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*
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**Wenli Zhong**

*Ocean U of China*
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Upper ~ 300 m
Ice Retreat

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

Ice loss even north of Greenland!

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

Feb 25, 2018
winter

Moore et al. (GRL, 2018)

Aug 2020
summer

Schweiger et al. (Nature CE&E, 2021)

later today: Axel Schweiger’s talk
Ice Change

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

Median (1981-2010)

Beaufort Sea

Sept 16, 2021

Complicated 2D geometry!
Ice Change

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

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

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Ocean surface warming

Sea Surface Temperature (SST)

UpTempO buoys

Sept 16, 2021

Sept 14, 2021

Complicated 2D geometry!

Complicated SST!

http://psc.apl.washington.edu/UpTempO/
Ocean surface warming

Sea Surface Temperature (SST)

Sept 14, 2021

UpTempO buoys

Sept 16, 2021

Alaska
Greenland

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...

Li et al. (Nature Comm., 2022)

Incr. SLP
\[ \rightarrow \text{ incr. } F_{\text{solar}} \]
\[ \rightarrow \text{ warming upper ocean} \]

1982-2020 Aug. SST trend (°C/yr)
Ocean surface warming

\[ \frac{dT_{0-50 \text{ m}}}{dt} \text{ (2000-2018)} \]

Ocean Reanalysis (ORAS5)

Wind-nudging runs (CESM ensemble)

60% from internal climate variability!

(vs. global warming)

Li et al. (Nature Comm., 2022)

Incr. SLP ➔ incr. \( F_{\text{Solar}} \) ➔ warming upper ocean

1982-2020 Aug. SST trend (°C/yr)
Ocean surface warming

\[ \frac{dT}{dt}_{0-50 \text{ m}} (2000-2018) \]

Ocean Reanalysis (ORAS5)

Wind-nudging runs (CESM ensemble)

Li et al. (Nature Comm., 2022)

Incr. SLP $\rightarrow$ incr. F_{solar}

$\rightarrow$ warming upper ocean

60% from internal climate variability!

(vs. global warming)

...so it could change

1982-2020 Aug. SST trend (°C/yr)

Warming
Ocean surface warming

http://psc.apl.washington.edu/UpTempO/
Ocean surface warming

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

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

Cold

UpTempO buoys

Sept 14, 2021

2 weeks later: icy!

Fournier et al. (GRL, 2022, in prep.)
Surface → Subsurface Warming?

Surface: N. Chukchi Sea

Subsurface: Beaufort Gyre

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?

Subsurface: Beaufort Gyre

Surface: N. Chukchi Sea

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

N. Chukchi Sea Heating

Beaufort Gyre Heat Content

Yes!

Timmermans et al. (Science Adv., 2018)
Ocean surface freshening


Overall freshening:

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

Polyakov et al. (Frontiers MarSci., 2020)
Ocean surface freshening


Overall freshening:

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- Less net ice growth
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…but mostly in the Amerasian Basin

Polyakov et al. (Frontiers MarSci., 2020)
Surface freshening $\rightarrow$ upper ocean stratifying?

\[ S(z) \sim \rho(z) \]

- fresher
- not changing?
Is the upper ocean stratifying?

\[ \Delta \text{halocline avail. pot. energy (APE)} \]


\[ 10^4 \text{ J/m}^2 \]

...Yes, mostly in the Amerasian Basin

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

Polyakov et al. (Frontiers MarSci., 2020)
Is the upper ocean stratifying?

Δ halocline avail. pot. energy (APE)
[2006-2017] − [1981-1995]

less stratified

more stratified

similar to
Δ 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?

\[ \Delta \text{halocline avail. pot. energy (APE)} \]


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

Woodgate & Peralta-Ferriz (GRL, 2021)
Amerasian Basin (AB): stratification

PSW: Pacific Summer Water: more
PWW: Pacific Winter Water: fresher

Enhanced stratification

$S(z) \sim \rho(z)$

Freshwater shoaling

Woodgate & Peralta-Ferriz (GRL, 2021)
Amerasian Basin (AB): kinetic energy

Zhong et al. (JGR, 2017)
Amerasian Basin (AB): kinetic energy

The surface is spinning up!

Zhong et al. (JGR, 2017)

Spreen et al. (GRL, 2011)
Amerasian Basin (AB): kinetic energy

Zhong et al. (JGR, 2017)

Zhong et al. (GRL, 2019)

2007/2008: Step increase!
Amerasian Basin (AB): kinetic energy

AB surface $u_{geo}$ (1992-2014)

Faster ocean

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?

**Diffusivity** (150 - 400 m depth)

Guthrie et al. (JGR, 2013)

*Also:* Guthrie & Morison (GRL, 2021)
**Is there more ocean mixing at depth?**

Nope!

Enhanced stratification

**Amerasian Basin (AB): kinetic energy**

**Diffusivity (150 - 400 m depth)**

No trends

Enhanced stratification

Guthrie et al. (JGR, 2013)

*Also: Guthrie & Morison (GRL, 2021)*
Amerasian Basin (AB): \textit{kinetic energy}

Is there more ocean mixing at depth?

Enhanced stratification

Nope!

However:

- \textit{incr large-amplitude IGW events} \hspace{1cm} Dosser & Rainville (JPO, 2016)

Guthrie et al. (JGR, 2013)

Also: Guthrie & Morison (GRL, 2021)
Amerasian Basin (AB): punching through the stratification

Zhong et al. (JGR, 2022)
Amerasian Basin (AB): *punching through the stratification*

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

Zhong et al. (JGR, 2022)
Amerasian Basin (AB): *punching through the stratification*

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

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

Thinning ice in the AB  $\rightarrow$ incr. winter ice growth / brine rejection / convection

Zhong et al. (JGR, 2022)
Amerasian Basin (AB): *punching through the stratification*

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

Incr. stratification is *patchy* and can be overcome

Obs. winter ocean-to-ice heat flux (W/m²)

**Thinning ice in the AB** → incr. winter ice growth / brine rejection / convection

Zhong et al. (JGR, 2022)
Eurasian Basin (EB): “Atlantification”

...really, “N. Atlantification”

shallow MLD
stronger stratification
colder, fresher

deep MLD
weak stratification
warm, salty

MLD: Mixed Layer Depth (m)

Tjiputra et al. (GeoModel Dev/Disc, 2012)
Eurasian Basin (EB): “Atlantification”

More surface ↔ subsurface communication

Polyakov et al. (Science, 2017)
Eurasian Basin (EB): kinetic energy

Polyakov et al. (J Climate, 2020)

Stronger currents & mixing at depth
Eurasian Basin (EB): kinetic energy

**Historical conditions**

- Ice
- SML
- HC
- Double diffusion
- AW

**Current conditions**

- Ice
- Turbulent mixing

**Forced by:**
- Incr. wind ➔ ocean (looser ice)
- Decr. stratification

Polyakov et al. (J Climate, 2020)

Stronger currents & mixing at depth

Polyakov et al. (GRL, 2020)
Summary

**Amerasian Basin: Incr. stratification**

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

**Amerasian Basin:** *Incr. stratification*
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**Eurasian Basin:** *Decr. stratification*
- Direct surface/subsurface exchange
- Incr. mixing and subsurface current speed
Summary

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**Biochem implications:**
- Air-sea gas exchange
- Nutrient supply
- Zooplankton overwintering
**Summary**

**Amerasian Basin: Incr. stratification**
- Weak downward KE propagation, but:
  - Episodic & patchy vertical “punching through”
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**Eurasian Basin: Decr. stratification**
- Direct surface/subsurface exchange
- Incr. mixing and incr. subsurface current speed

**Biochem implications:**
- Air-sea gas exchange
- Nutrient supply
- Zooplankton overwintering

Thank you!