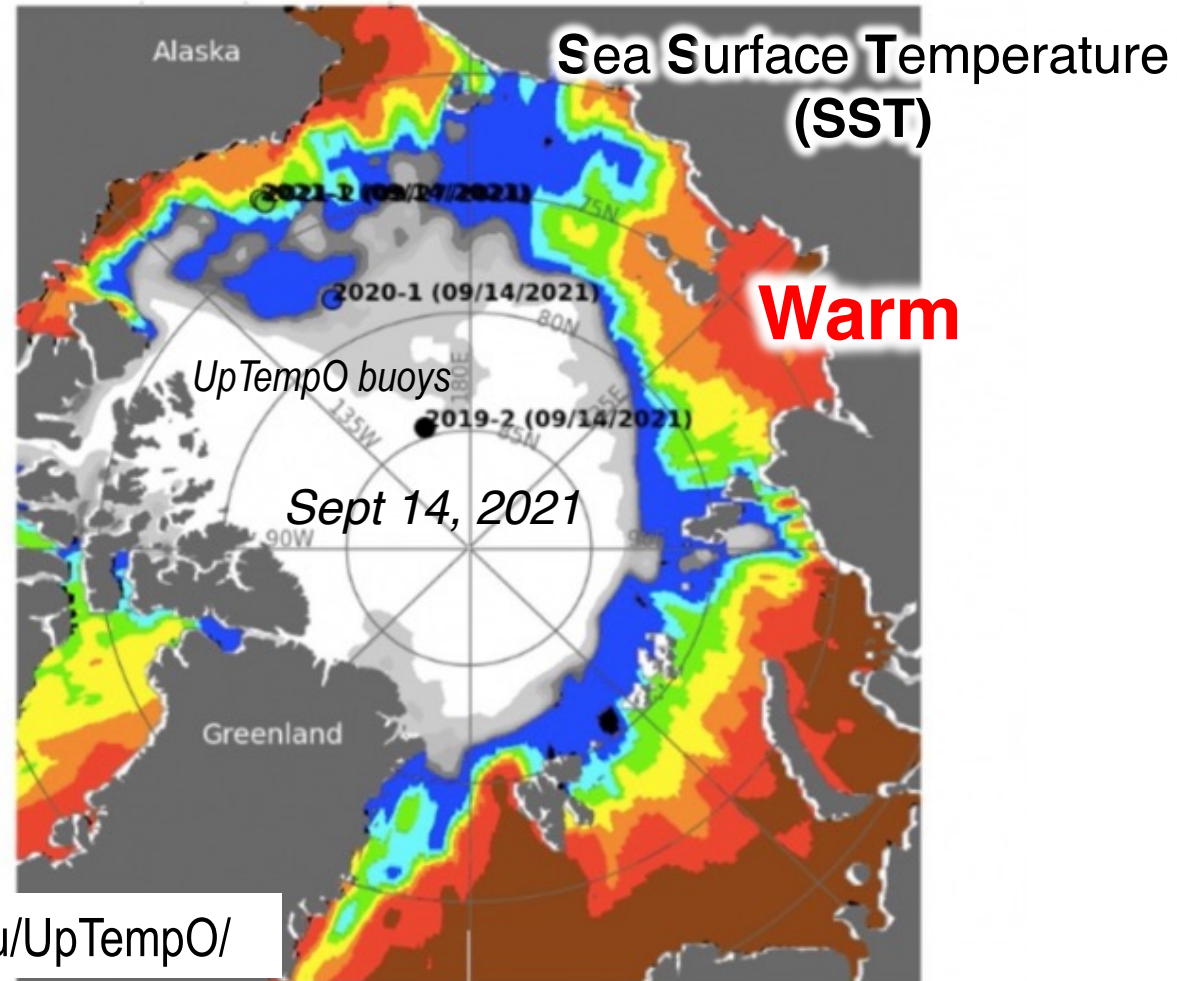
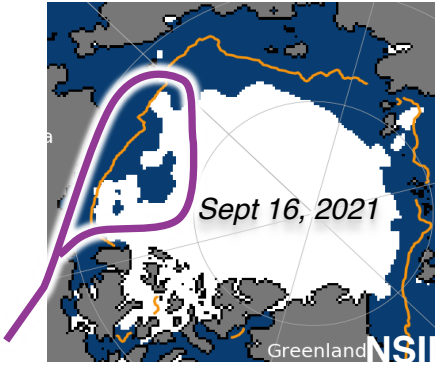
Complicated  
SST!

<http://psc.apl.washington.edu/UpTempO/>

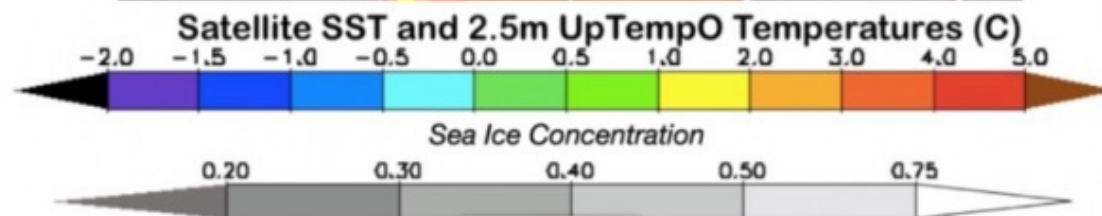




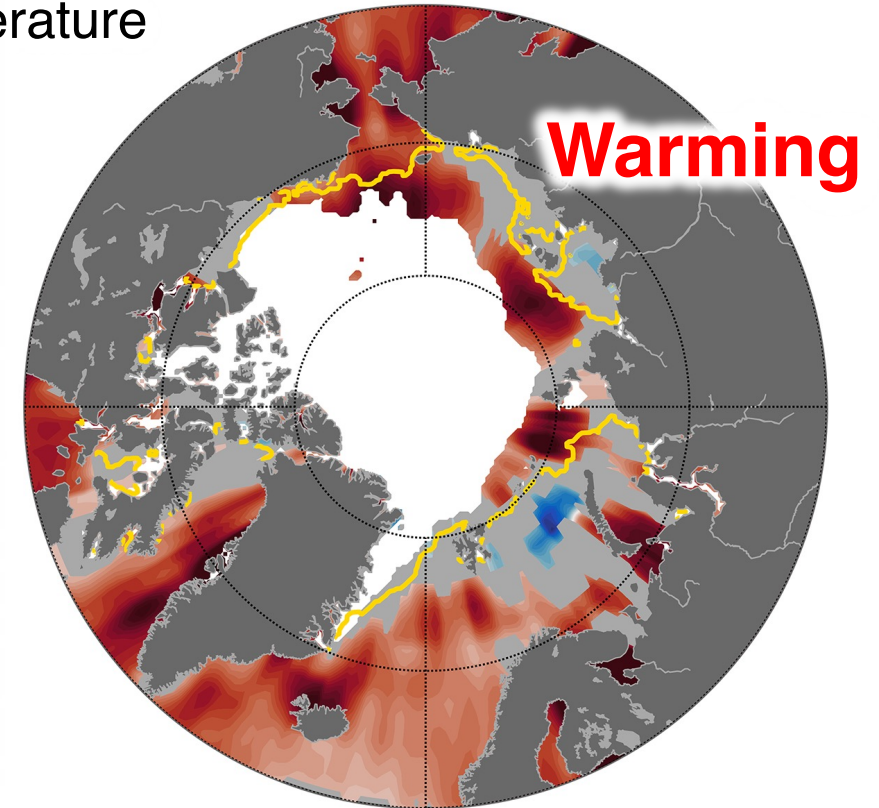
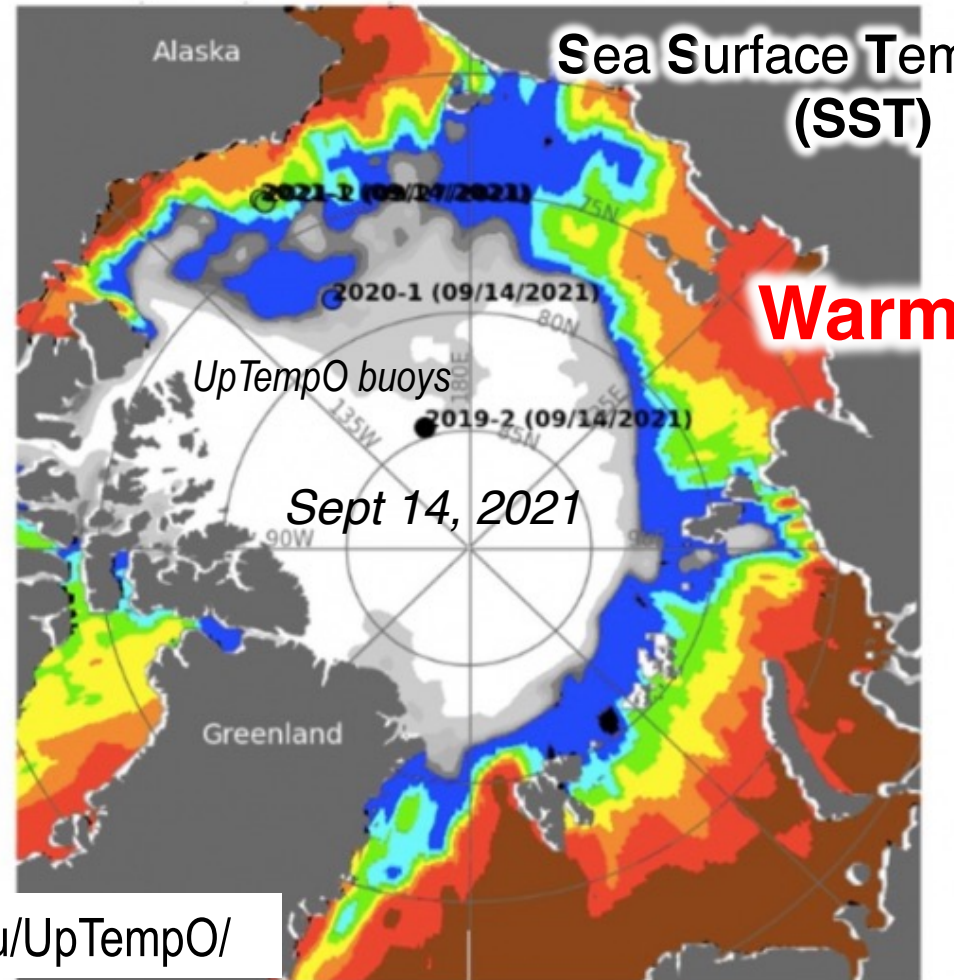
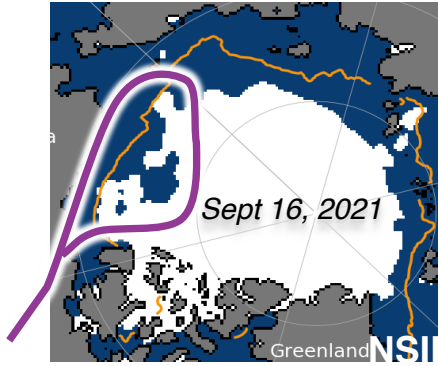
# Ocean surface warming



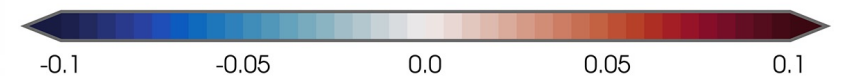
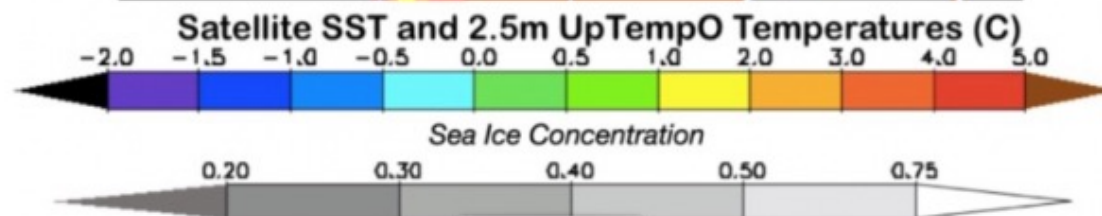
<http://psc.apl.washington.edu/UpTempO/>



# Ocean surface warming



<http://psc.apl.washington.edu/UpTempO/>



1982-2020 Aug. SST trend (°C/yr)

*Timmermans & Labe (NOAA, 2020)*

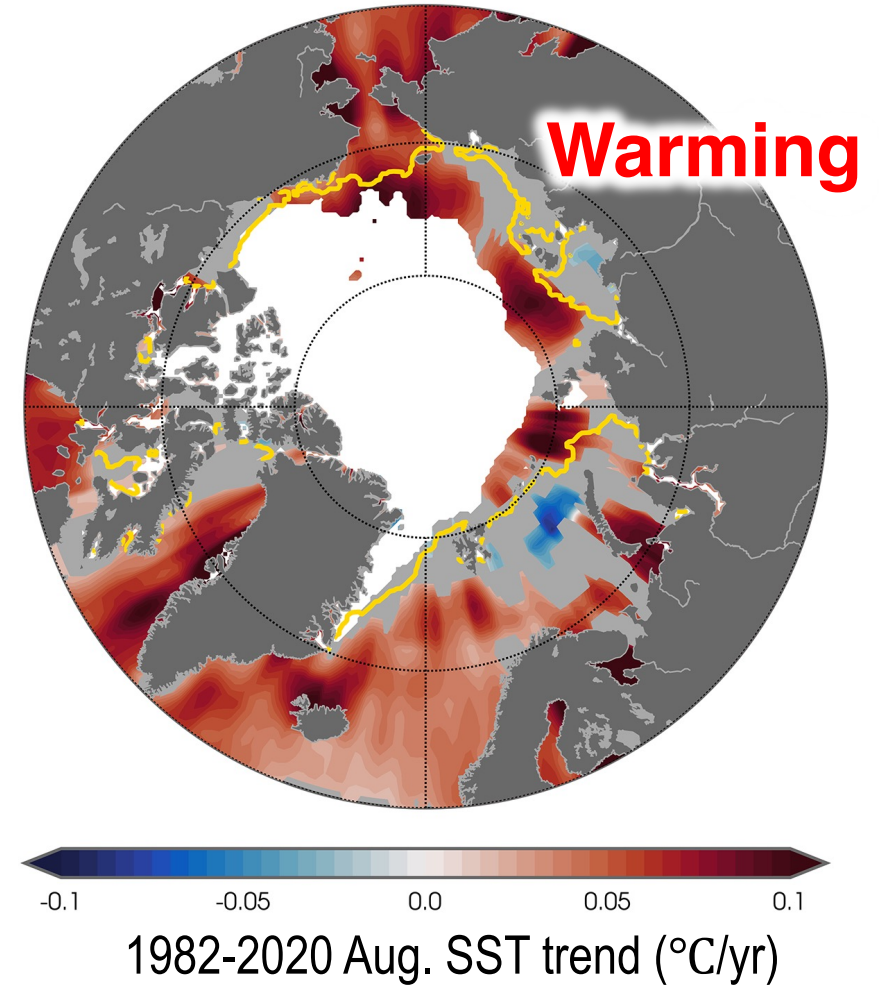


# Ocean surface warming



How much of this is due to:

- Global **warming** vs.
- Internal climate **variability**?



# Ocean surface warming

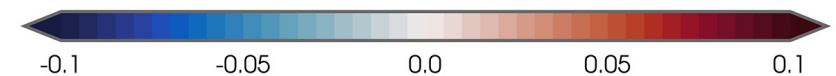
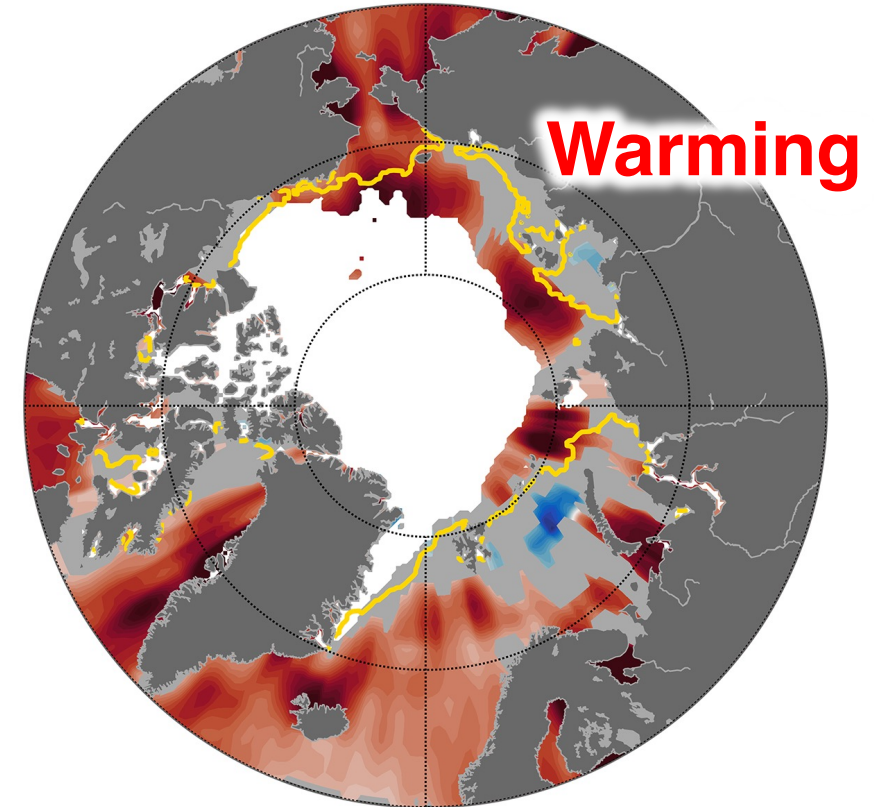
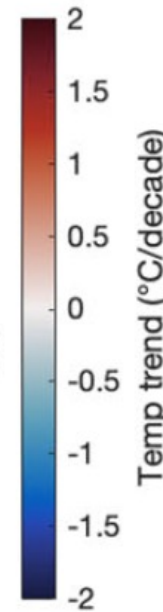
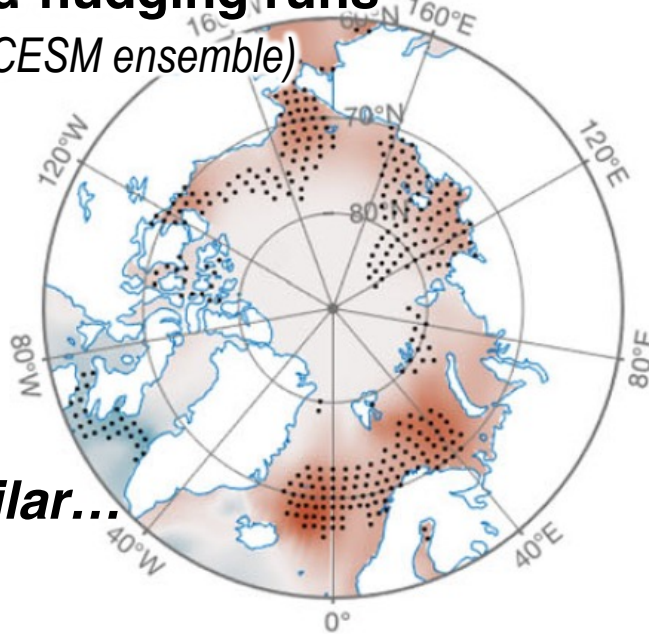
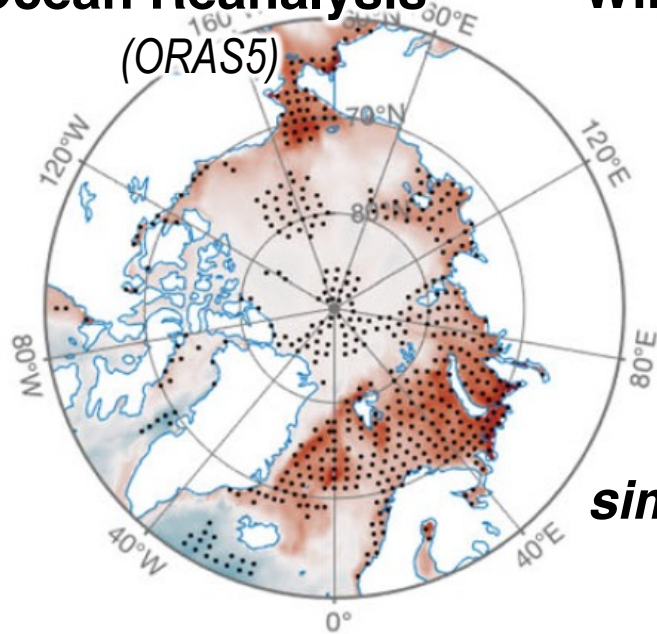


$$dT_{0-50\text{ m}}/dt \text{ (2000-2018)}$$

Ocean Reanalysis  
(ORAS5)

Wind-nudging runs  
(CESM ensemble)

similar...



1982-2020 Aug. SST trend (°C/yr)

Li et al. (Nature Comm., 2022)

Incr. **SLP**

→ incr. **F<sub>solar</sub>**

→ **warming** upper ocean



# Ocean surface warming



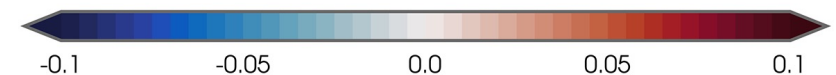
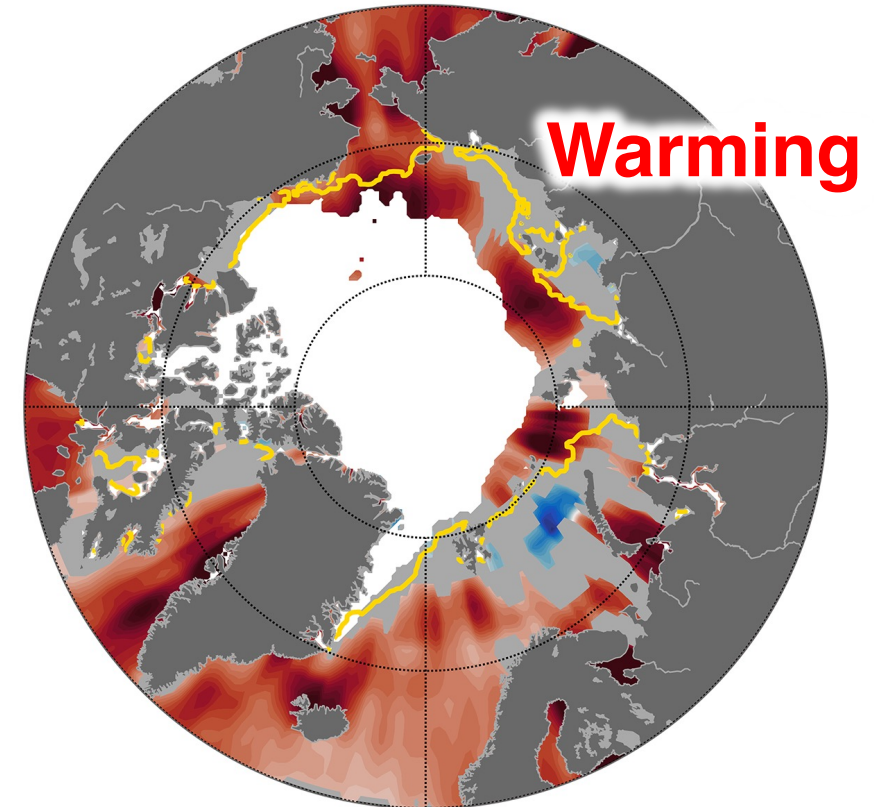
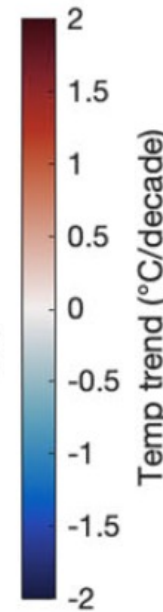
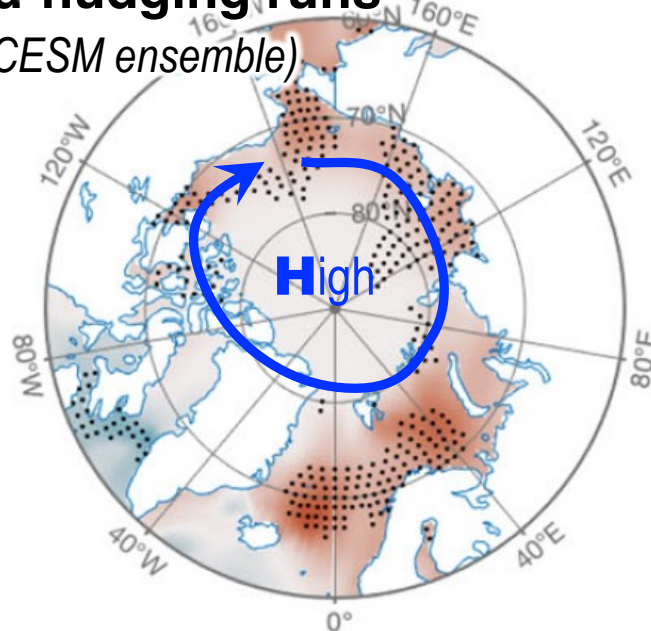
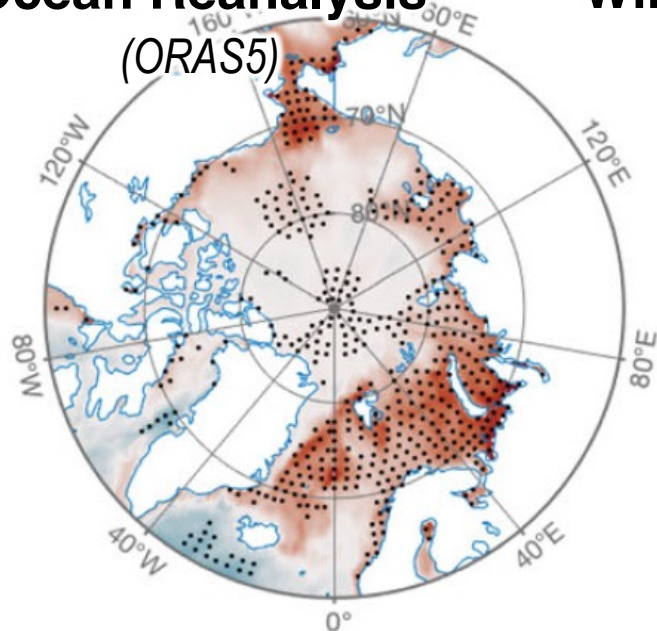
$$dT_{0-50\text{ m}}/dt \text{ (2000-2018)}$$

Ocean Reanalysis

(ORAS5)

Wind-nudging runs

(CESM ensemble)



1982-2020 Aug. SST trend (°C/yr)

Li et al. (Nature Comm., 2022)

Incr. **SLP**

→ incr. **F<sub>solar</sub>**

→ **warming** upper ocean

**60%** from internal climate variability!

(vs. global warming)

# Ocean surface warming



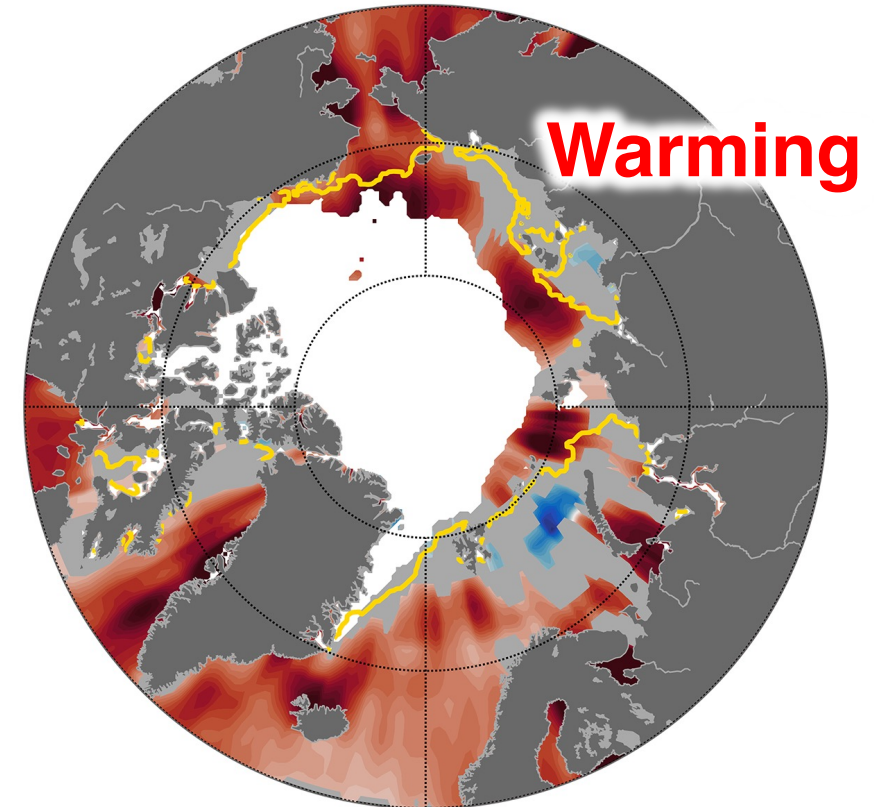
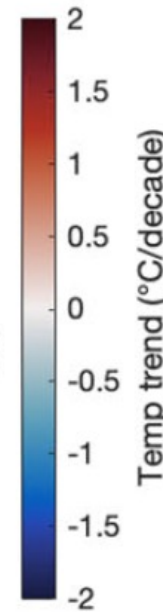
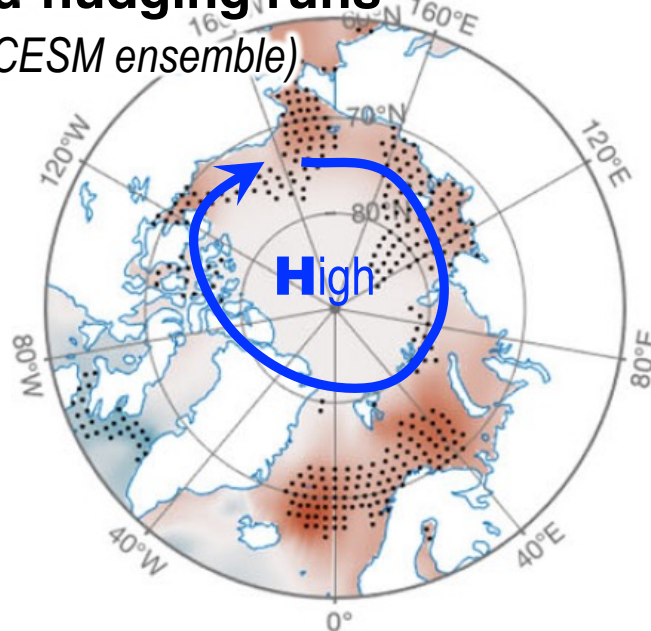
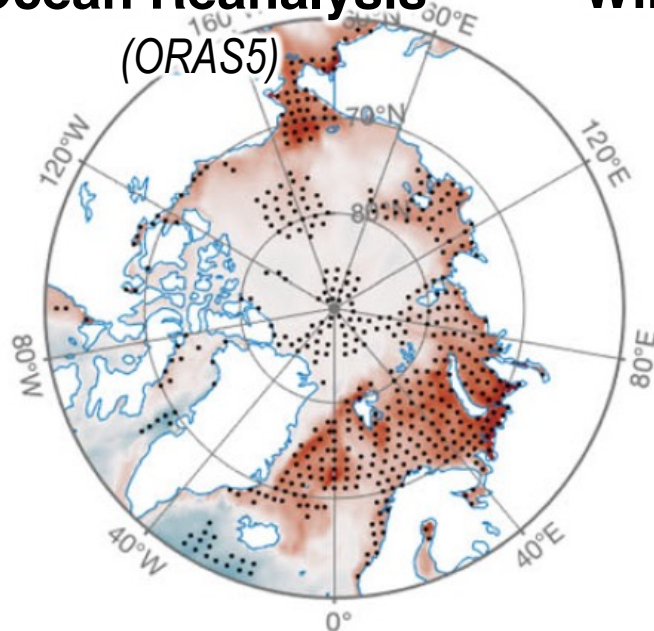
$$dT_{0-50\text{ m}}/dt \text{ (2000-2018)}$$

Ocean Reanalysis

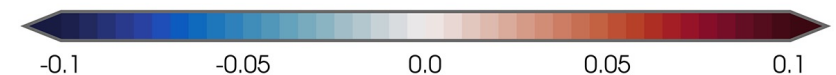
(ORAS5)

Wind-nudging runs

(CESM ensemble)



**Warming**



1982-2020 Aug. SST trend (°C/yr)

Li et al. (Nature Comm., 2022)

Incr. **SLP**

→ incr. **F<sub>solar</sub>**

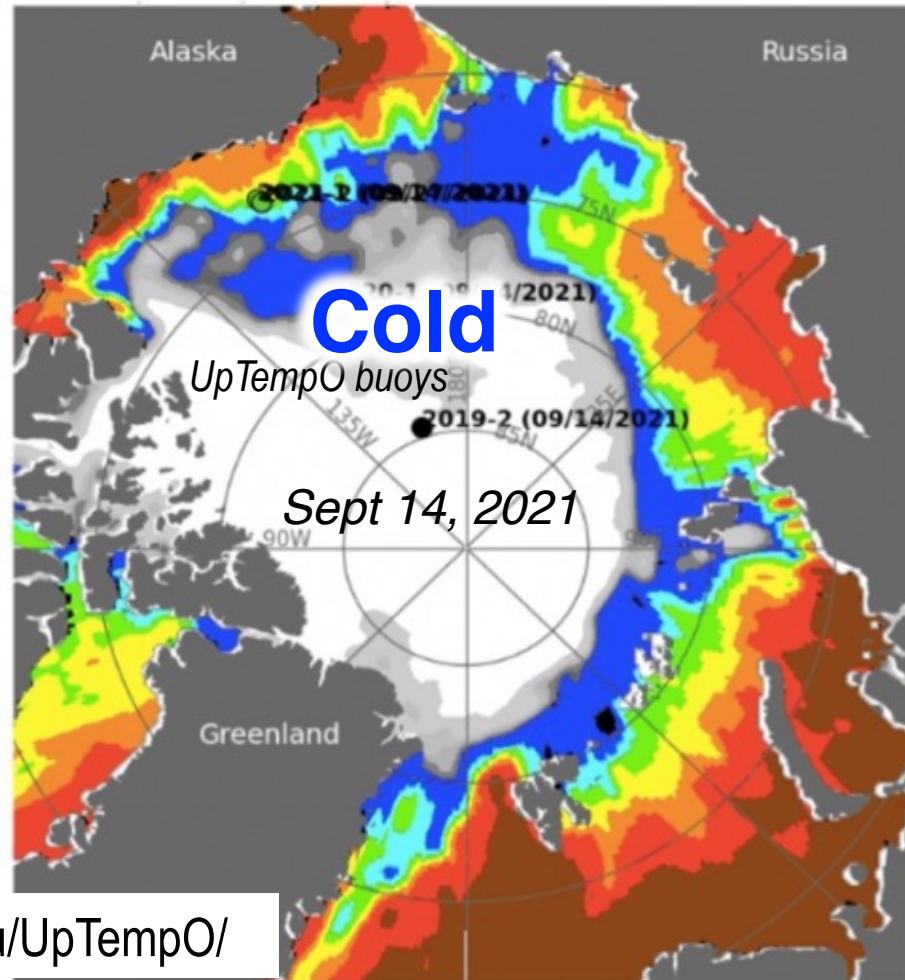
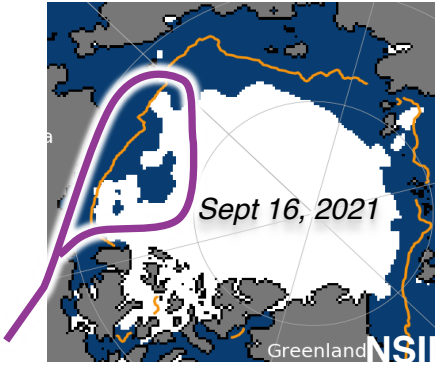
→ **warming** upper ocean

**60%** from internal climate variability!  
(vs. global warming)

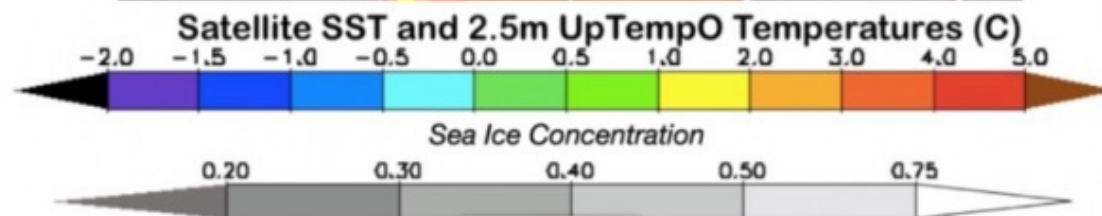
*...so it could change*



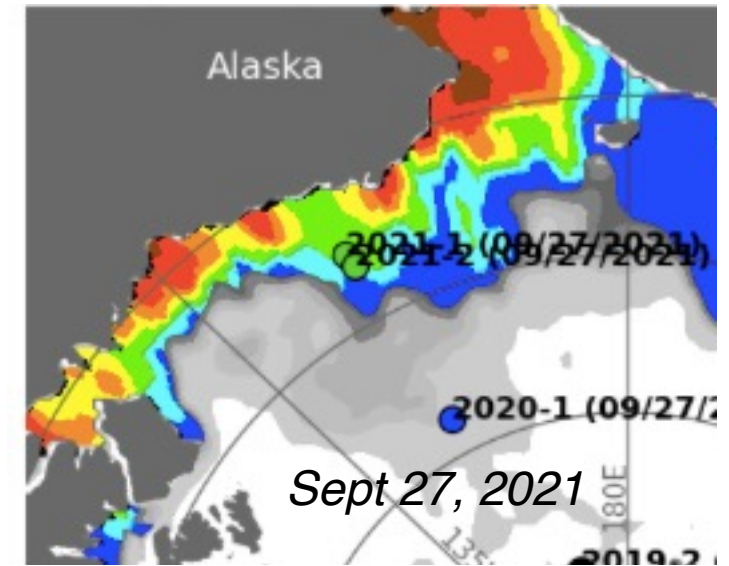
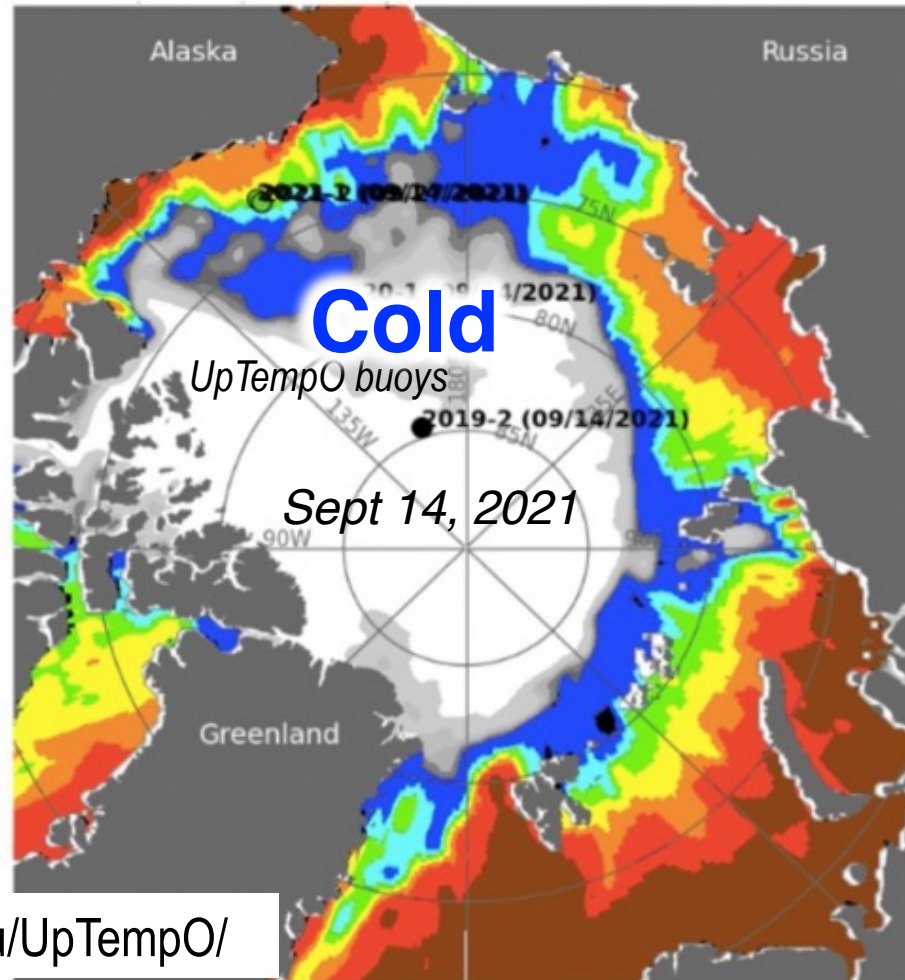
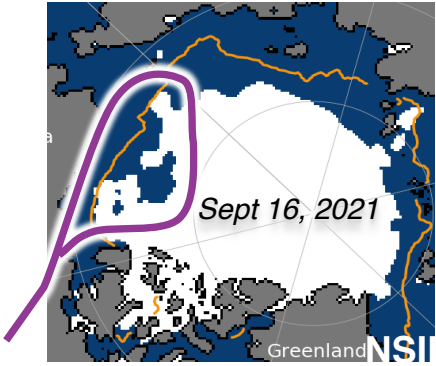
# Ocean surface warming



<http://psc.apl.washington.edu/UpTempO/>



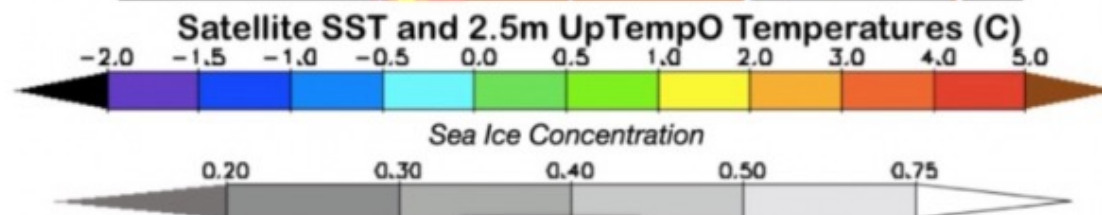
# Ocean surface warming



**2 weeks later: icy!**

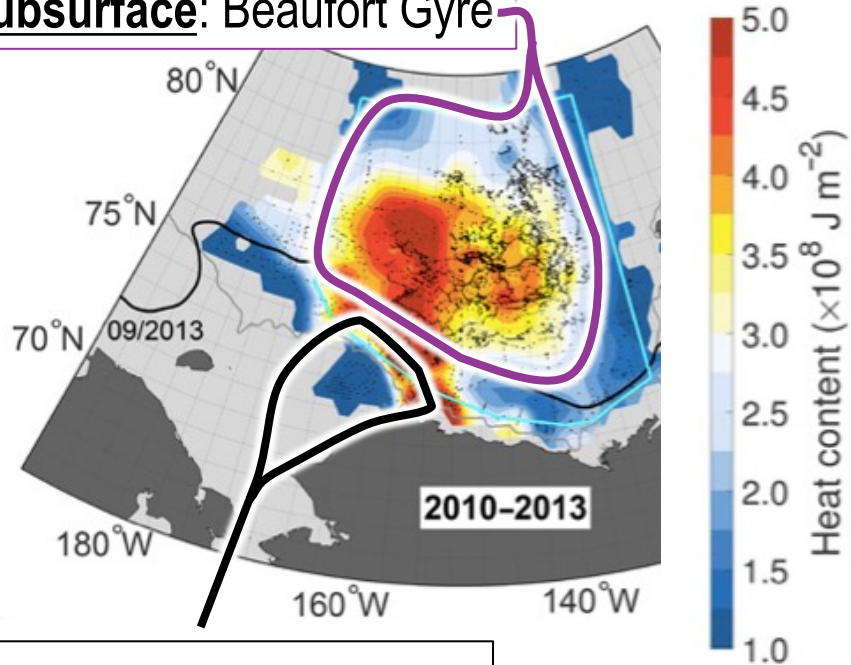
*Fournier et al. (GRL, 2022, in prep.)*

<http://psc.apl.washington.edu/UpTempO/>



# Surface → Subsurface Warming?

Subsurface: Beaufort Gyre



Surface: N. Chukchi Sea

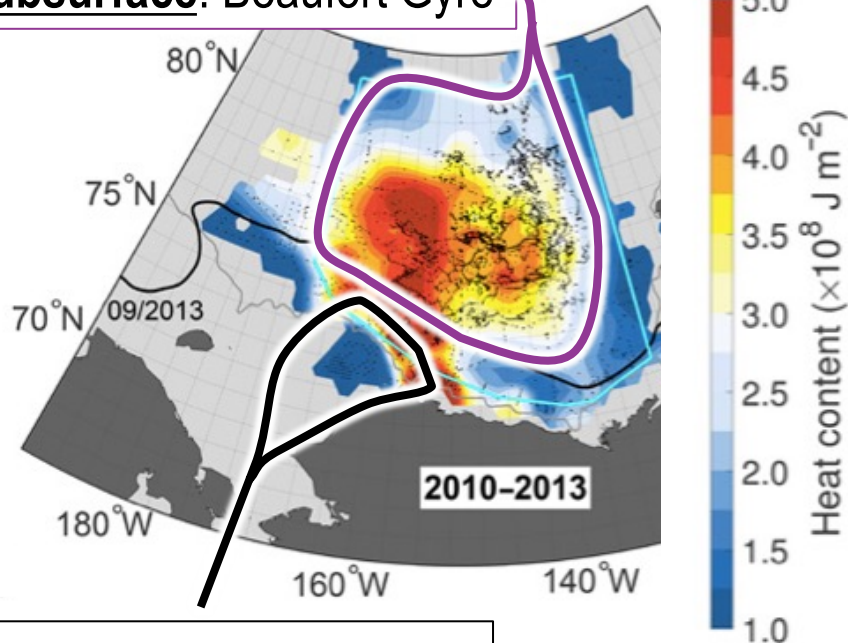
Heat content  
between  $S = 31$  &  $33$

*Timmermans et al. (Science Adv., 2018)*



# Surface → Subsurface Warming?

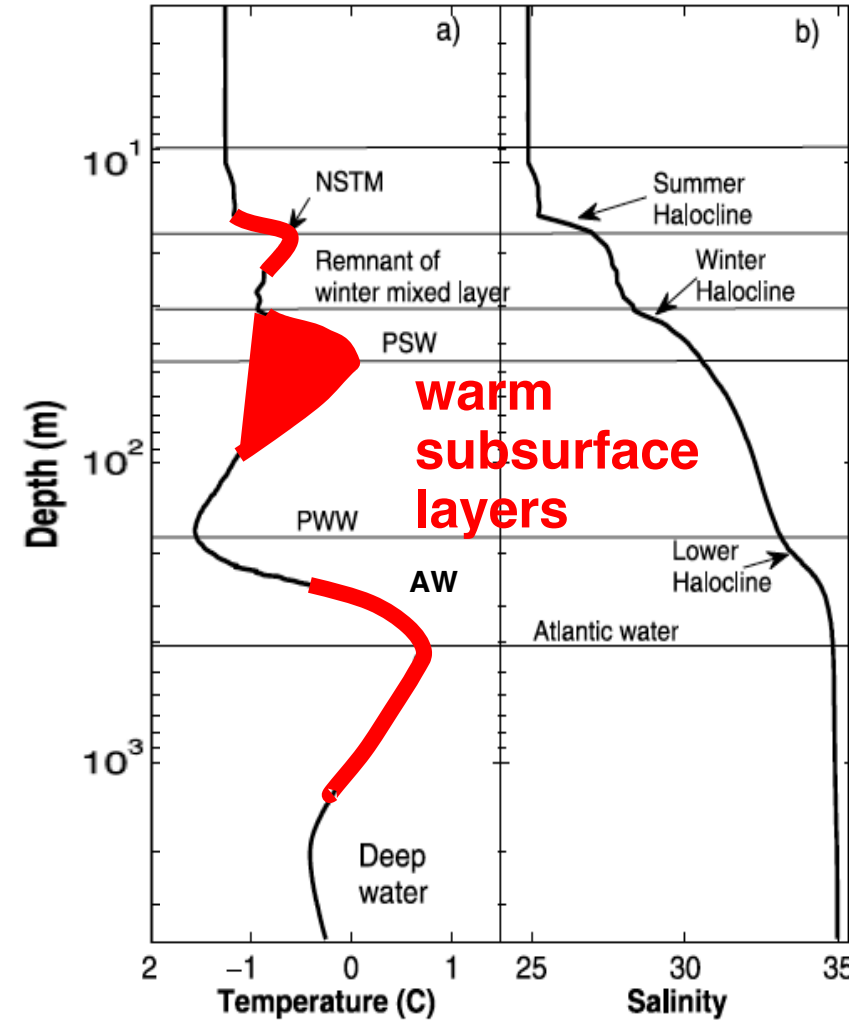
**Subsurface:** Beaufort Gyre



**Surface:** N. Chukchi Sea

Heat content  
between  $S = 31$  &  $33$

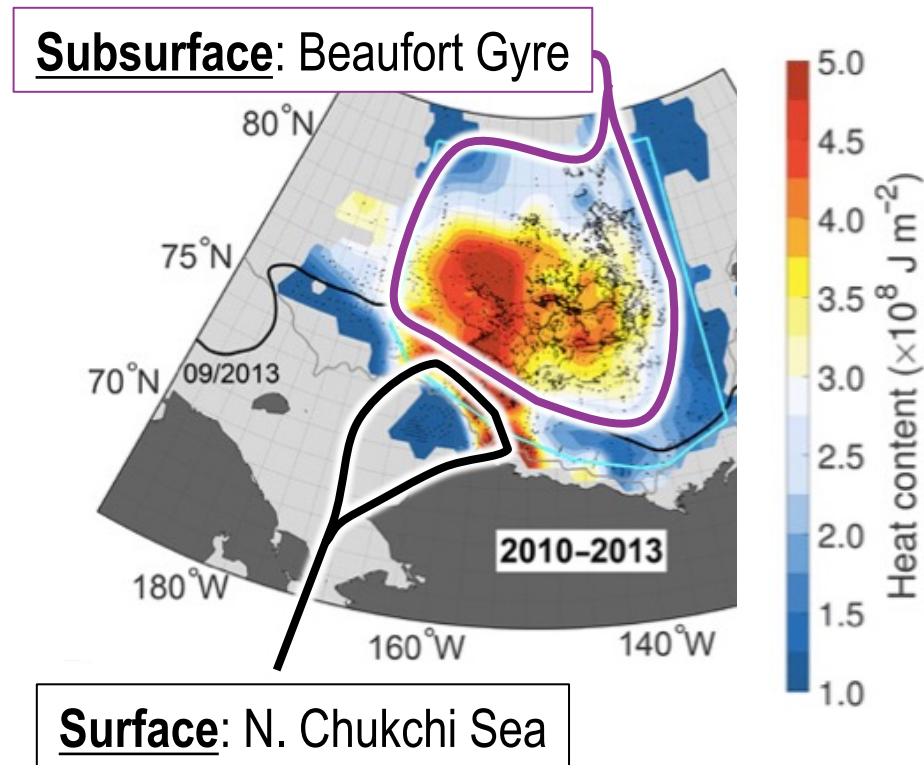
*Timmermans et al. (Science Adv., 2018)*



*Jackson et al. (JGR, 2010)*

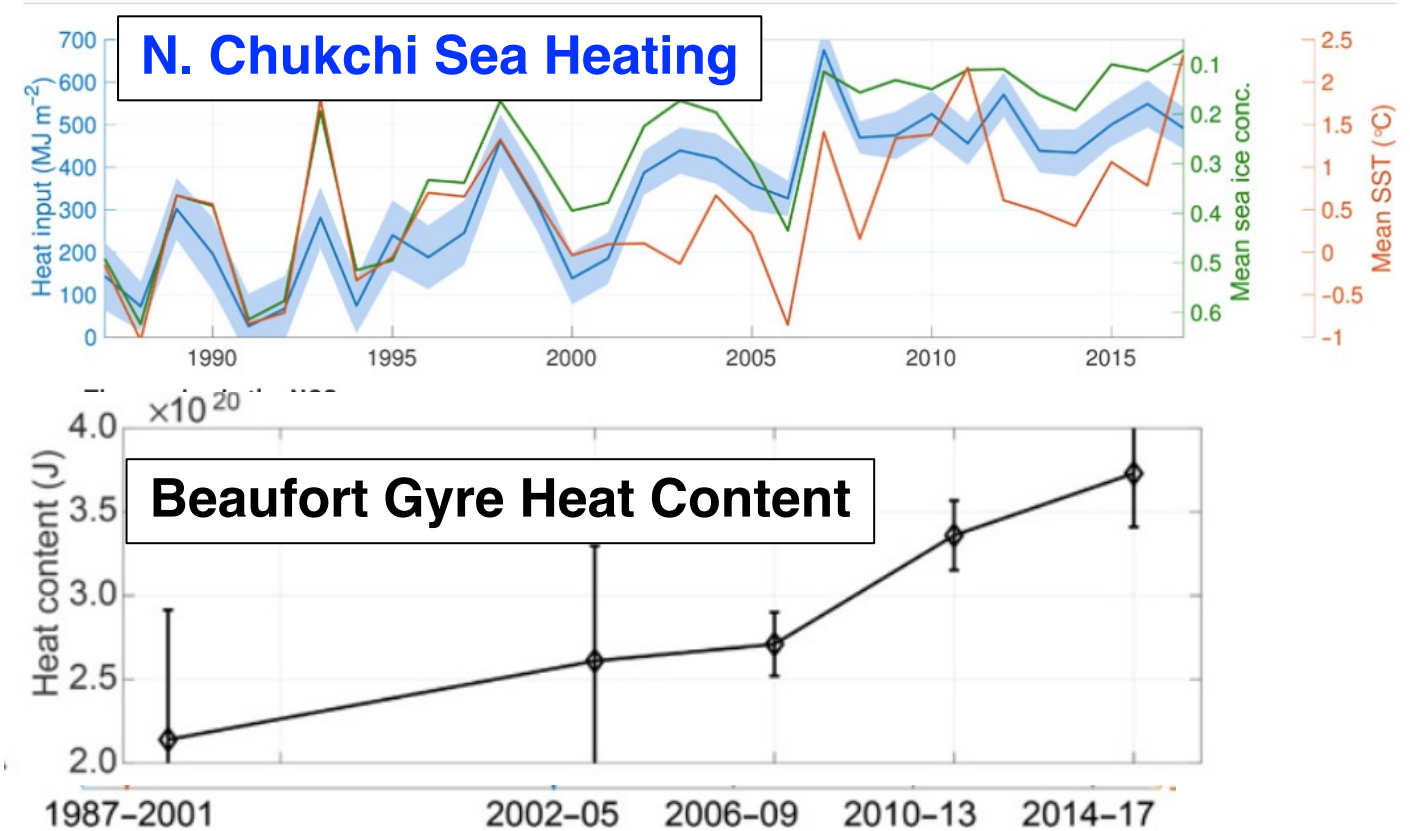


# Surface → Subsurface Warming?



Heat content  
between  $S = 31$  &  $33$

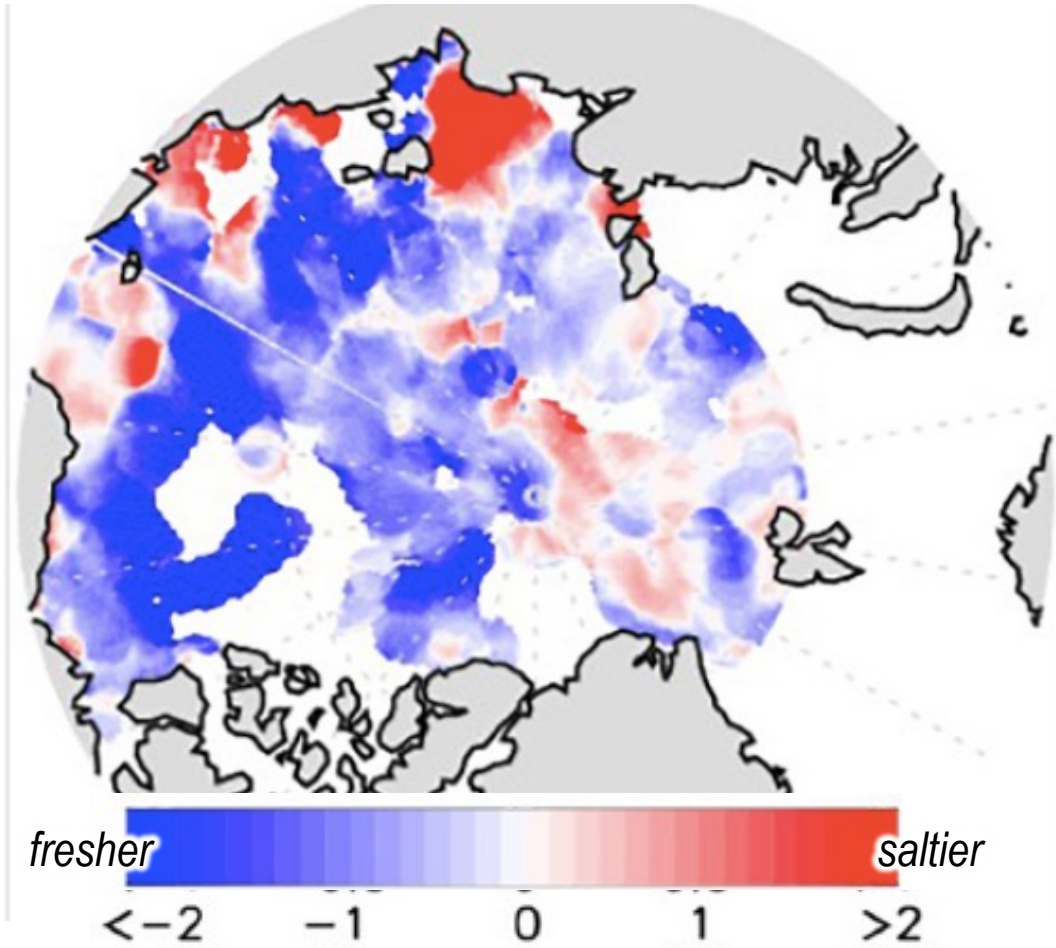
*Timmermans et al. (Science Adv., 2018)*



**Yes!**

# Ocean surface freshening

$\Delta$  mixed layer salinity: [2006-2017] – [1981-1995]



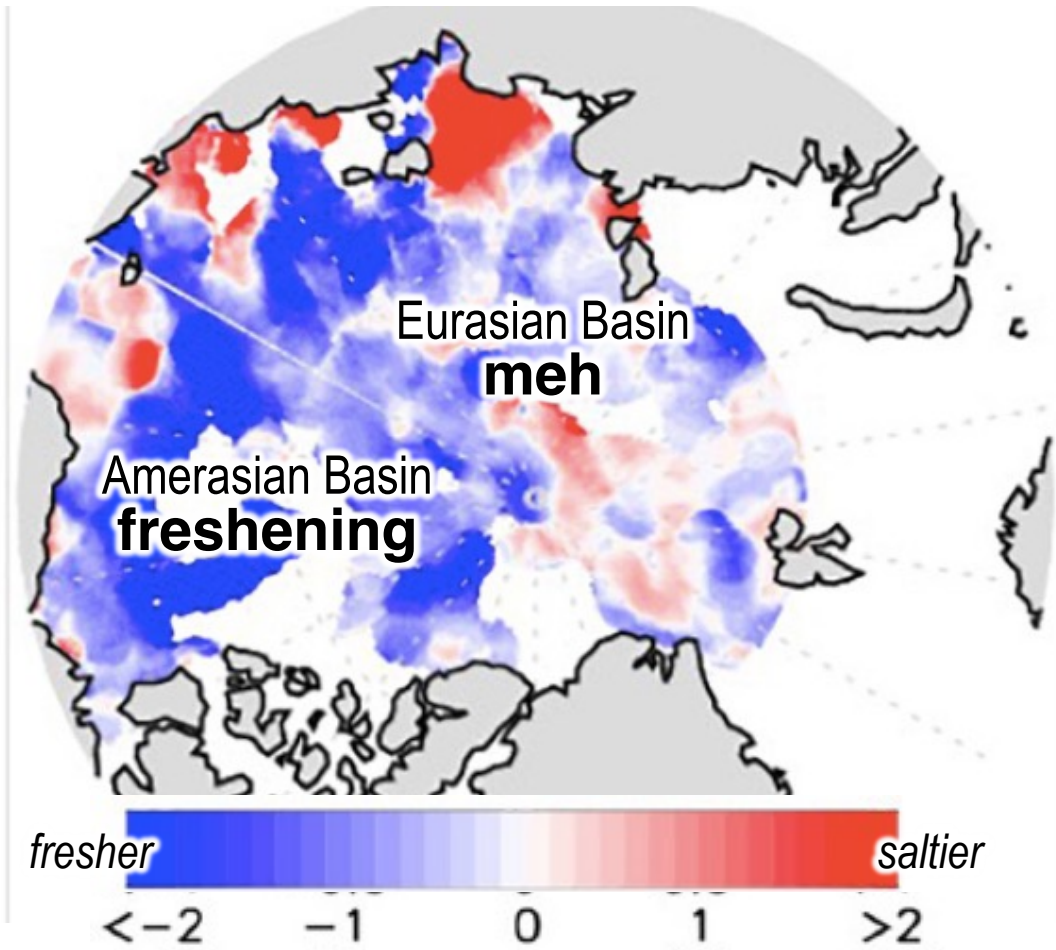
## Overall freshening:

- Incr. **river** discharge
- Less net **ice** growth
- Incr. **P-E**

Polyakov et al. (Frontiers MarSci., 2020)

# Ocean surface freshening

$\Delta$  mixed layer salinity: [2006-2017] – [1981-1995]



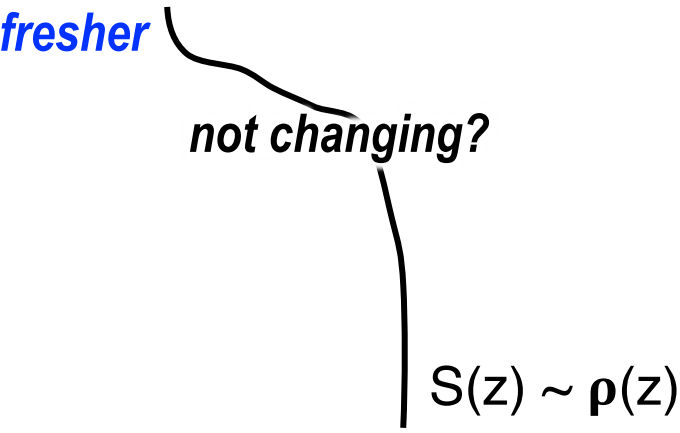
Polyakov et al. (Frontiers MarSci., 2020)

## Overall freshening:

- Incr. **river** discharge
- Less net **ice** growth
- Incr. **P-E**

*...but mostly in the Amerasian Basin*

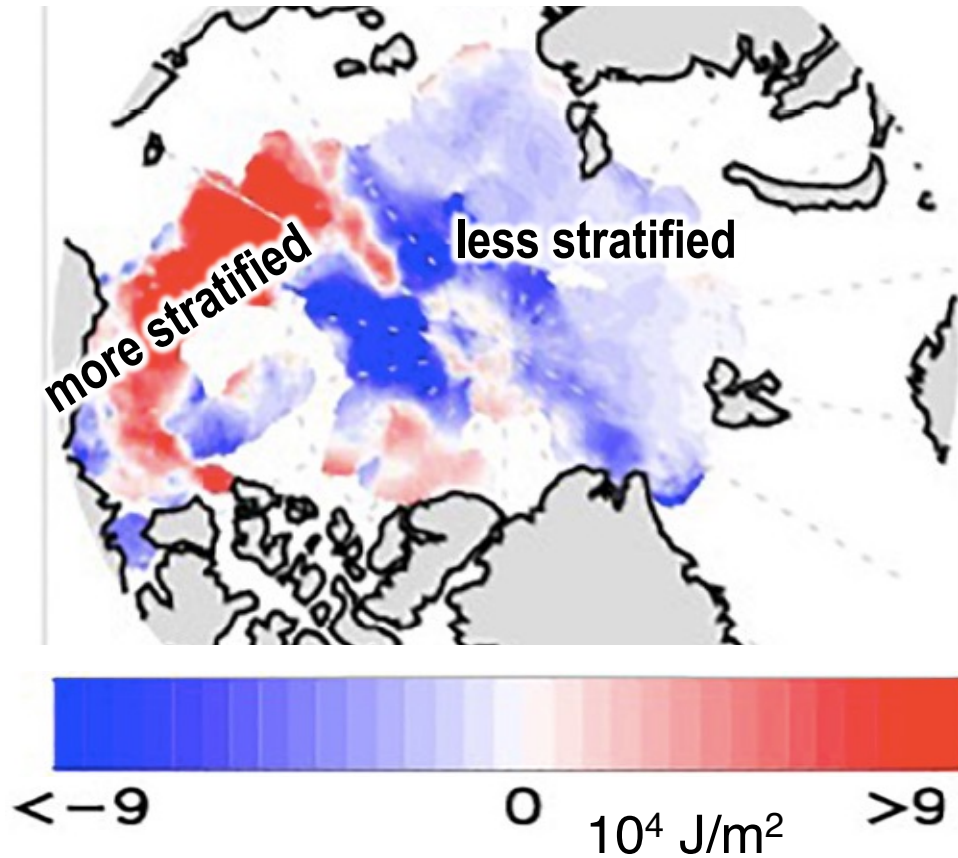
# Surface freshening → upper ocean stratifying?



# Is the upper ocean stratifying?

$\Delta$  halocline avail. pot. energy (APE)

[2006-2017] – [1981-1995]



... **Yes**, mostly in the Amerasian Basin

Also: Peralta-Ferriz & Woodgate (*Prog. Ocean.*, 2015)

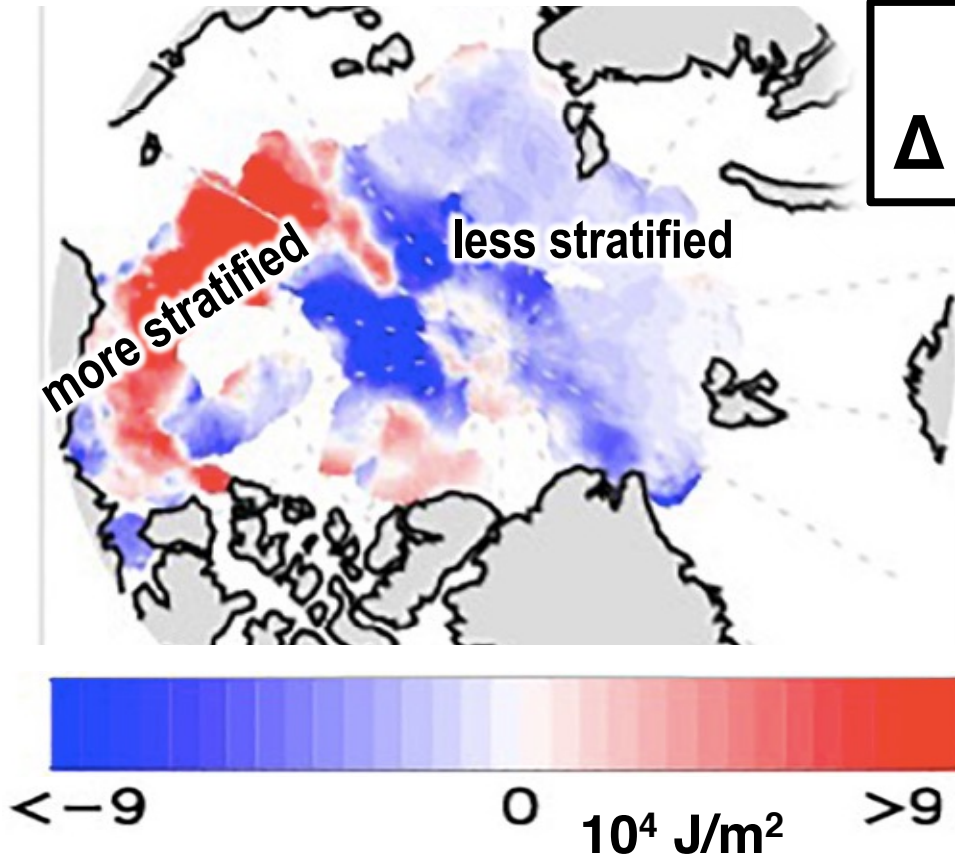
Polyakov et al. (*Frontiers MarSci.*, 2020)



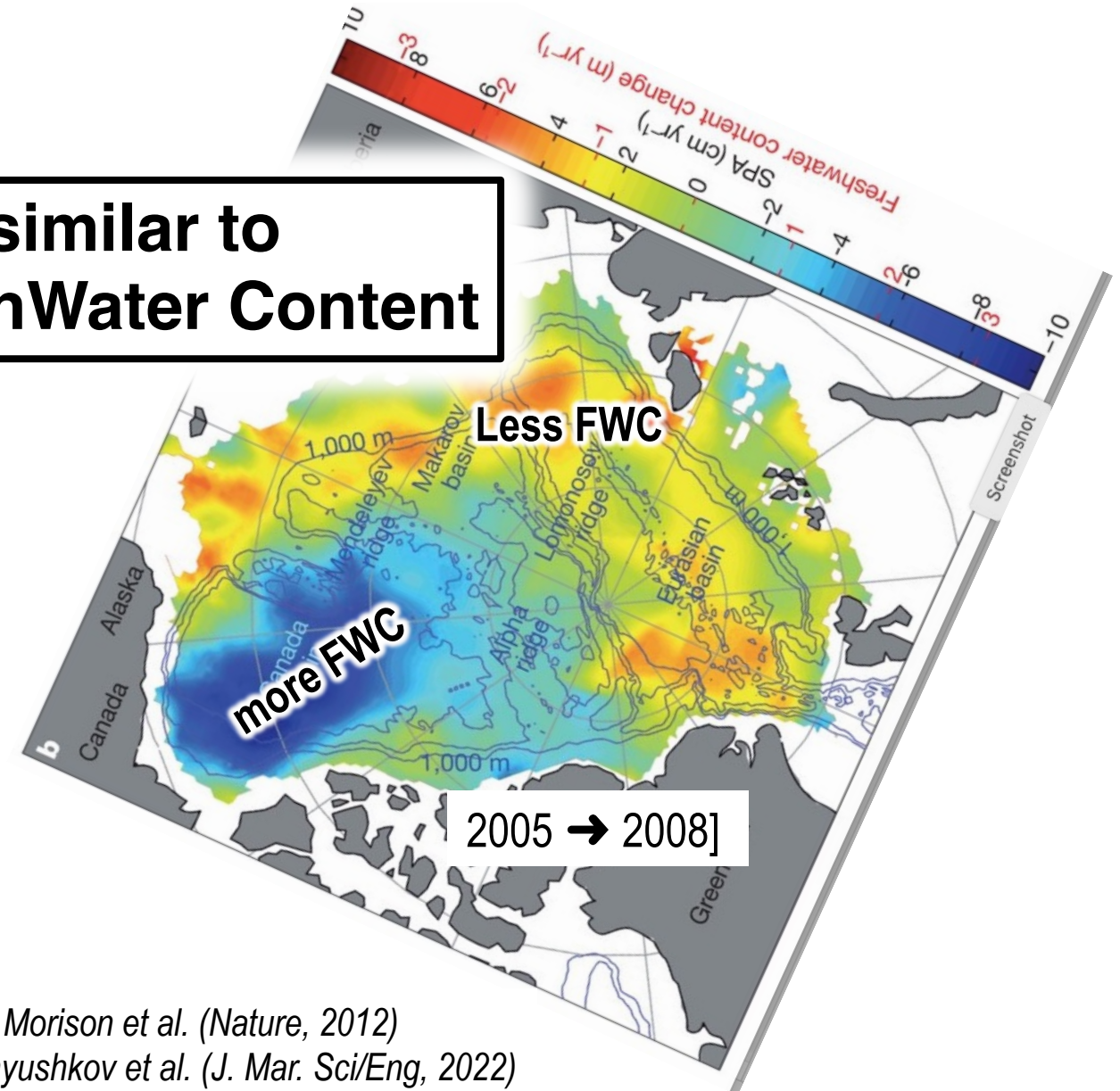
# Is the upper ocean stratifying?

$\Delta$  halocline avail. pot. energy (APE)

[2006-2017] – [1981-1995]



similar to  
 $\Delta$  FreshWater Content



Polyakov et al. (Frontiers MarSci., 2020)

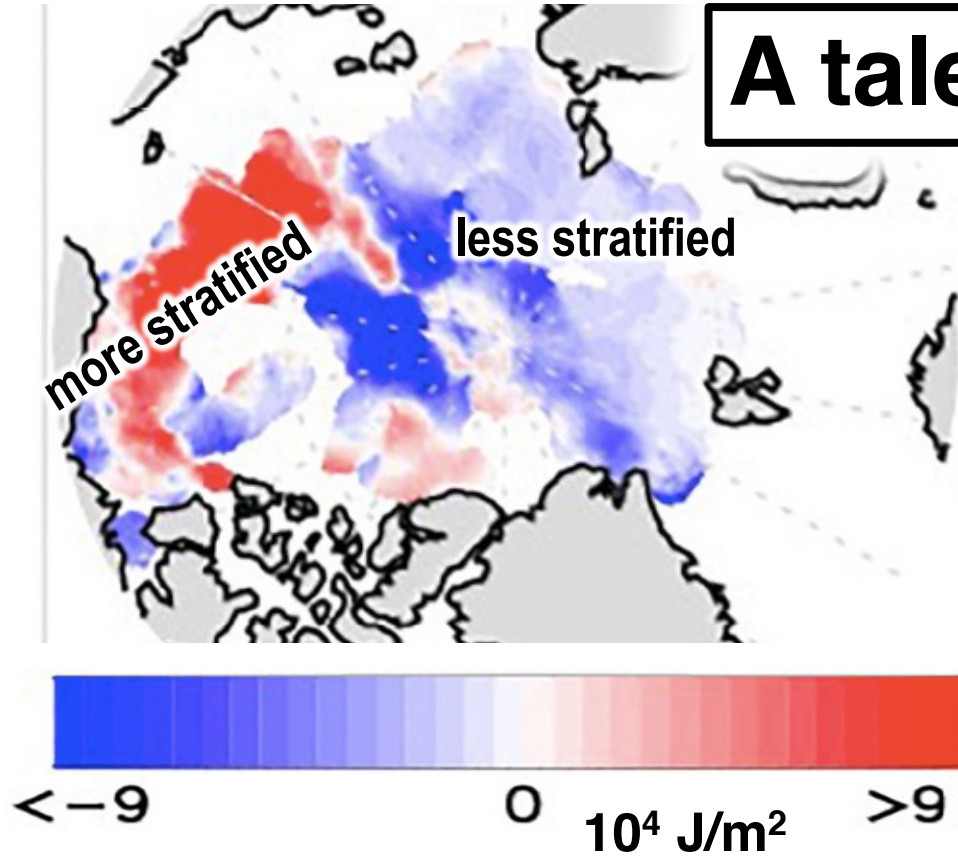
Morison et al. (Nature, 2012)  
Also: Pnyushkov et al. (J. Mar. Sci/Eng, 2022)

# Is the upper ocean stratifying?

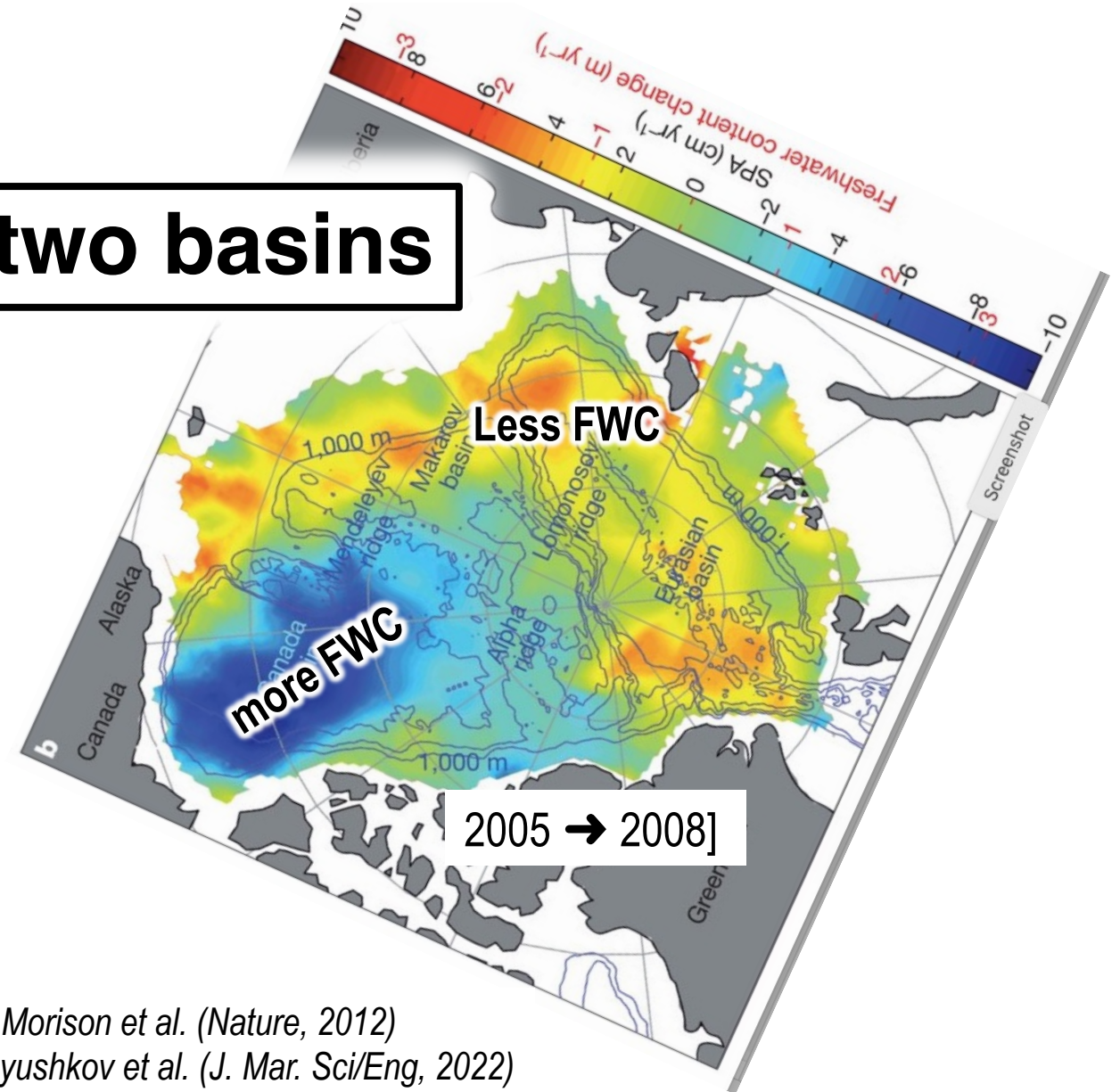
$\Delta$  halocline avail. pot. energy (APE)

[2006-2017] – [1981-1995]

**A tale of two basins**



Polyakov et al. (Frontiers MarSci., 2020)



Morison et al. (Nature, 2012)  
Also: Pnyushkov et al. (J. Mar. Sci/Eng, 2022)

# Amerasian Basin (AB): *stratification*



**PSW: Pacific Summer Water: **more****

**PWW: Pacific Winter Water: **fresher****

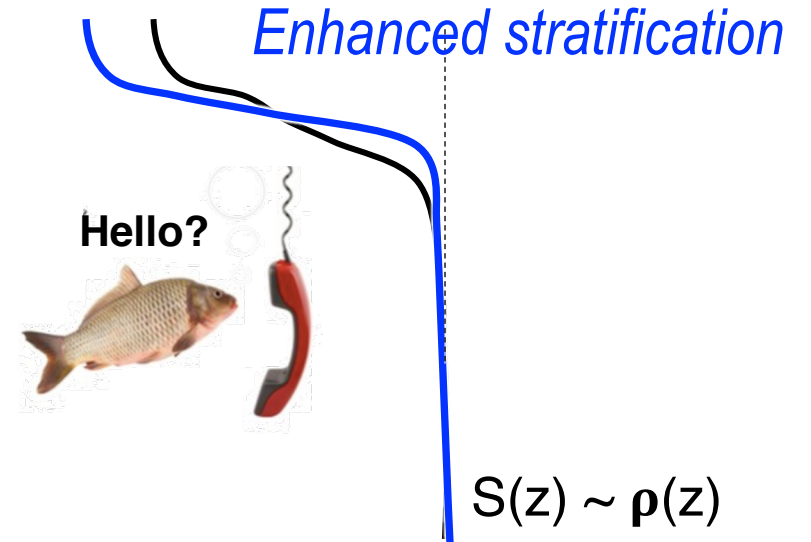
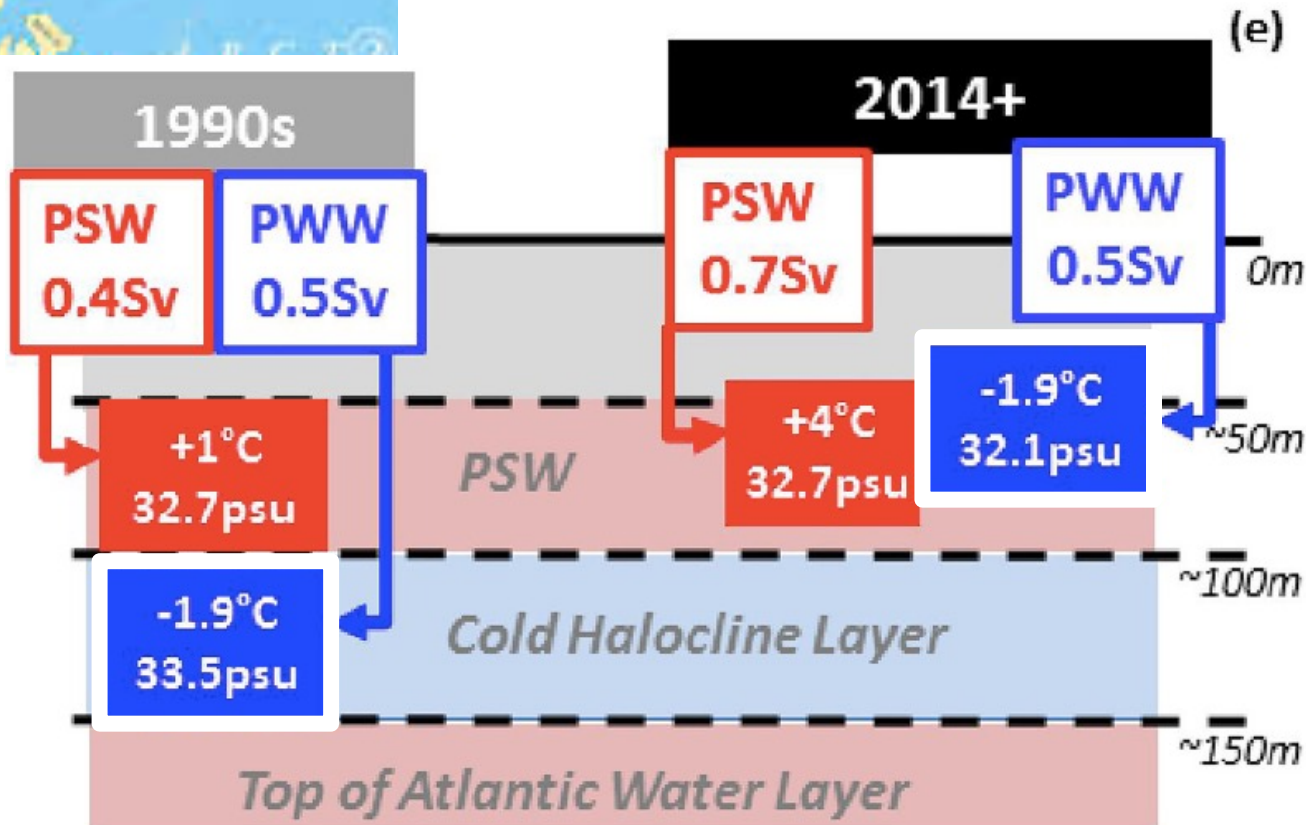


# Amerasian Basin (AB): *stratification*



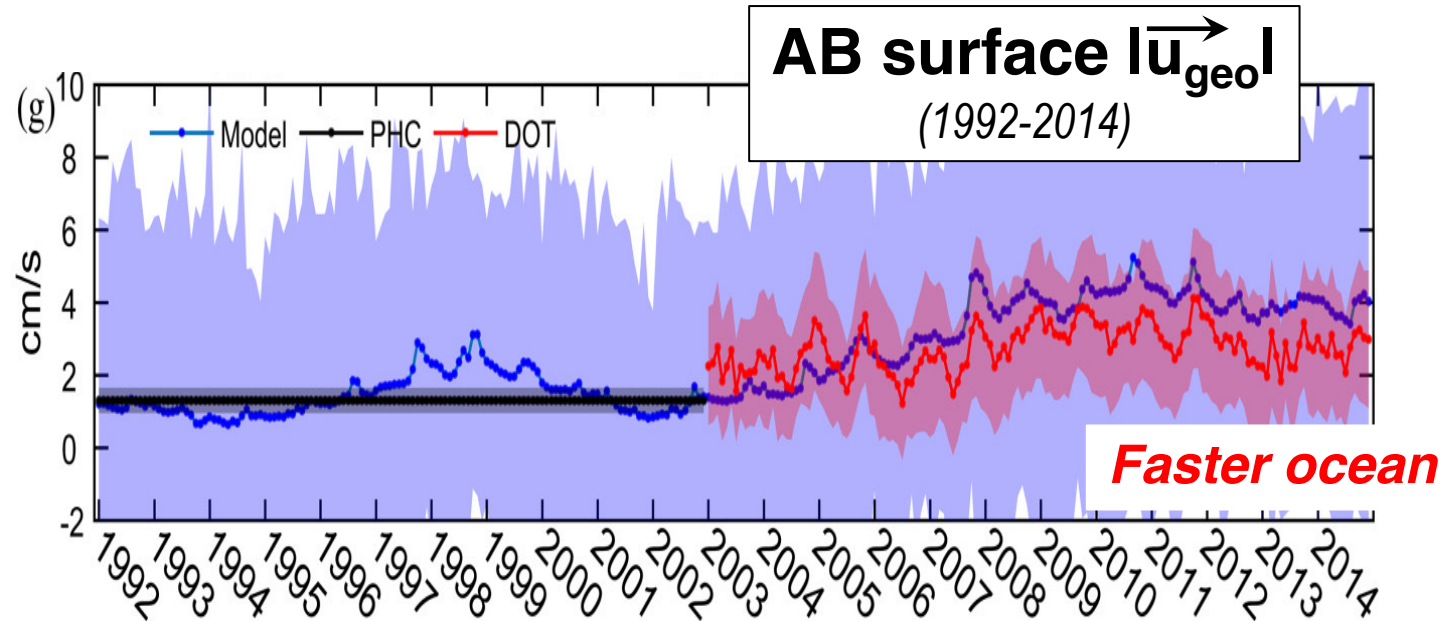
**PSW: Pacific Summer Water: **more****

**PWW: Pacific Winter Water: **fresher****



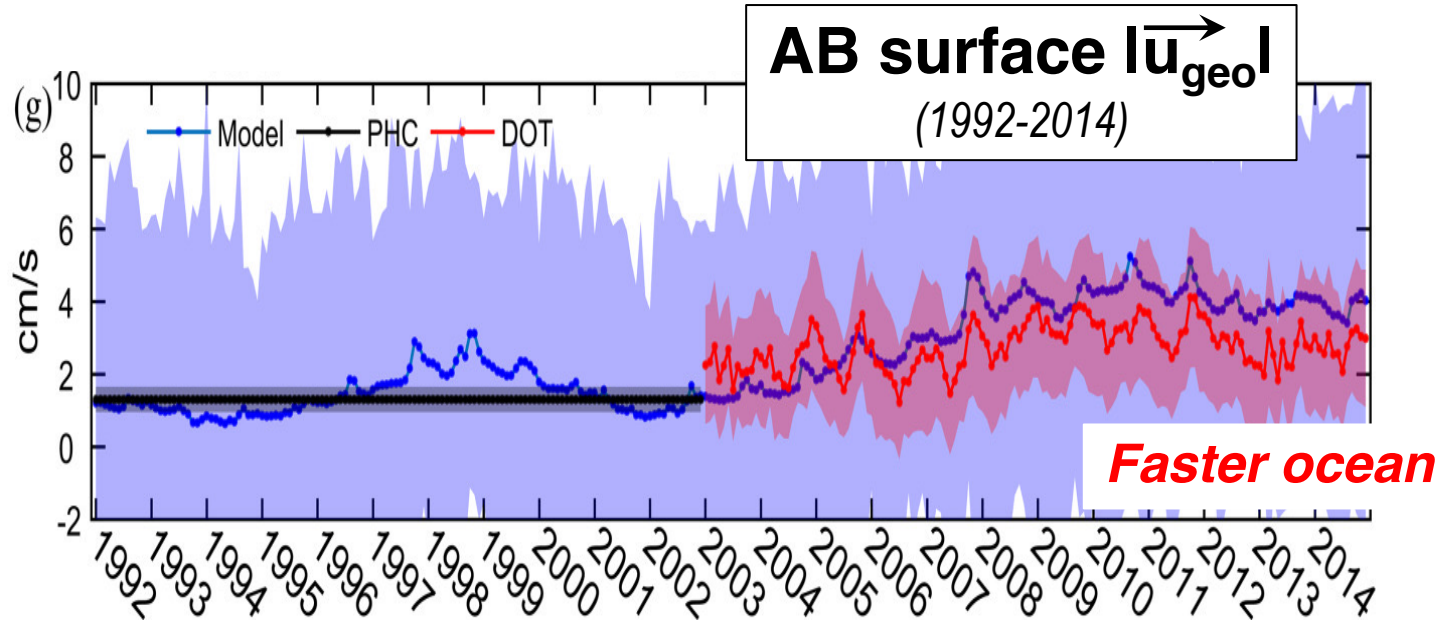
**Freshwater shoaling**

# Amerasian Basin (AB): *kinetic energy*

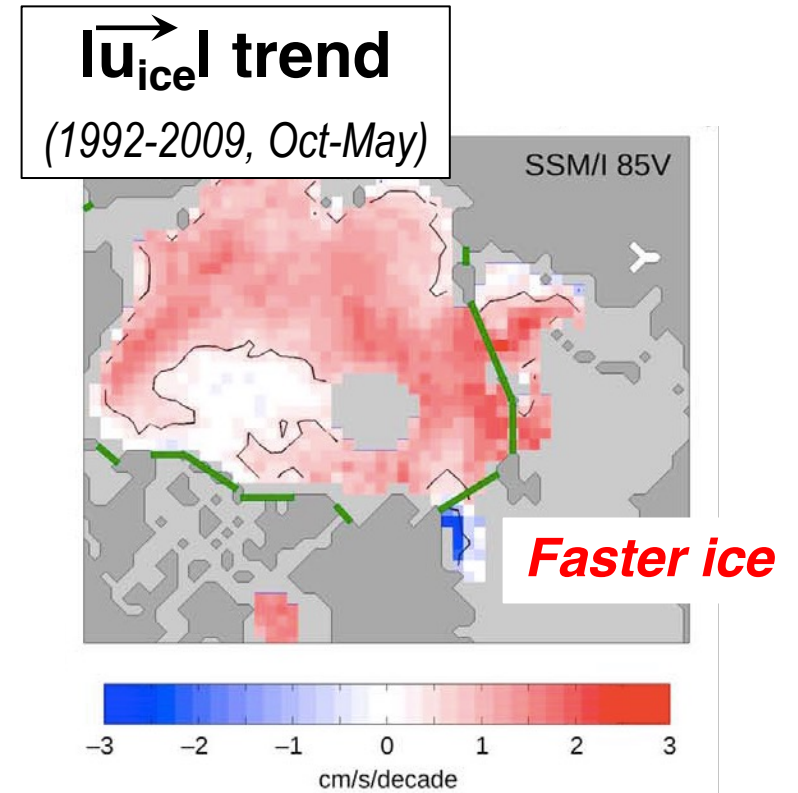


Zhong et al. (JGR, 2017)

# Amerasian Basin (AB): *kinetic energy*



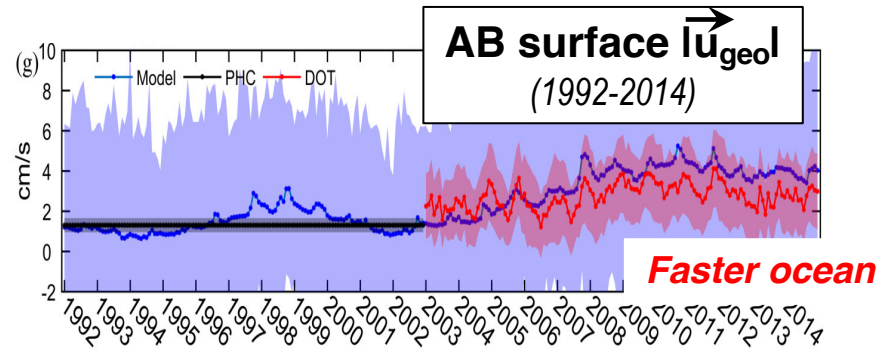
Zhong et al. (JGR, 2017)



Spren et al. (GRL, 2011)

## The surface is spinning up!

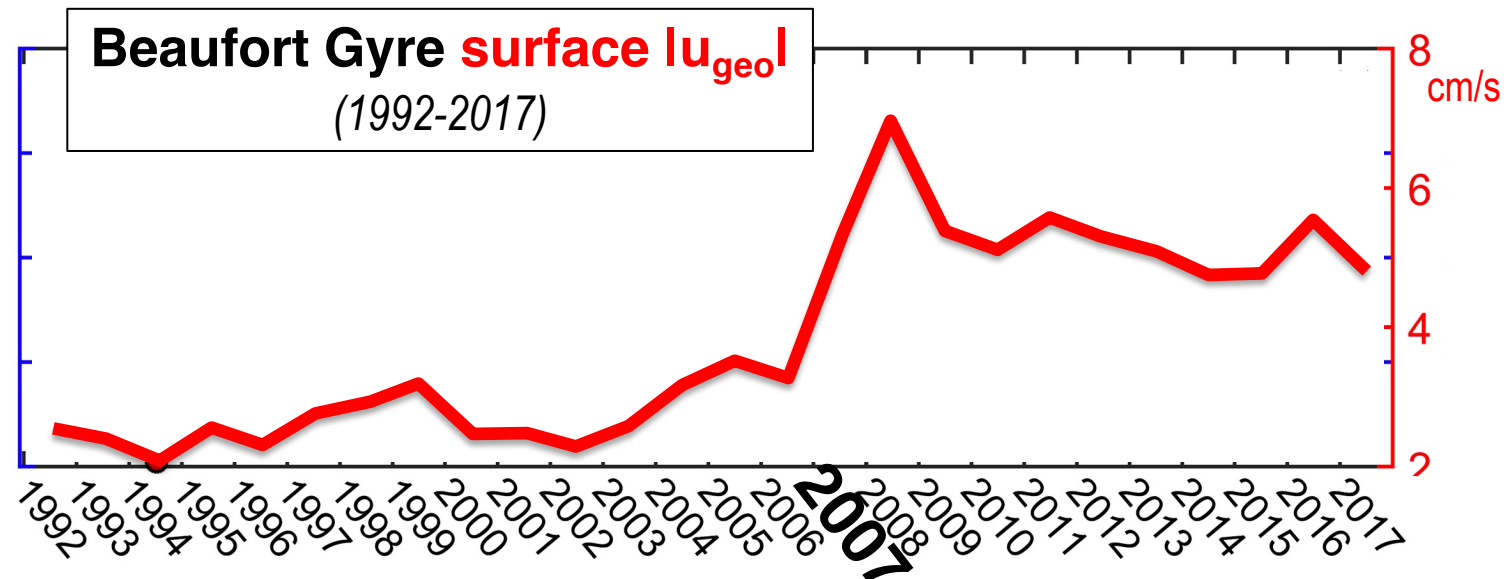
# Amerasian Basin (AB): *kinetic energy*



Zhong et al. (JGR, 2017)

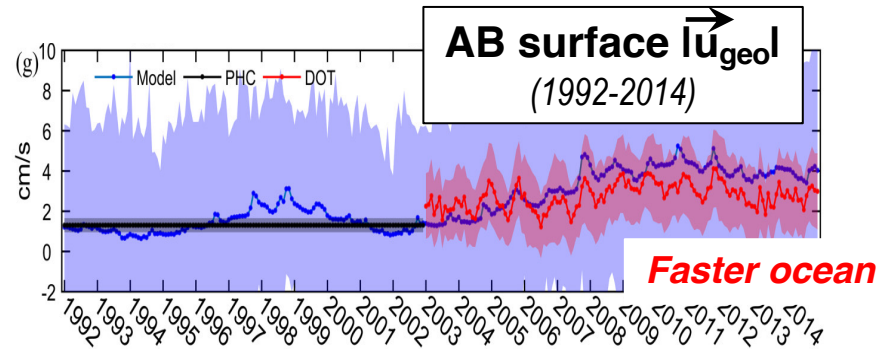
*revisited...*

Zhong et al. (GRL, 2019)



**2007/2008: Step increase!**

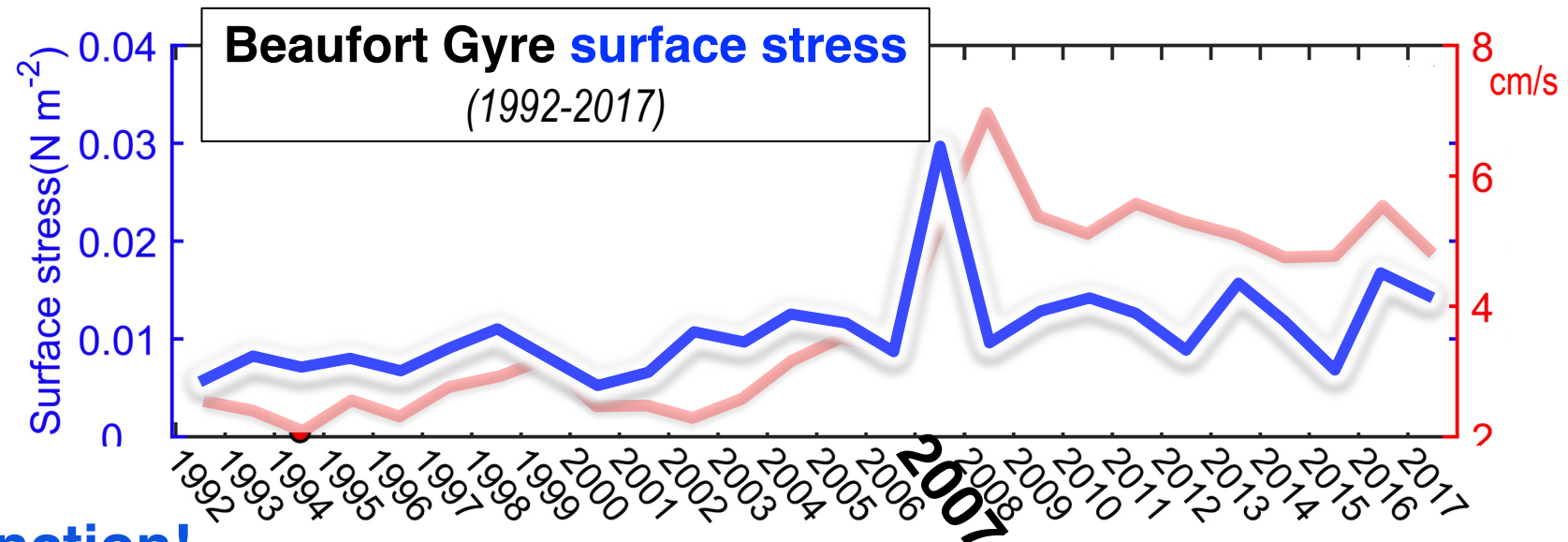
# Amerasian Basin (AB): *kinetic energy*



Zhong et al. (JGR, 2017)

*revisited...*

Zhong et al. (GRL, 2019)



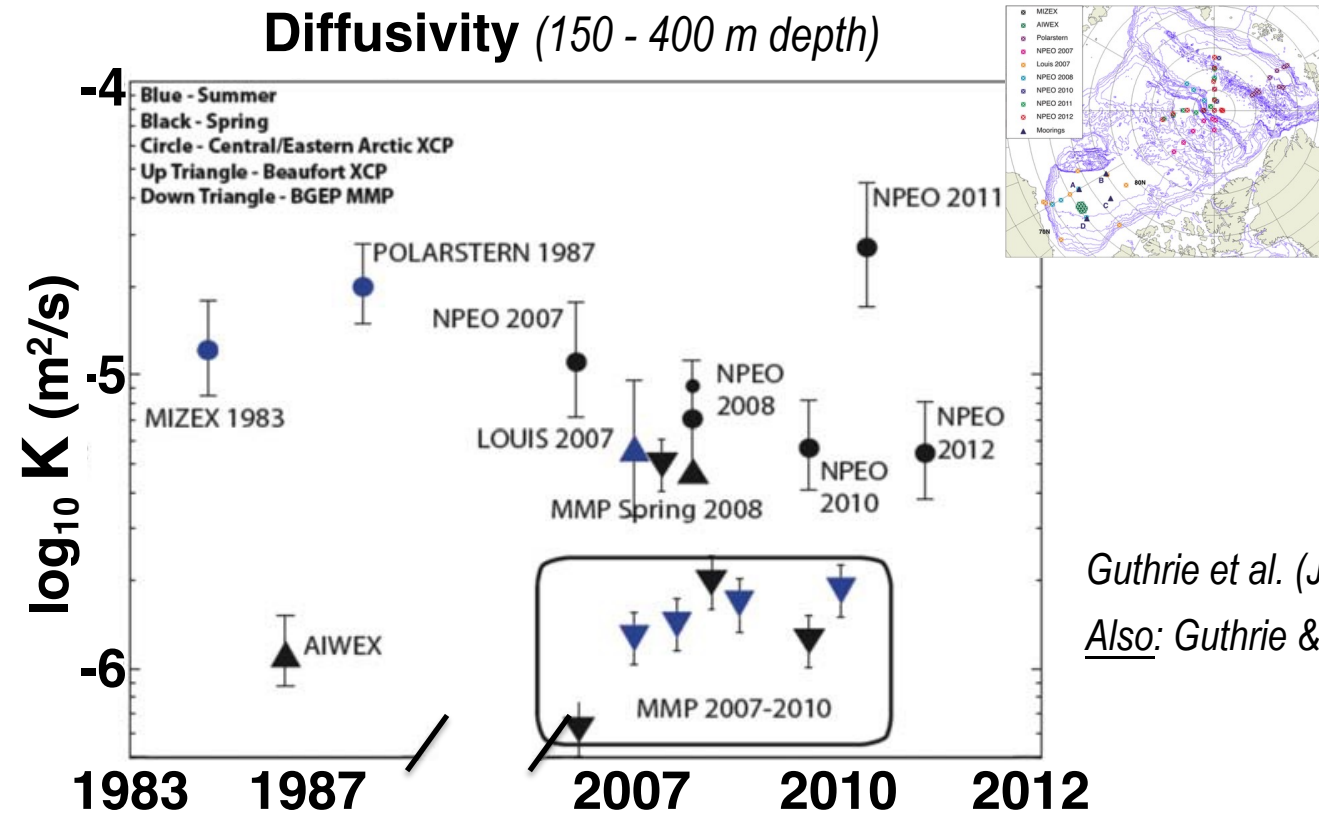
## Summer 2007: Impulse function!

- Early ice loss (low concentration, then retreat) ...hmmm



# Amerasian Basin (AB): *kinetic energy*

Is there more ocean  
mixing at depth?

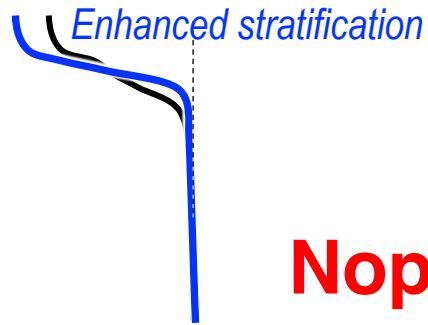


Guthrie et al. (JGR, 2013)

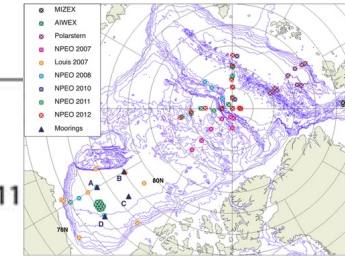
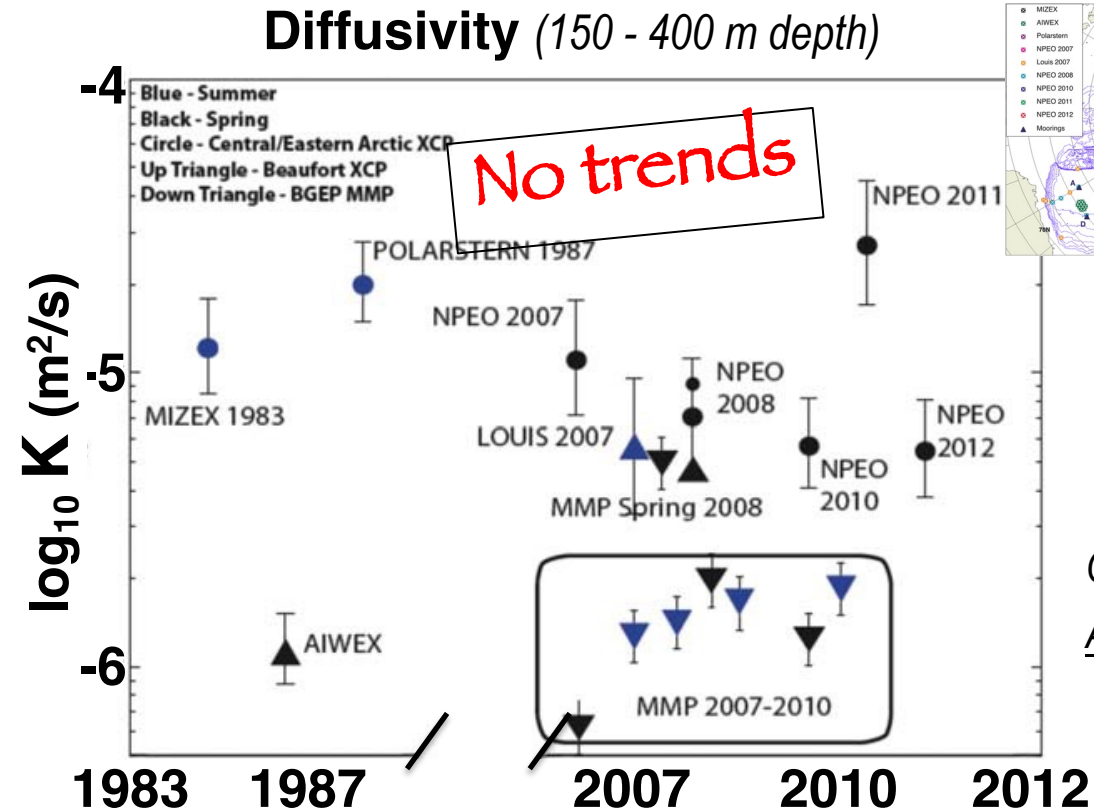
Also: Guthrie & Morison (GRL, 2021)

# Amerasian Basin (AB): *kinetic energy*

Is there more ocean  
mixing at depth?



Nope!

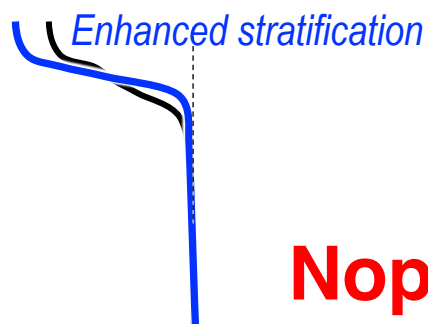


Guthrie et al. (JGR, 2013)

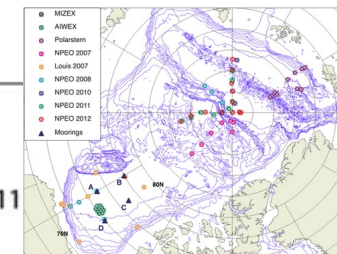
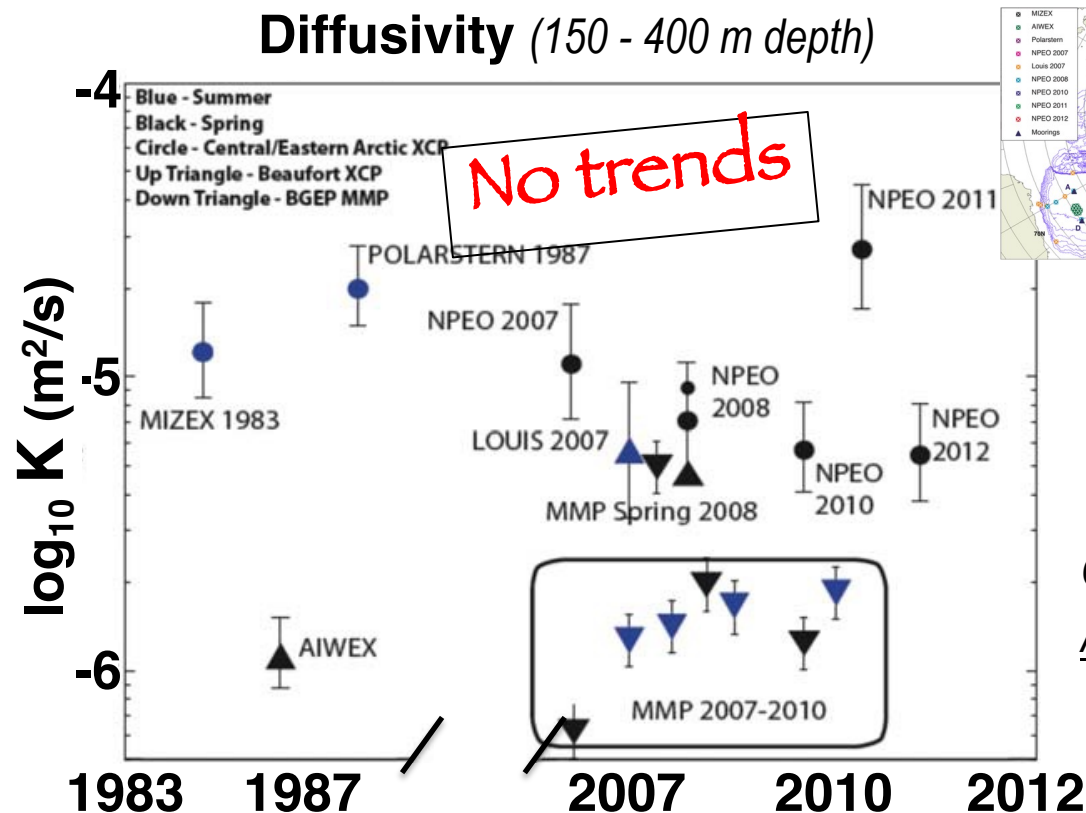
Also: Guthrie & Morison (GRL, 2021)

# Amerasian Basin (AB): *kinetic energy*

Is there more ocean  
mixing at depth?



Nope!



Guthrie et al. (JGR, 2013)

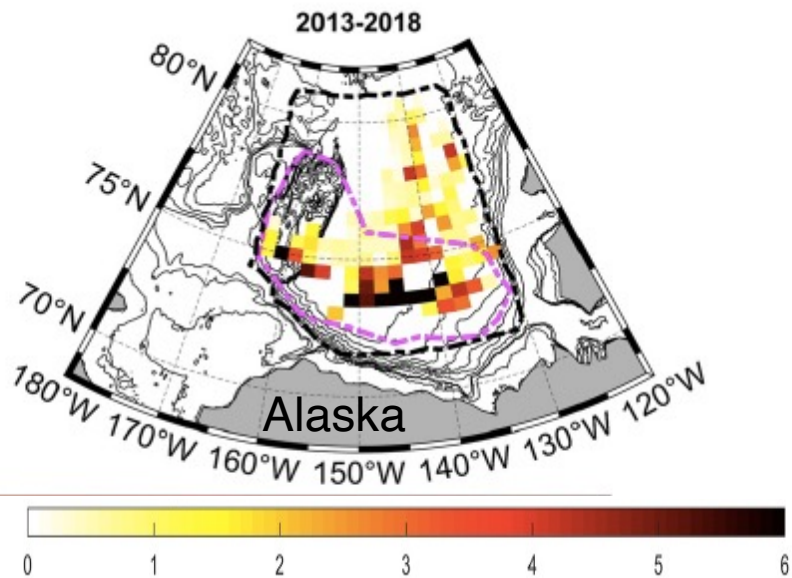
Also: Guthrie & Morison (GRL, 2021)

However:

- *incr* large-amplitude IGW events Dosser & Rainville (JPO, 2016)



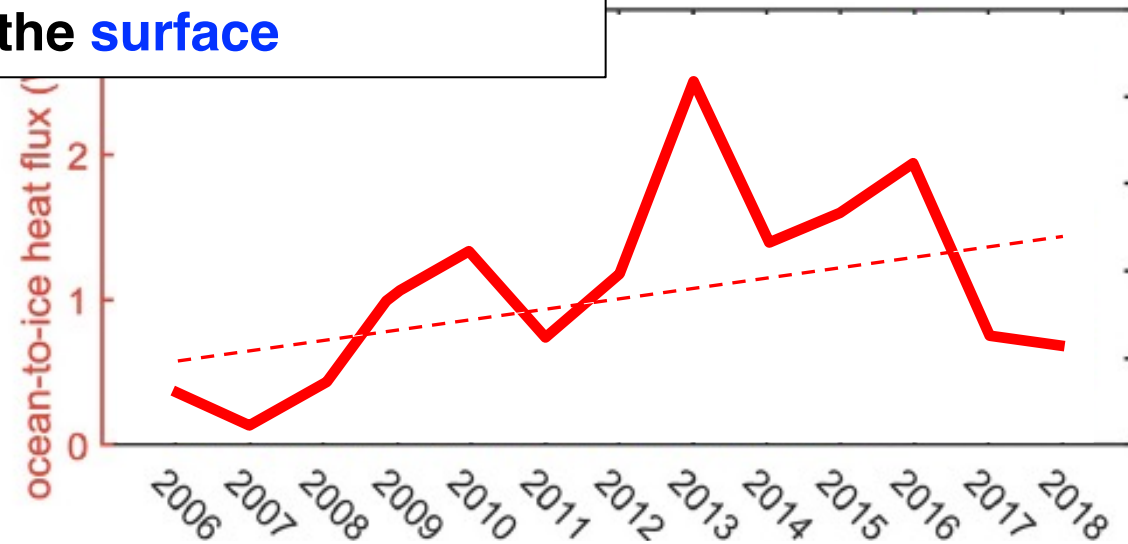
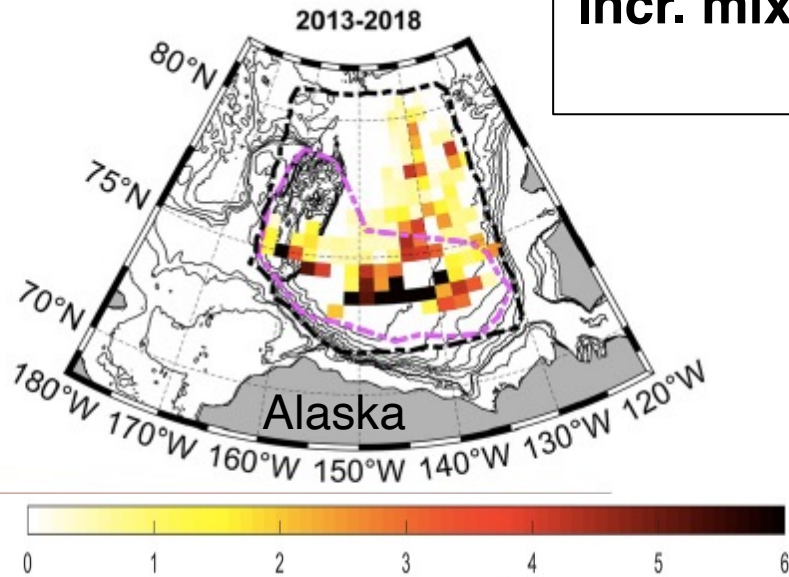
# Amerasian Basin (AB): *punching through the stratification*



Obs. winter ocean-to-ice heat flux ( $\text{W/m}^2$ )

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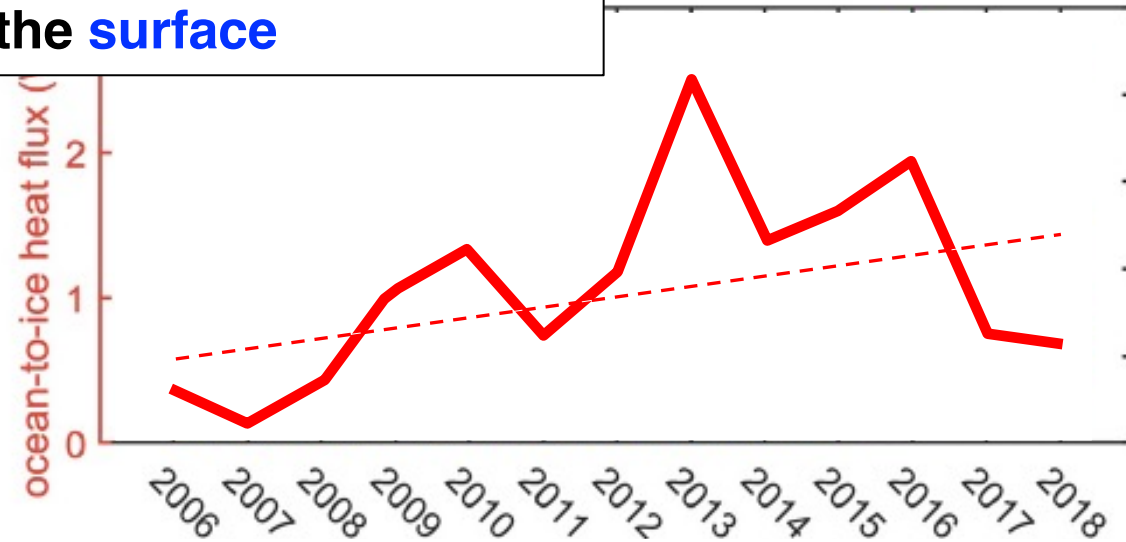
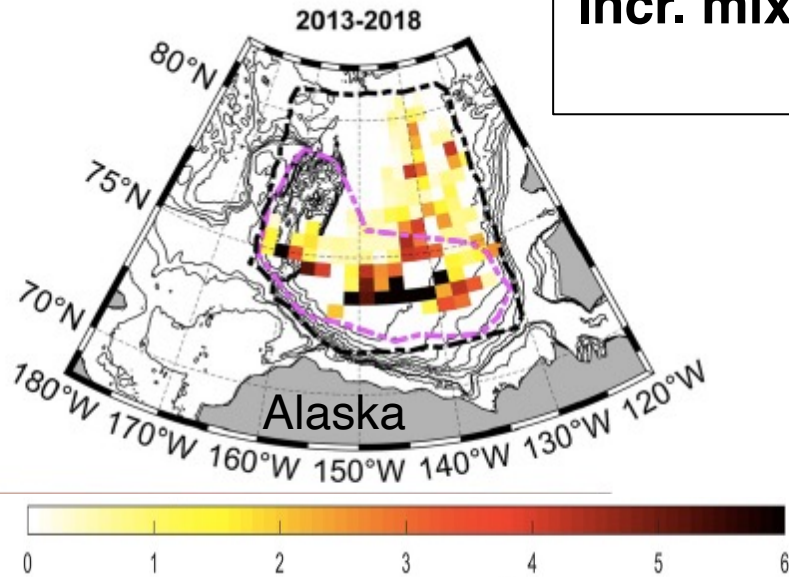
Incr. mixing of **subsurface** ocean heat  
to the **surface**



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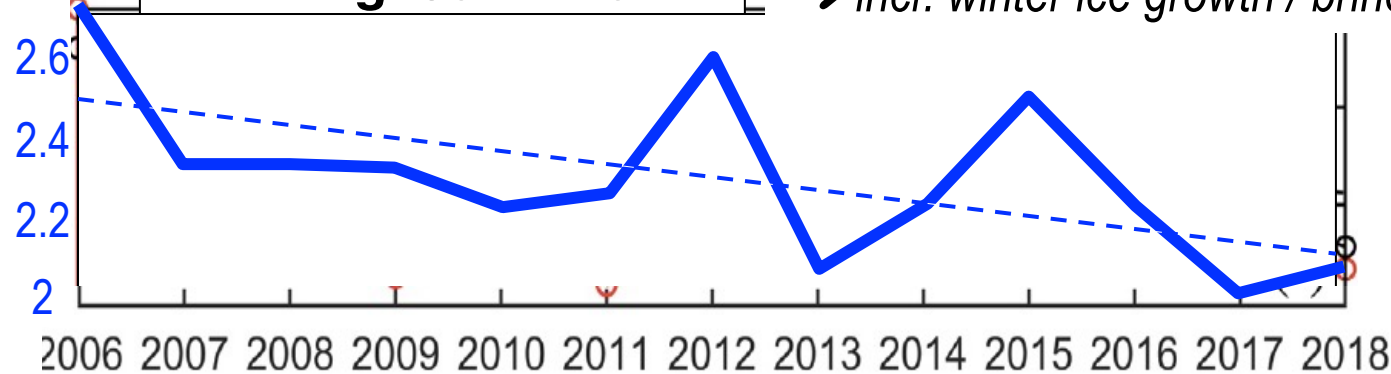
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**Thinning ice in the AB**

→ *incr. winter ice growth / brine rejection / convection*

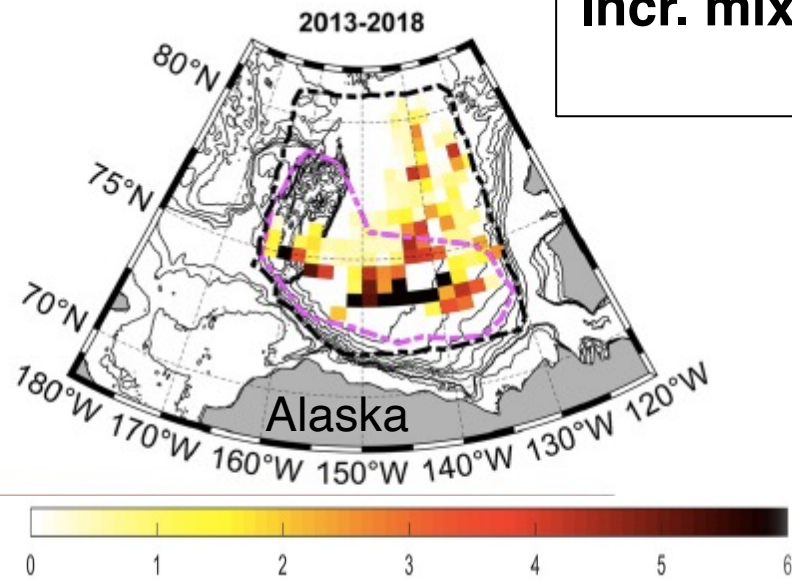


Ice thickness (m)



Zhong et al. (JGR, 2022)

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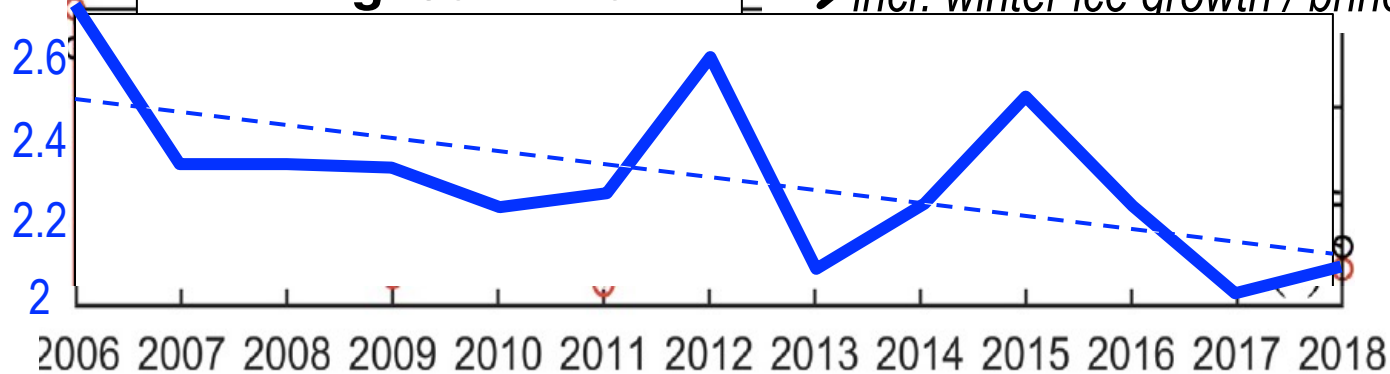
Incr. stratification is ***patchy*** and can be overcome

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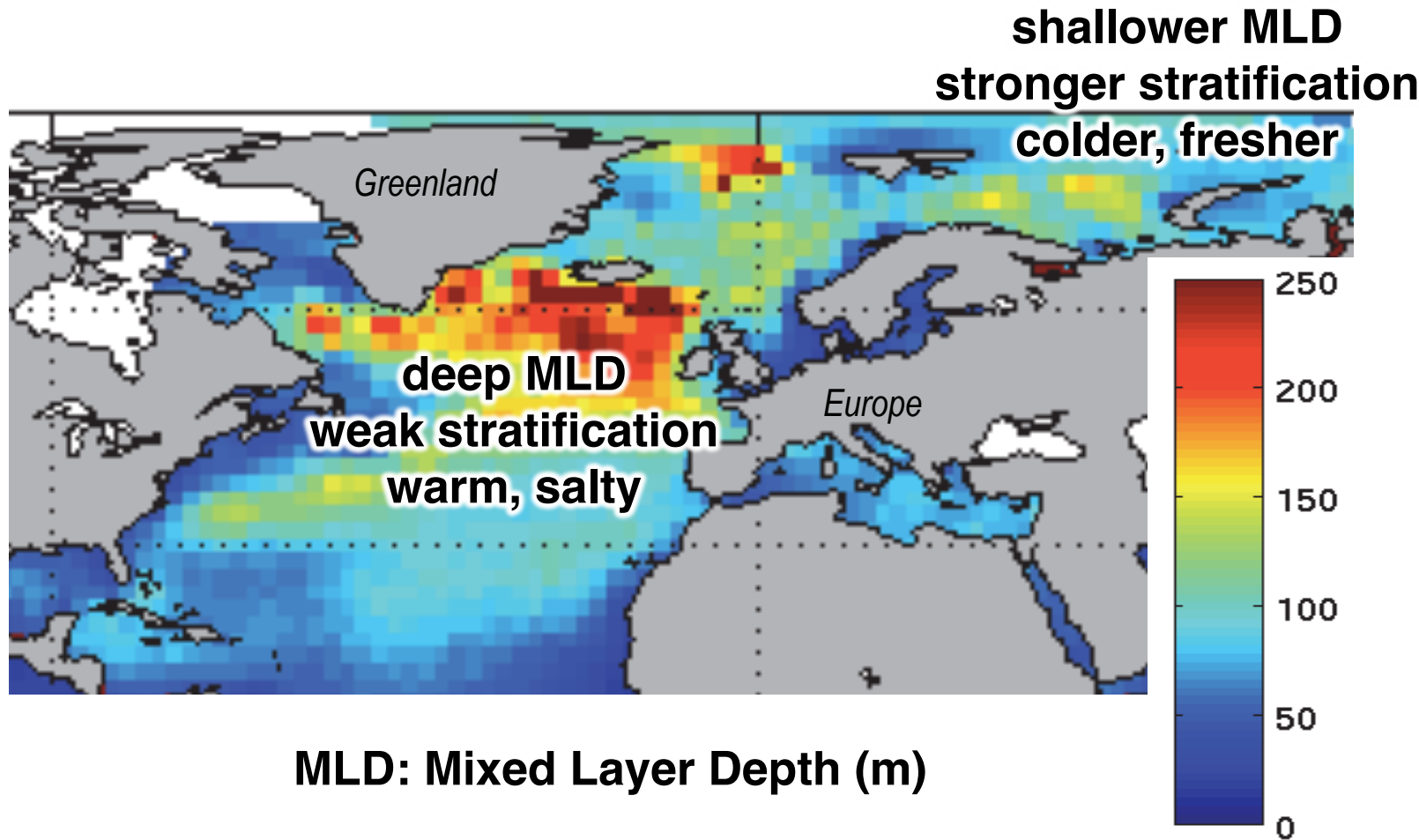


Ice thickness (m)



# Eurasian Basin (EB): “Atlantification”

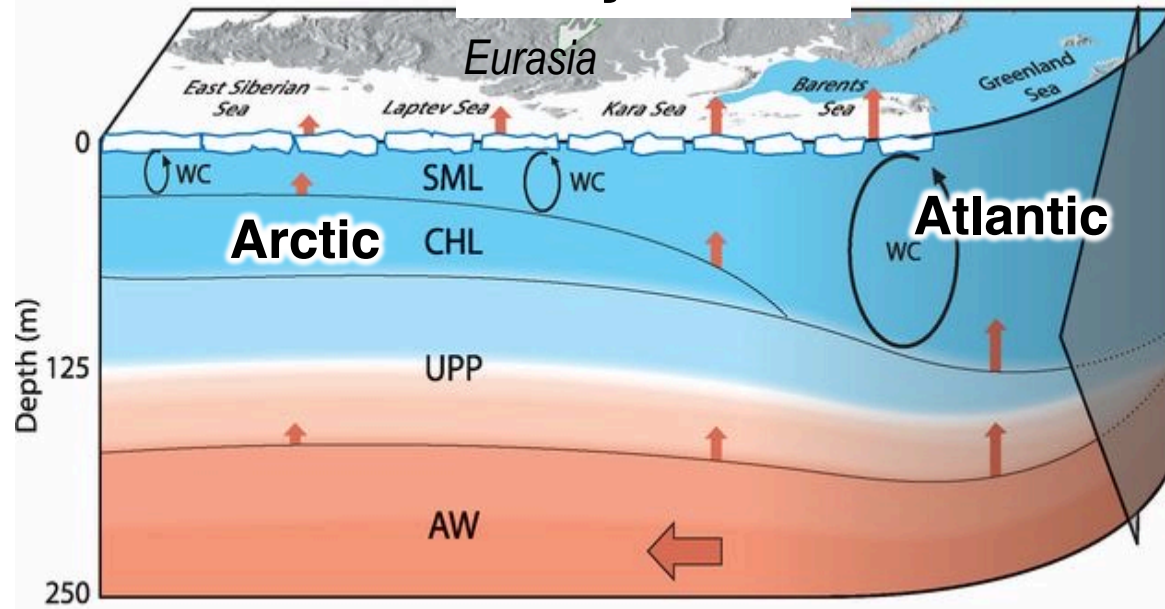
...really, “N. Atlantification”



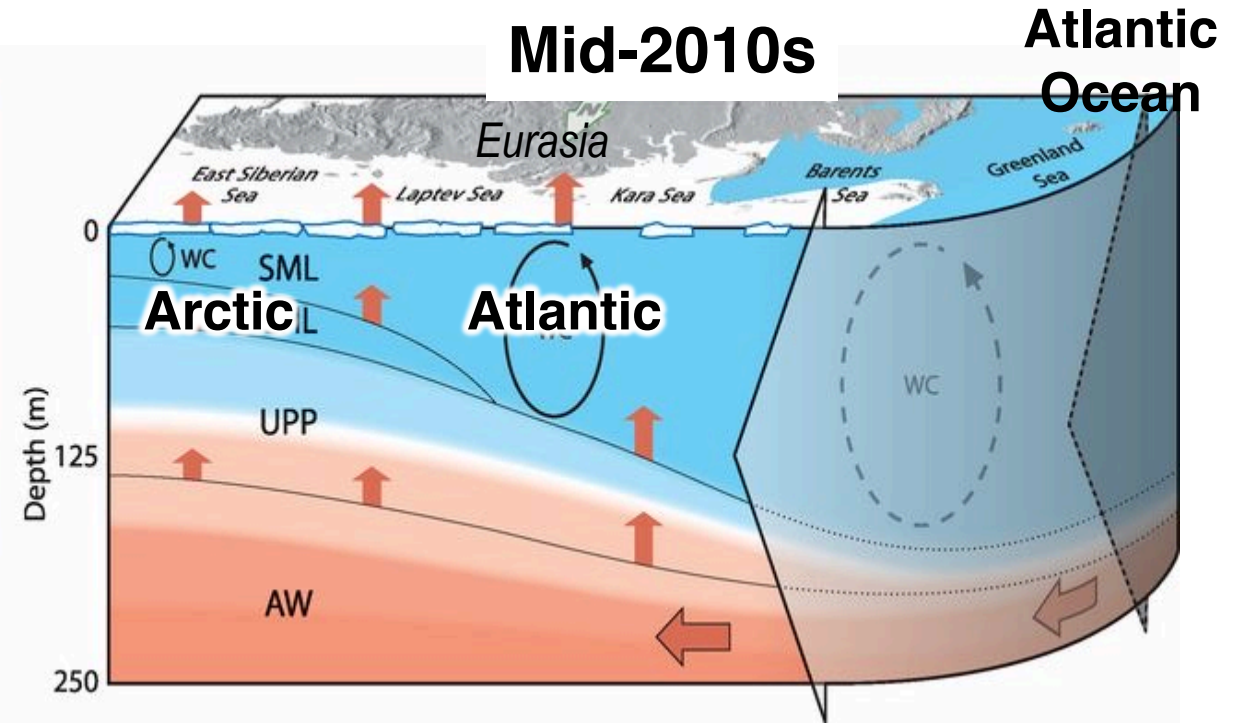


# Eurasian Basin (EB): “Atlantification”

Early 2000s

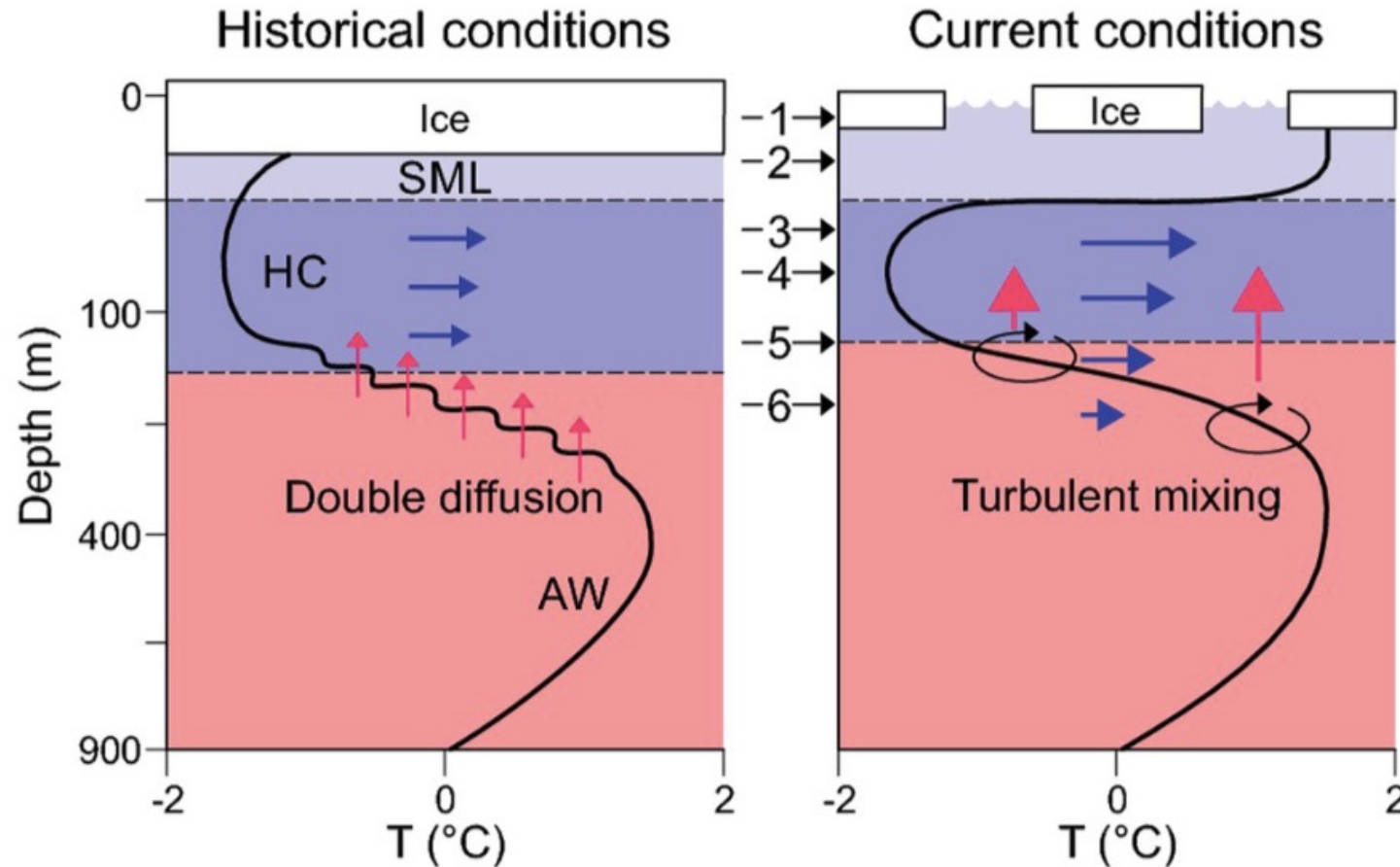


Mid-2010s



More **surface** ↔ **subsurface** communication

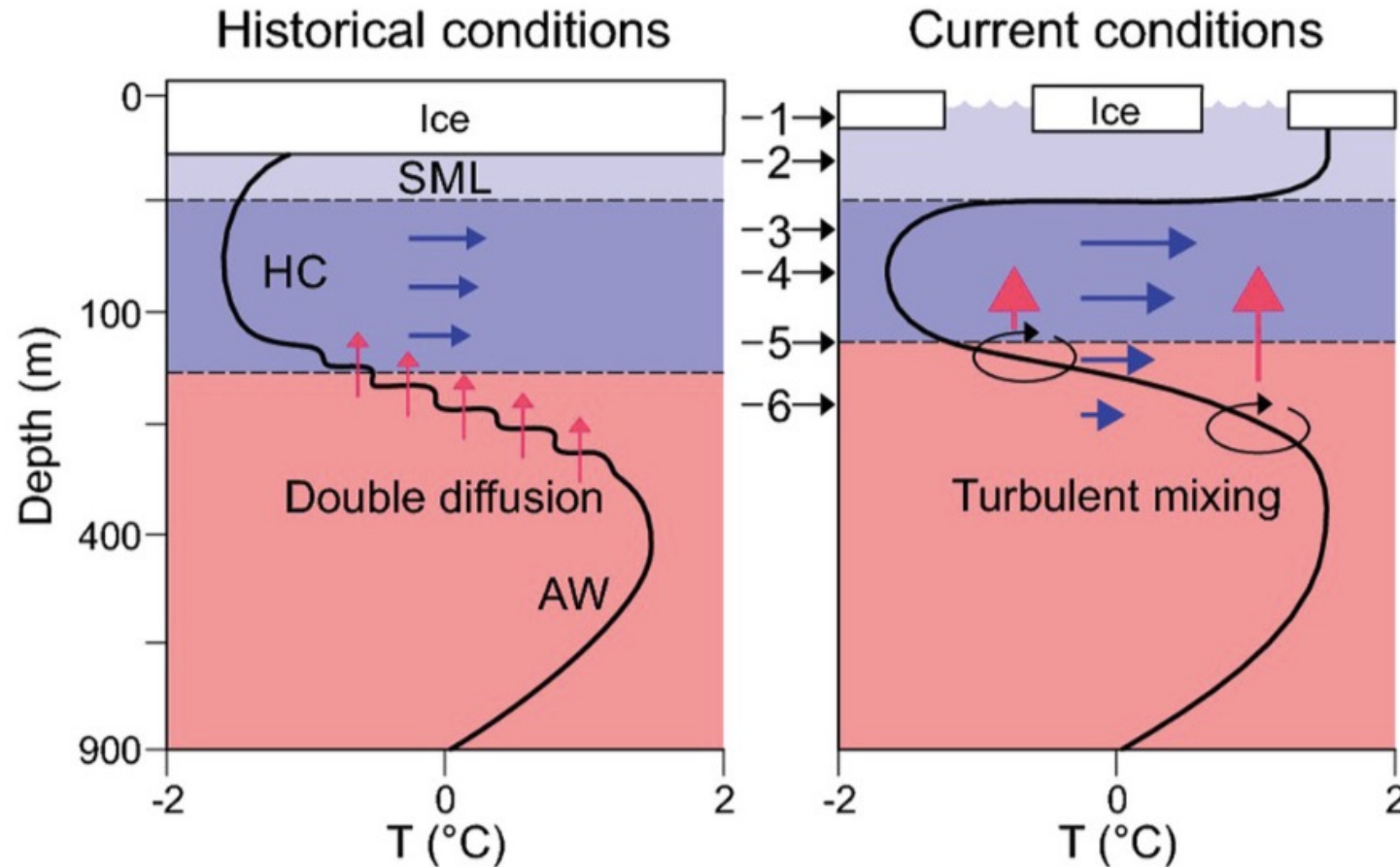
# Eurasian Basin (EB): *kinetic energy*



→  
**Stronger  
currents & mixing at depth**

*Polyakov et al. (J Climate, 2020)*

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→  
**Stronger  
currents & mixing at depth**

*Polyakov et al. (J Climate, 2020)*

## **Forced by:**

- Incr. wind → ocean (*looser ice*)
- Decr. stratification

*Polyakov et al. (GRL, 2020)*

# Summary

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- Weak downward KE propagation, but:
  - Episodic & patchy vertical “punching through”
  - Lateral (isopycnal) exchanges

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## Biochem implications:

- Air-sea **gas** exchange
- **Nutrient** supply
- **Zooplankton** overwintering

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Thank you!