Filling in the Map:

The space-time geography of Arctic Ocean mixing and why it matters

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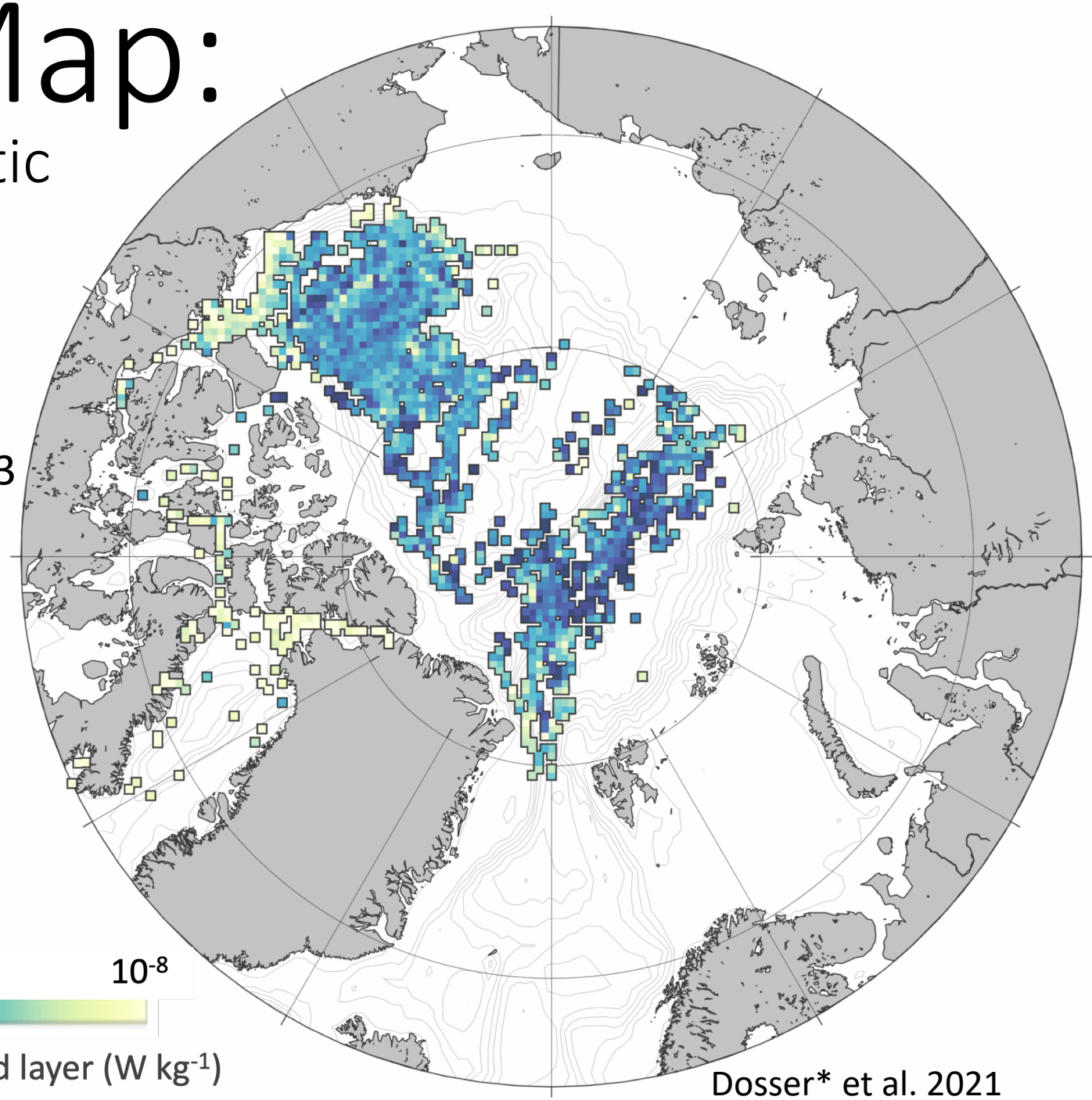
Jacquie-Lee Epstein* (MSc 2018)
Benjamin O'Connor* (BSc 2020)
Becky Brooks* (summer intern, 2022)
Hayley Dosser* (PDF)
& many valued collaborators…

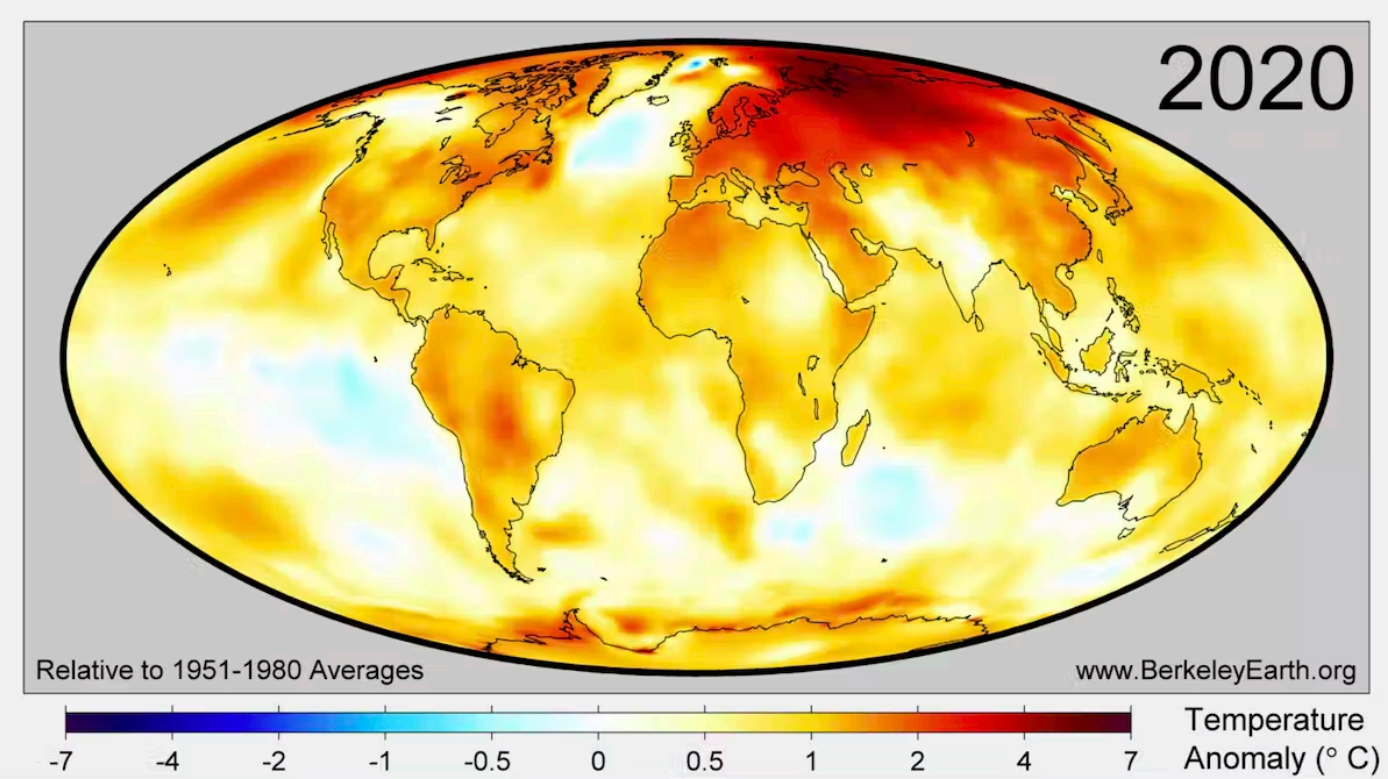


Dosser* et al. 2021

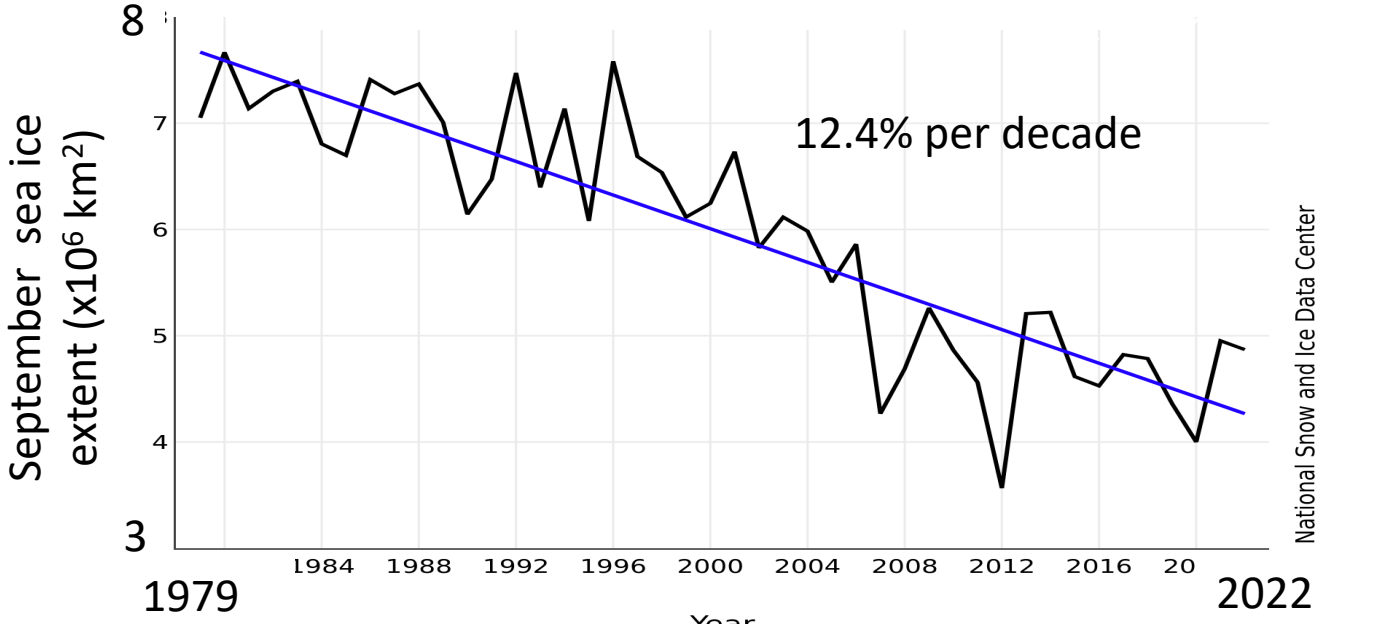
EGU General Assembly 2023

Vienna, Austria | April 25, 2023

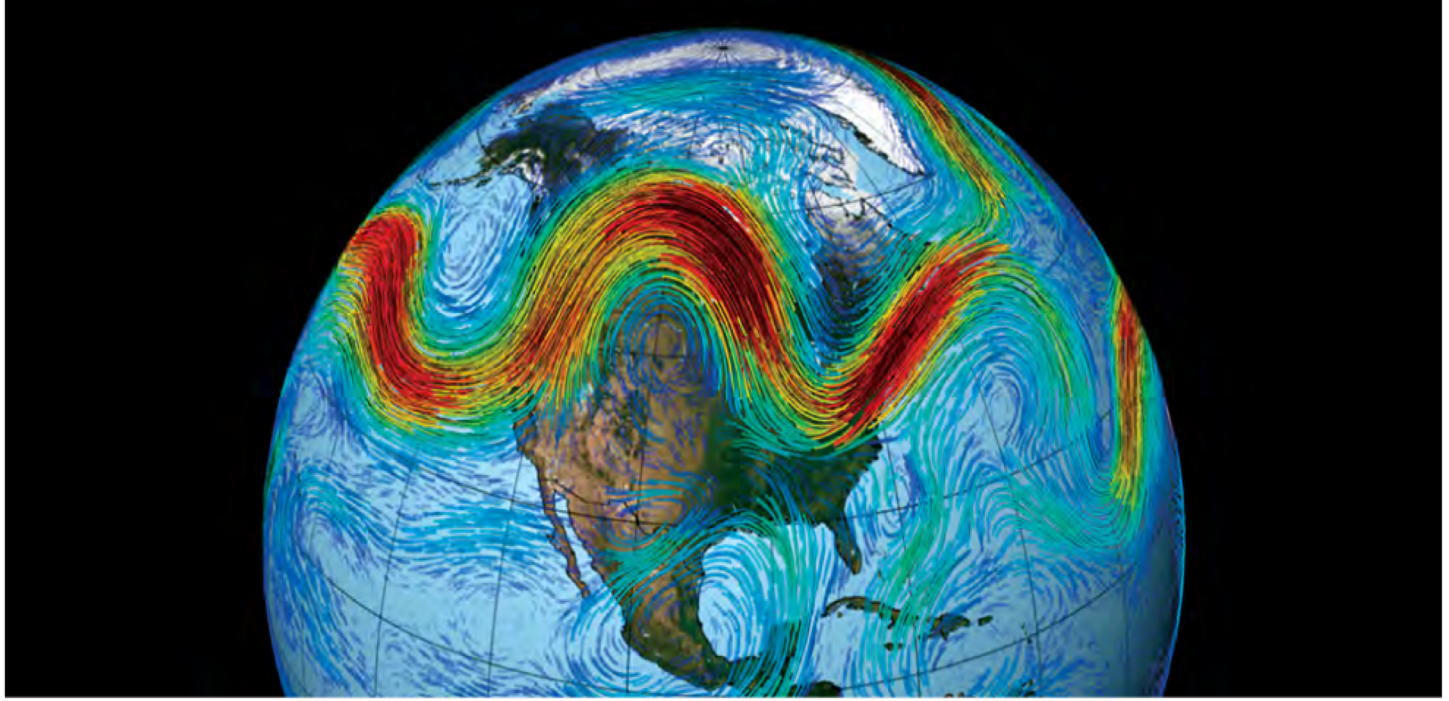
The Arctic is changing faster than anywhere else on Earth.



- temperatures are rising
- land & sea ice is melting
- permafrost is thawing
- ecosystems are changing
- people's lives are being affected

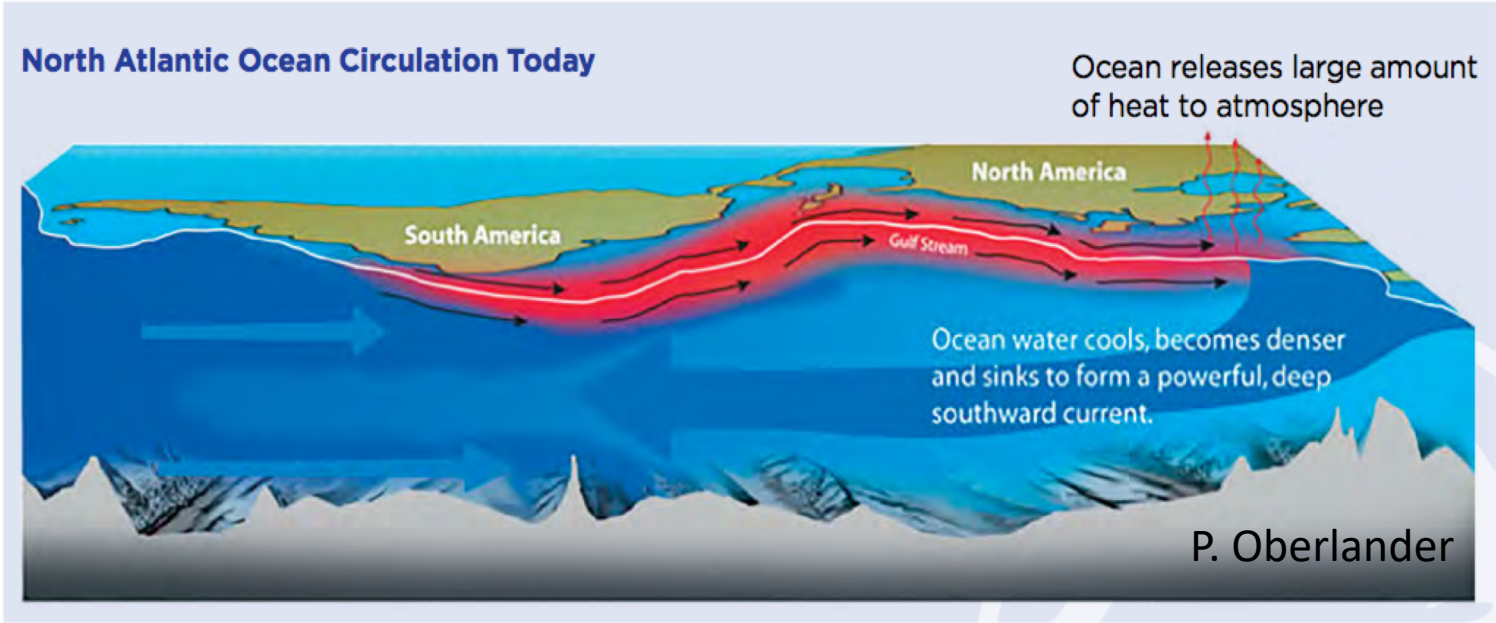


These changes have global impact.

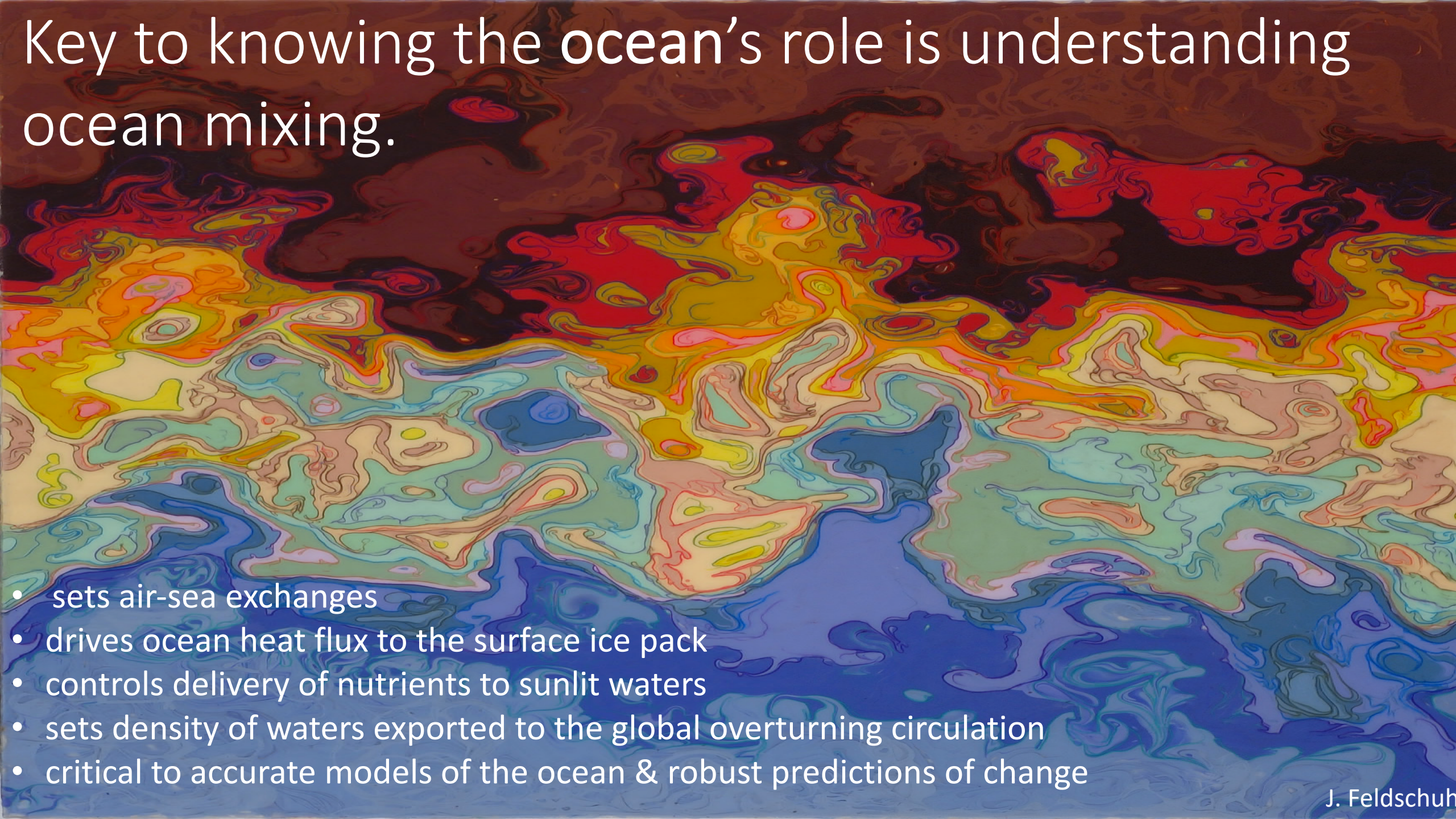


NASA

- global sea level rise
- N. Hemisphere weather
- ocean overturning circulation
- global food sources
- climate change feedbacks



Key to knowing the **ocean**'s role is understanding ocean mixing.

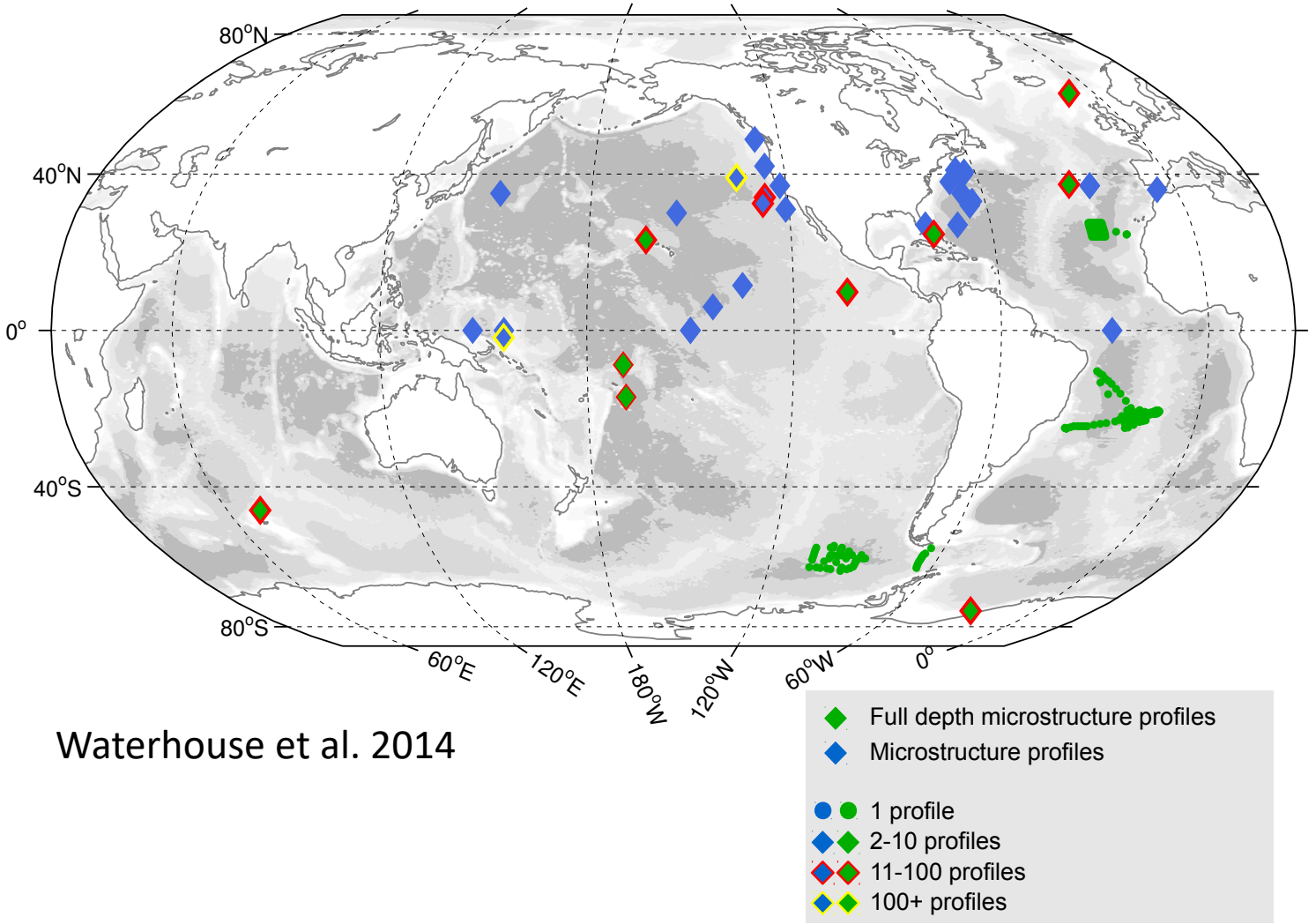


- sets air-sea exchanges
- drives ocean heat flux to the surface ice pack
- controls delivery of nutrients to sunlit waters
- sets density of waters exported to the global overturning circulation
- critical to accurate models of the ocean & robust predictions of change

J. Feldschuh

Our understanding of ocean mixing is limited by a scarcity of measurements.

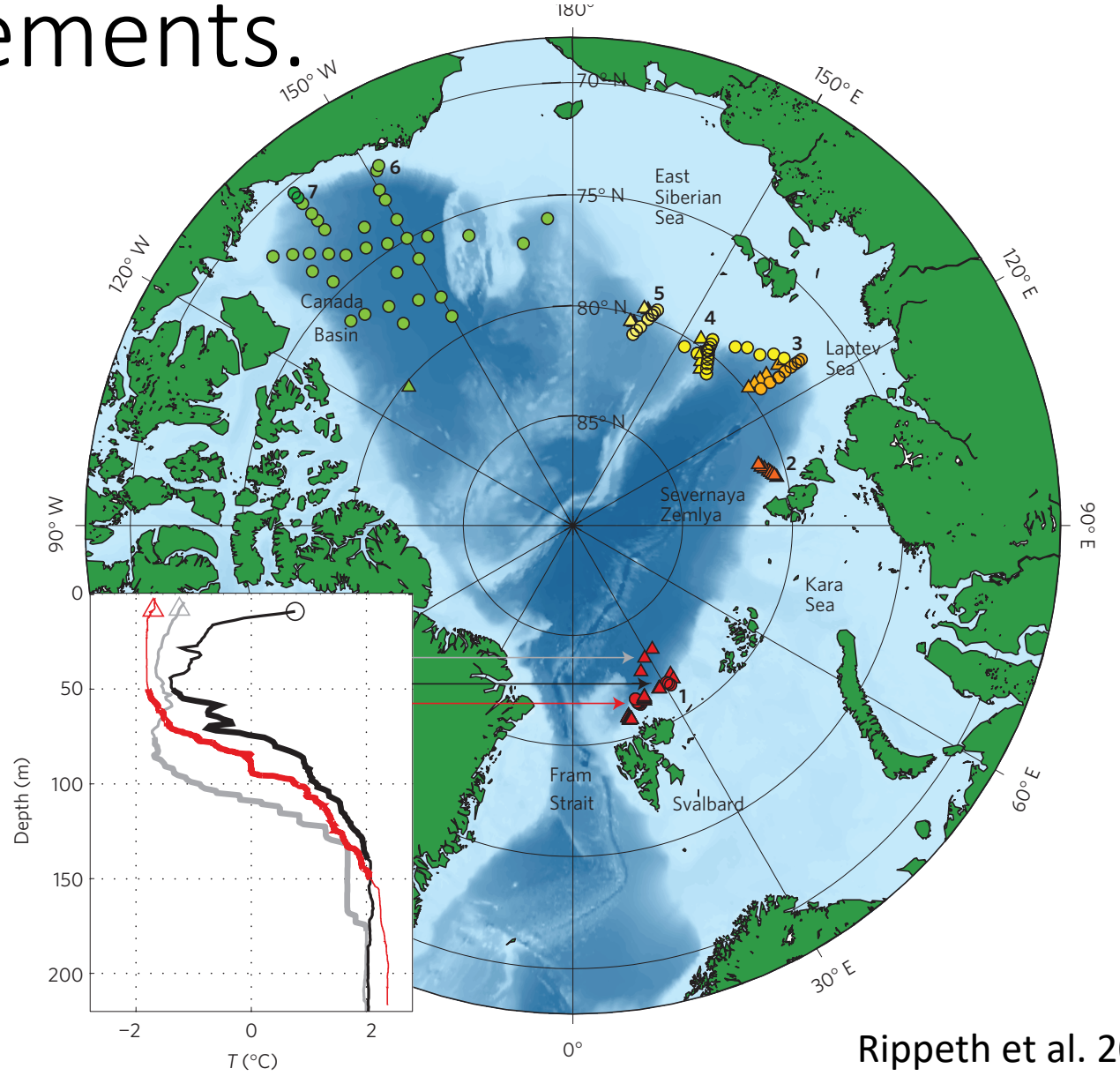
- measuring ocean turbulence is difficult, time-consuming & requires specialized instrumentation → measurements in the world's oceans remain sparse



Waterhouse et al. 2014

Our understanding of ocean mixing is limited most by a scarcity of measurements.

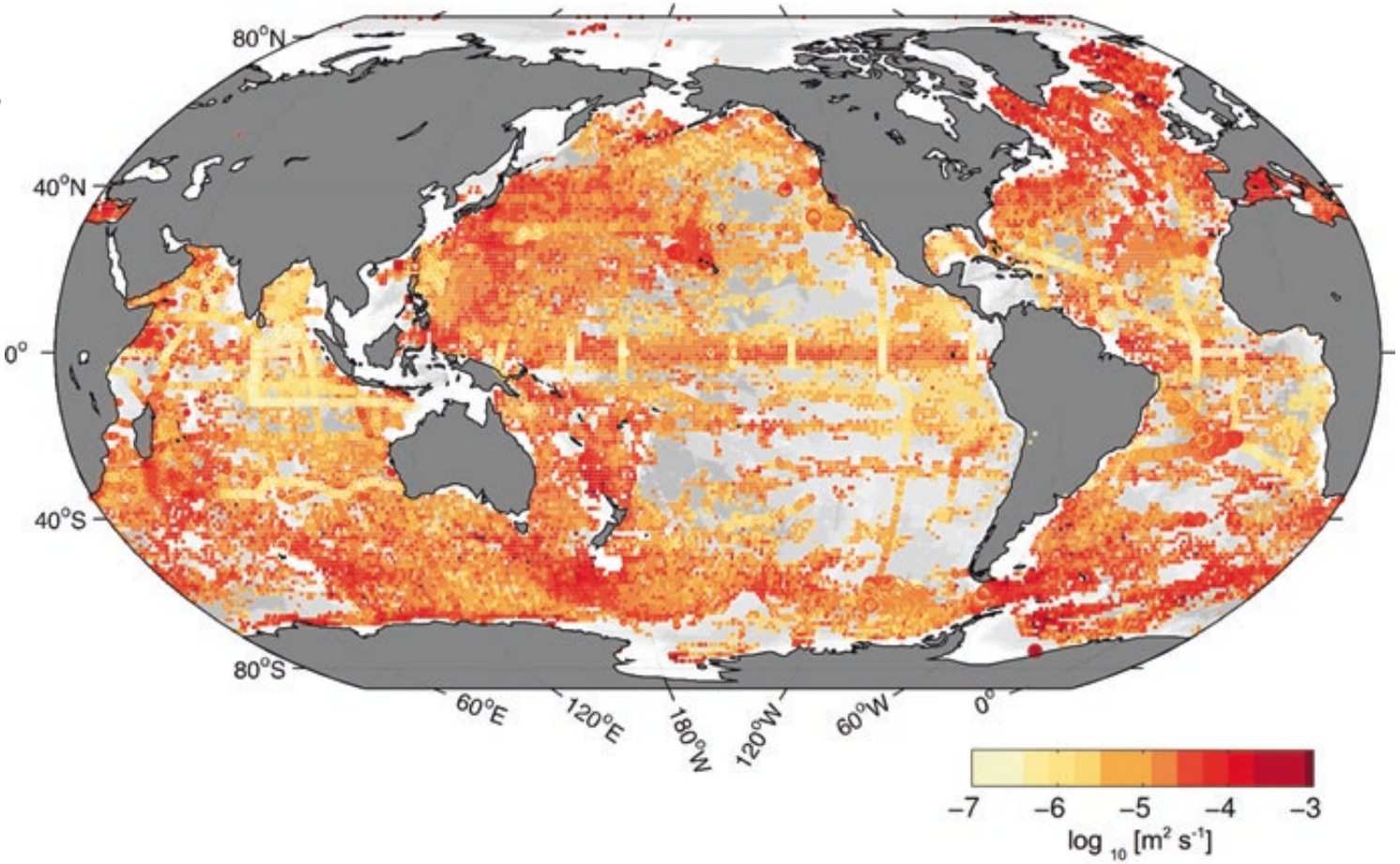
- measuring ocean turbulence is difficult, time-consuming & requires specialized instrumentation → measurements in the world's oceans remain sparse
- 'direct' measurements of ocean mixing in the Arctic Ocean are **extremely** rare



Rippeth et al. 2015

Our understanding of ocean mixing is limited most by a scarcity of measurements.

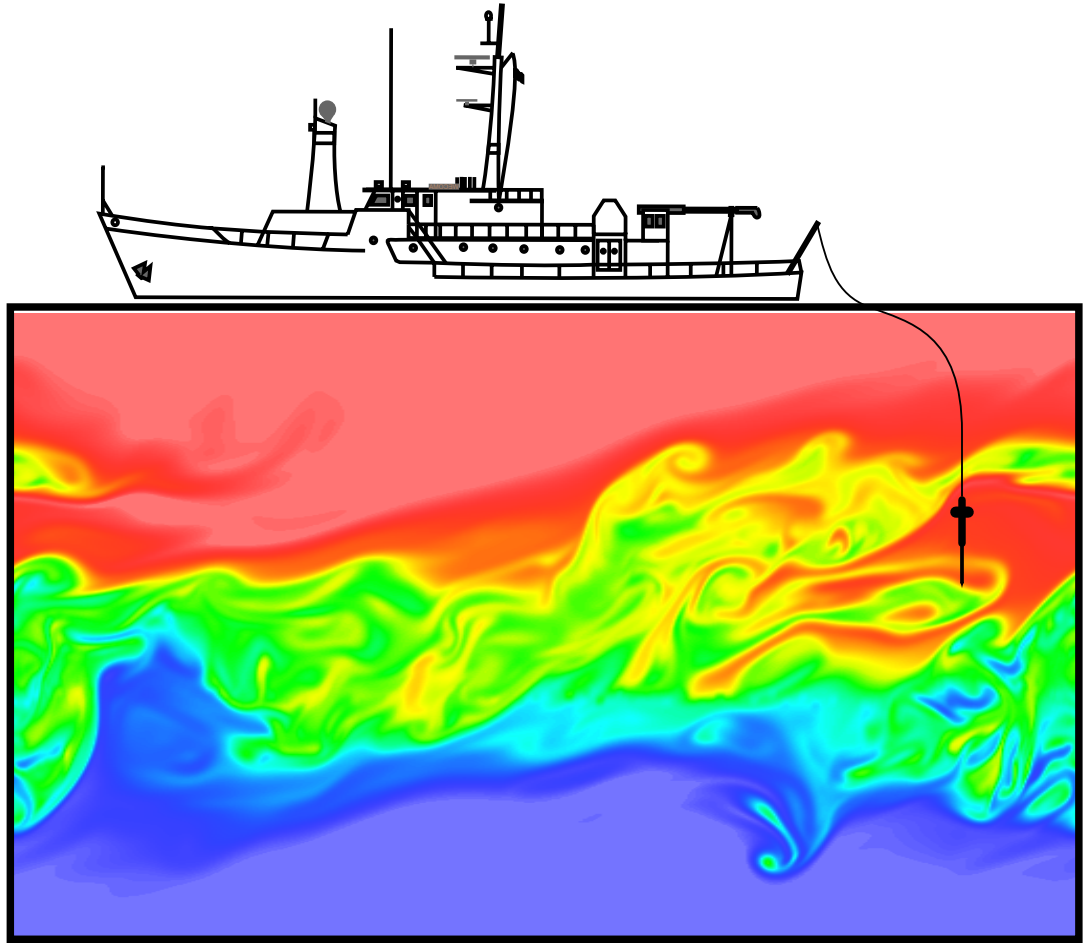
- measuring ocean turbulence is difficult, time-consuming & requires specialized instrumentation → measurements in the world's oceans remain sparse
- 'direct' measurements of ocean mixing in the Arctic Ocean are **extremely** rare
- large-scale studies of mixing using 'indirect' methods have thus far largely excluded this region



updated from Waterhouse et al. 2014

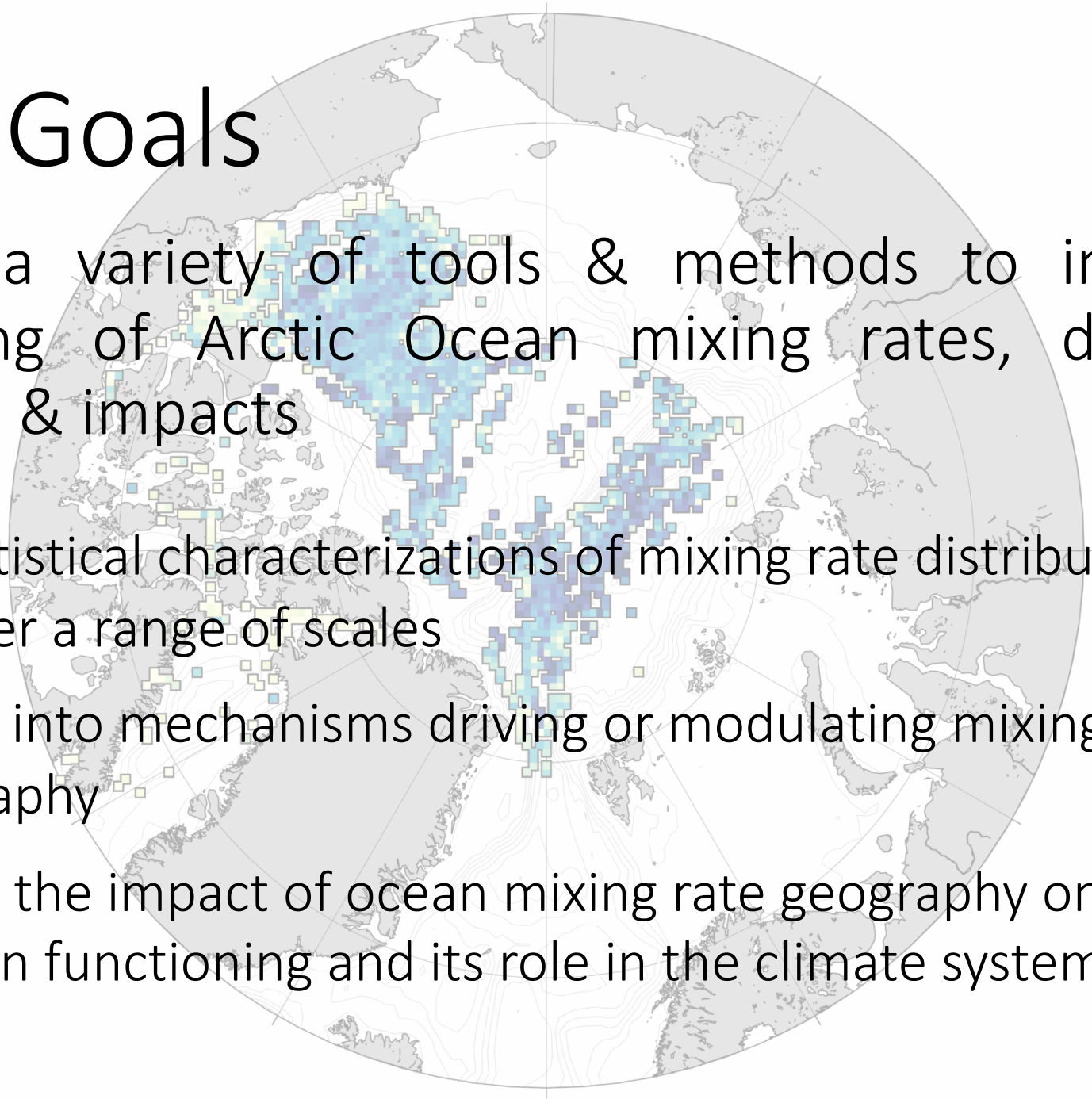
Our understanding of ocean mixing is limited most by a scarcity of measurements.

- lack of data makes it difficult to:
  - put isolated measurements into context
  - robustly characterize mean mixing rates & their space-time variability
  - understand governing physics/dynamical processes responsible for setting mixing rates & their variability
  - understand the unique Arctic Ocean mixing environment characterized by very low energy and very high stratification



OSU Mixing Group

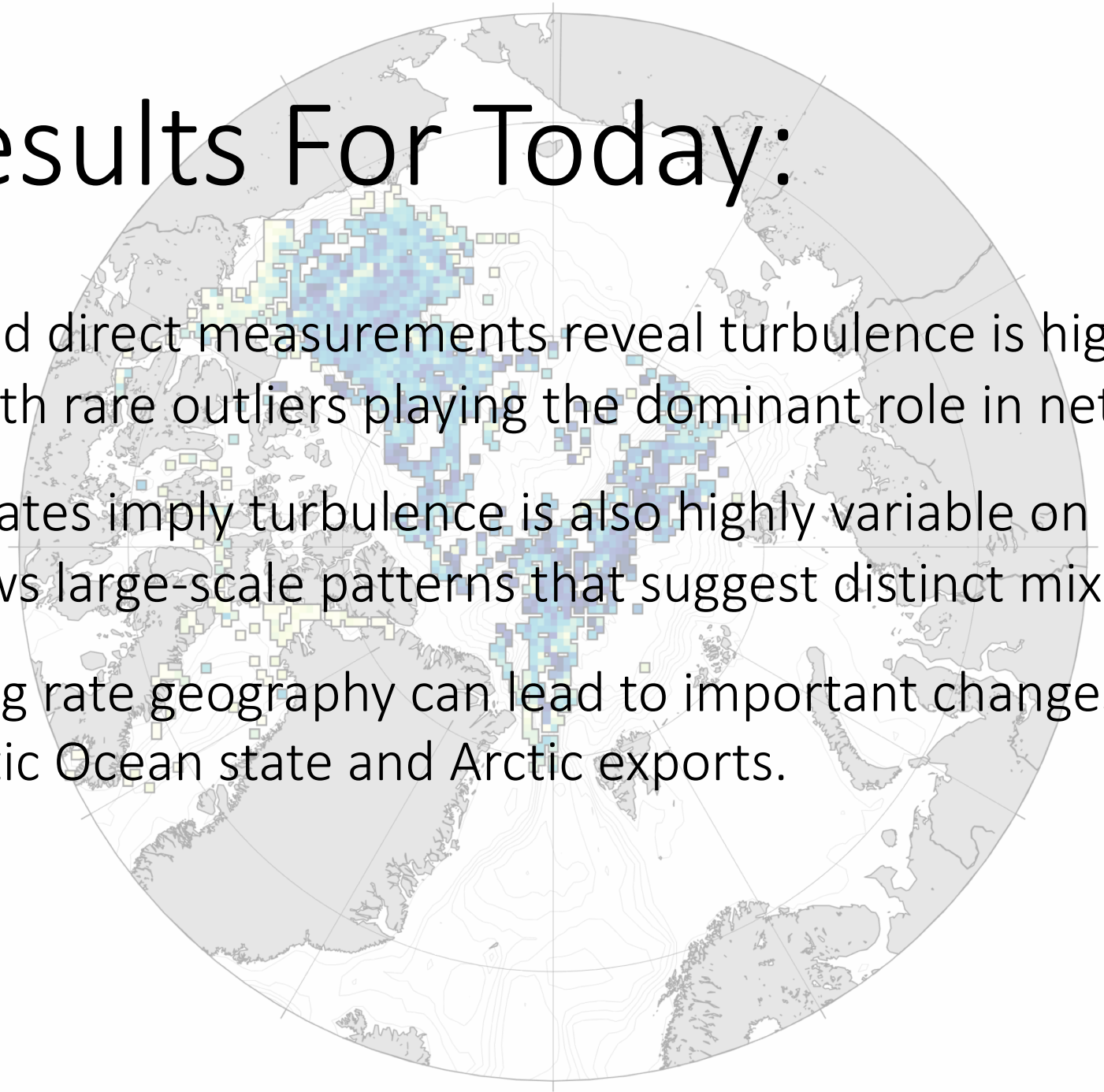
Research Goals



to employ a variety of tools & methods to improve our understanding of Arctic Ocean mixing rates, distributions, mechanisms & impacts

1. provide statistical characterizations of mixing rate distributions in time & space over a range of scales
2. gain insight into mechanisms driving or modulating mixing rate space-time geography
3. understand the impact of ocean mixing rate geography on large-scale Arctic Ocean functioning and its role in the climate system

3 Key Results For Today:



1. Highly-resolved direct measurements reveal turbulence is highly variable on local scales with rare outliers playing the dominant role in net mixing fluxes.
2. Indirect estimates imply turbulence is also highly variable on the pan-Arctic scale but shows large-scale patterns that suggest distinct mixing regimes.
3. Variable mixing rate geography can lead to important changes in the modelled Arctic Ocean state and Arctic exports.

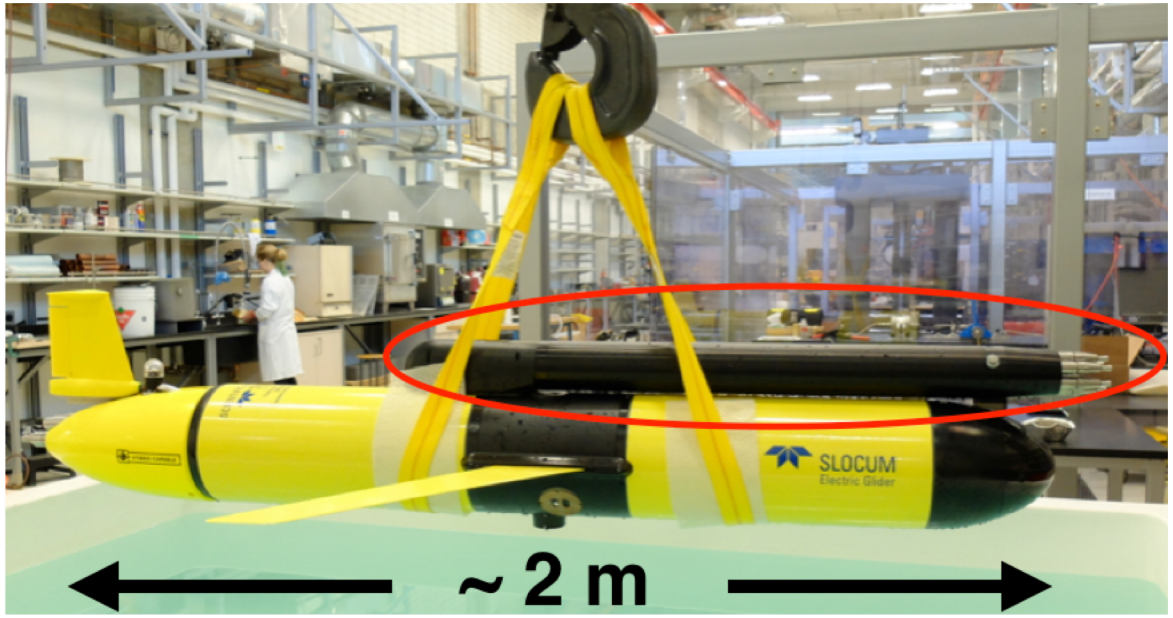
Key Result 1:

Turbulence is highly variable on local scales…

Key Result 1 brought to you by:

The Turbulence-Sensing Glider “Mike”

- 'directly’ measures turbulence via installation of a specialized turbulent-sensing package



T. Howatt*

Rockland Scientific International

Key Result 1 brought to you by:

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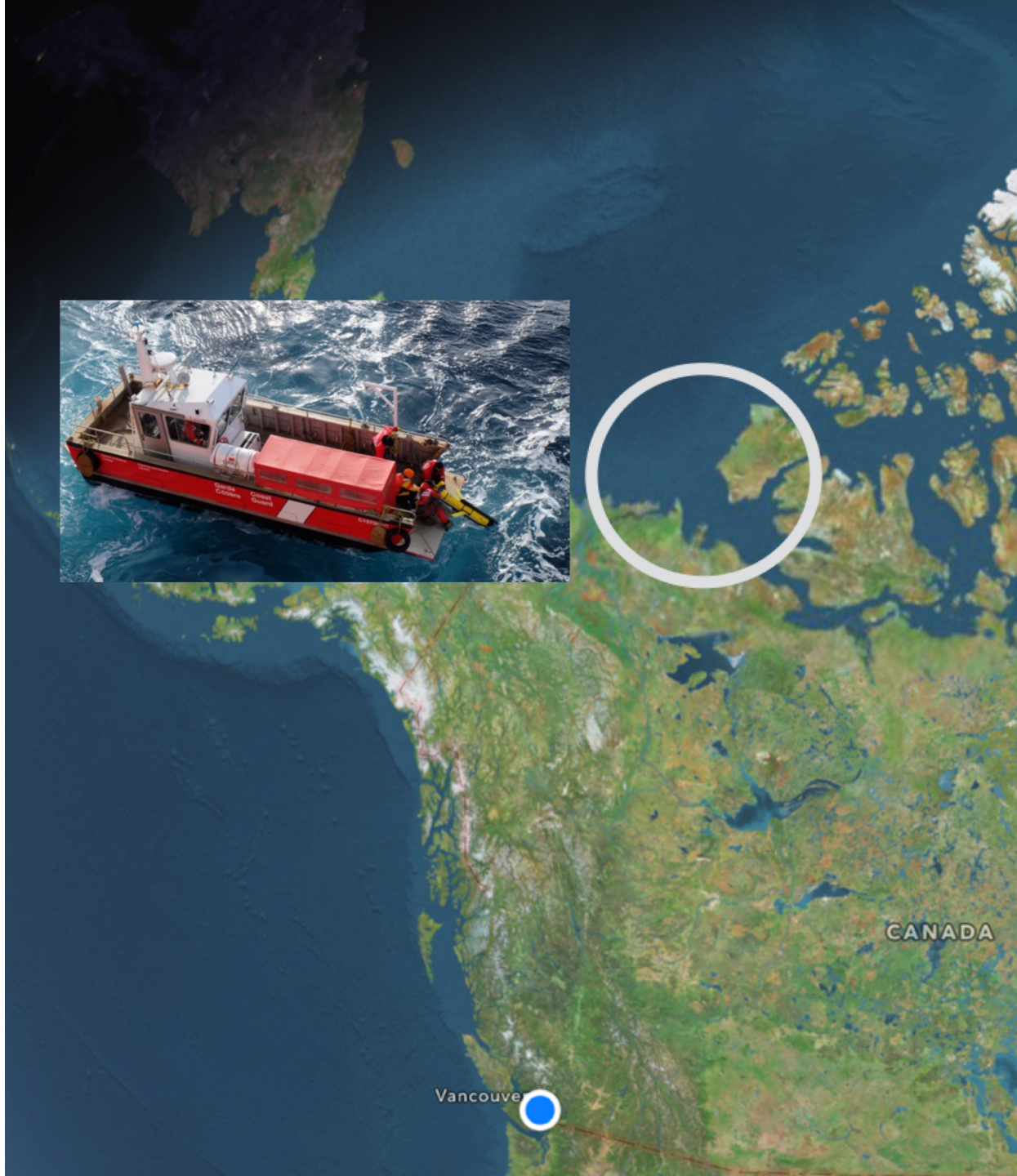
- in 2015, made uniquely-resolved observations of turbulence in the “quiet” Beaufort Sea



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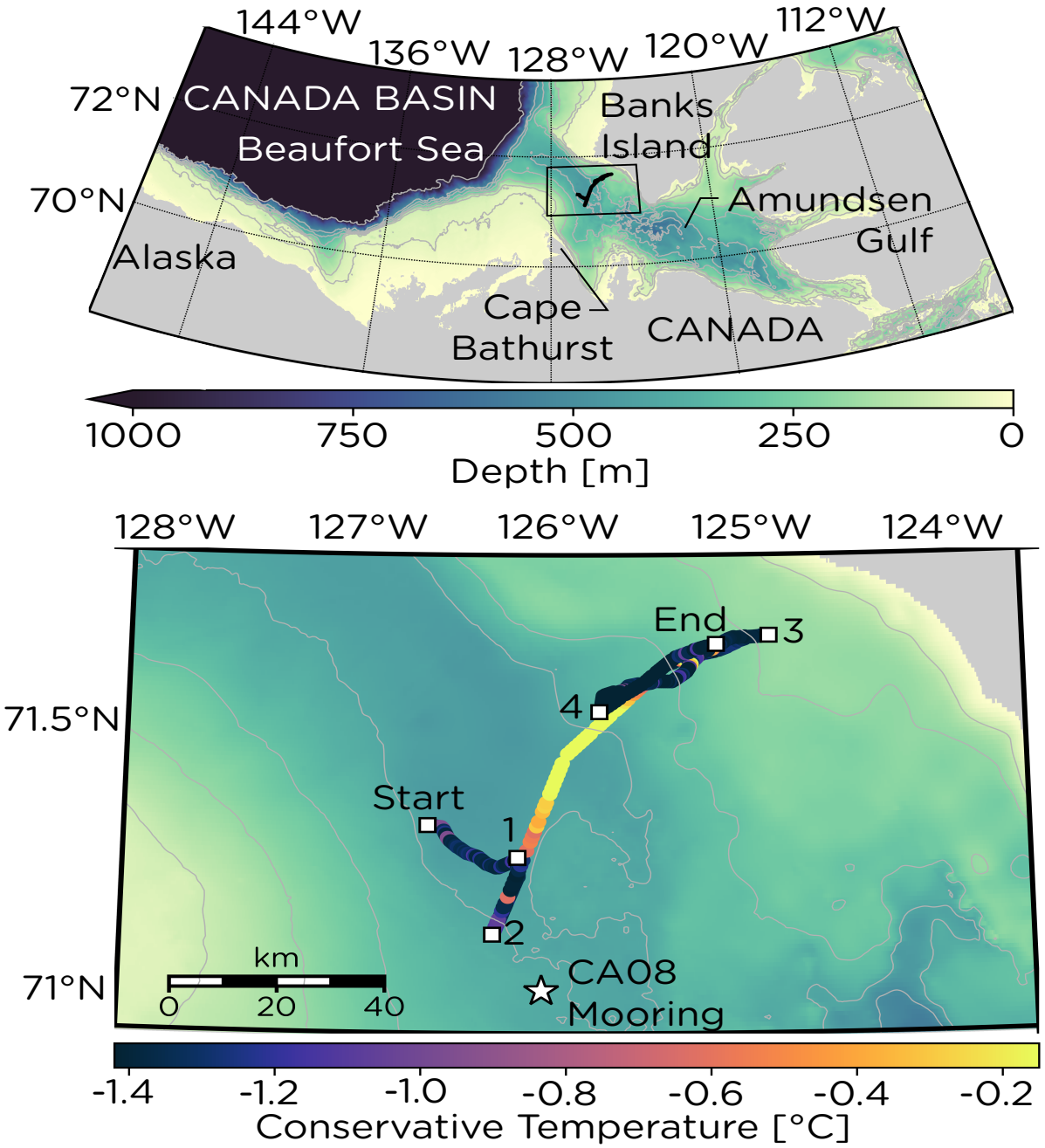
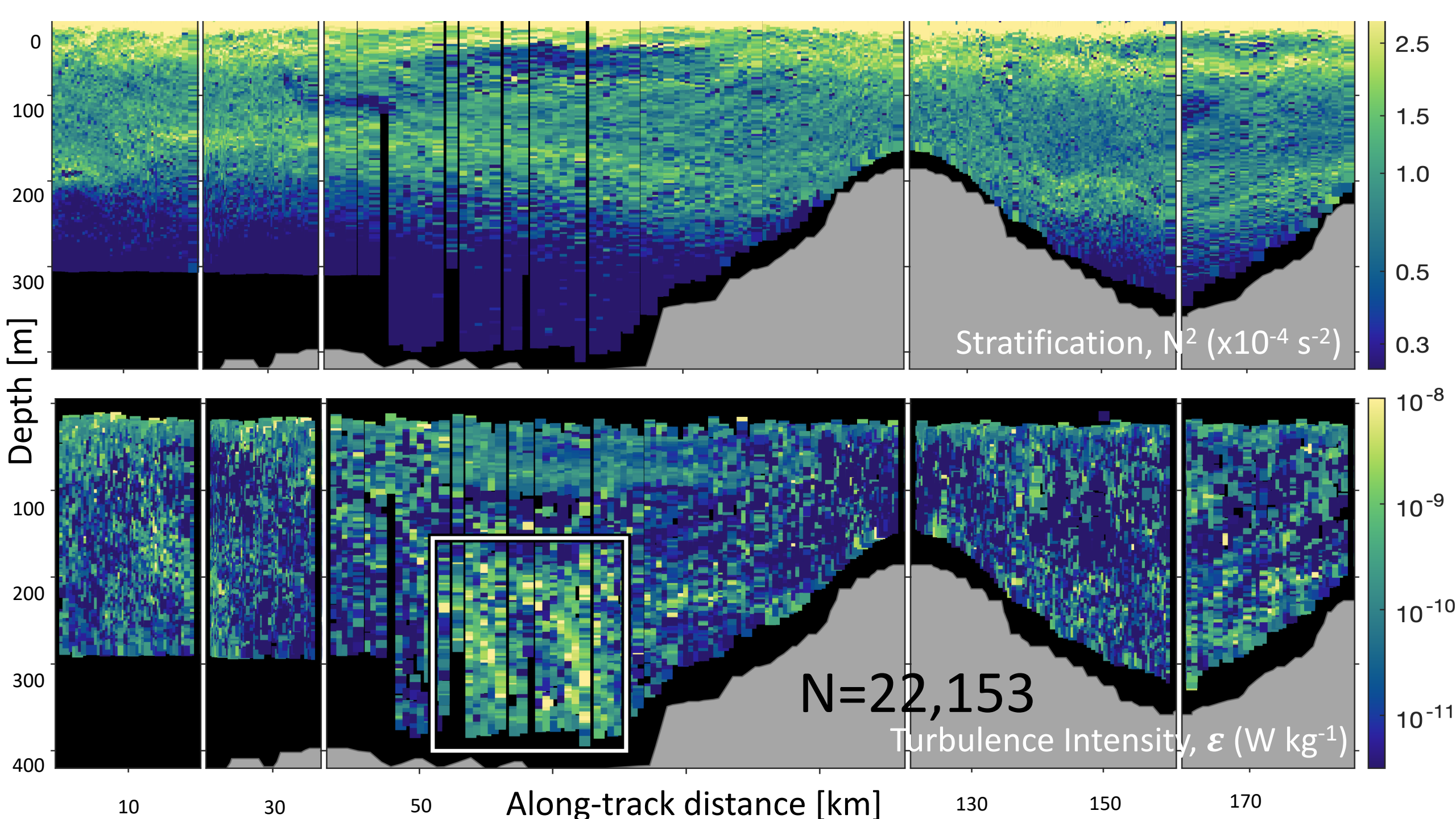
The Turbulence-Sensing Glider “Mike”

- 'directly’ measures turbulence via installation of a specialized turbulent-sensing package
- in 2015, made uniquely-resolved observations of turbulence in the “quiet” Beaufort Sea
- 11 days – 185 km track – 345 CTD & turbulent microstructure profiles: the densest turbulence sampling scheme in the western Arctic to date!

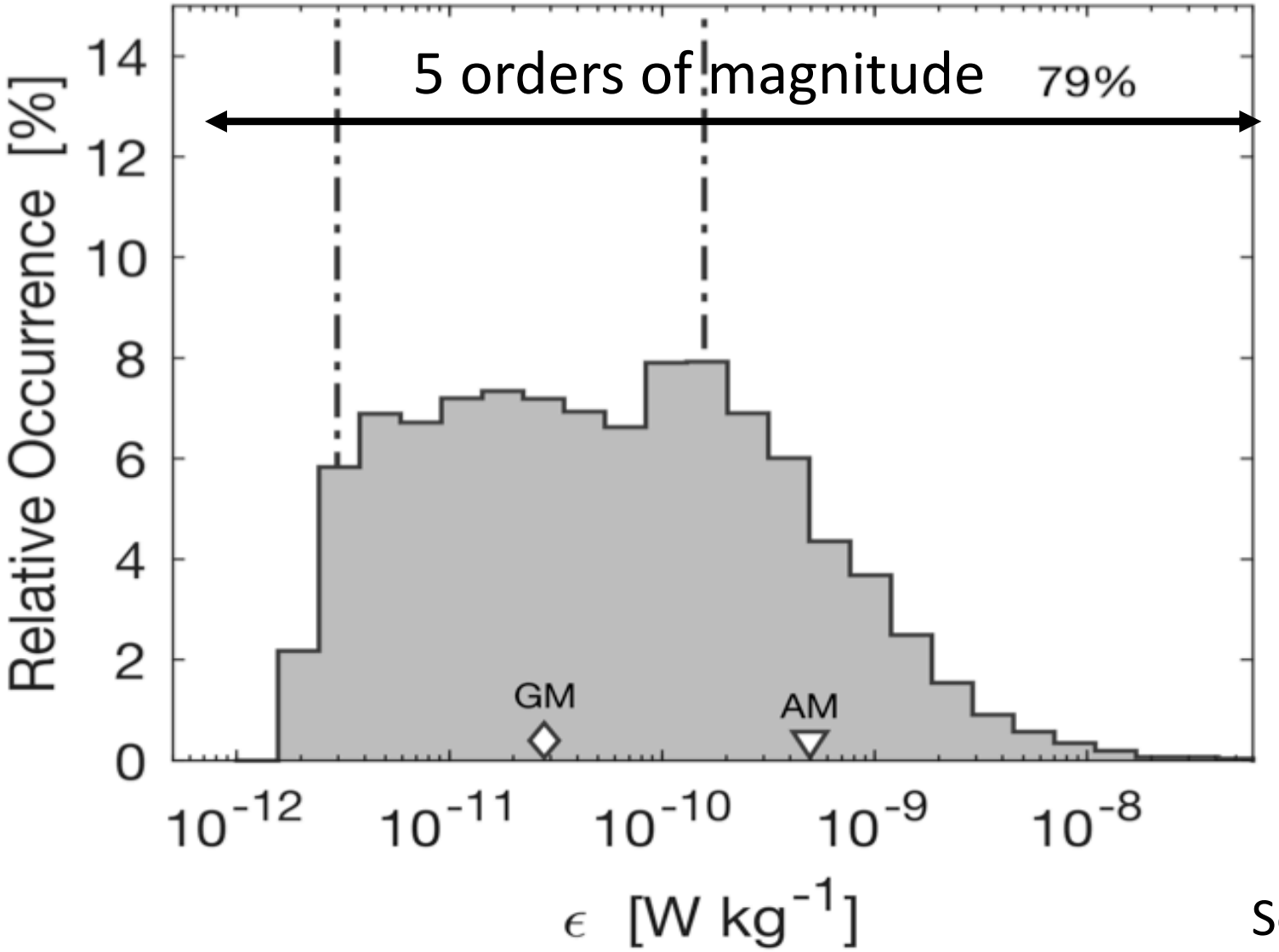


Scheifele* et al. 2021


Depth [m]
0
100
200
300
400
Stratification, N² (x10⁻⁴ s⁻²)
2.5
1.5
1.0
0.5
0.3
N=22,153
Turbulence Intensity, ε (W kg⁻¹)
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10
30
50
Along-track distance [km]
130
150
170

Key Result 1:

Turbulence is highly variable on local scales…

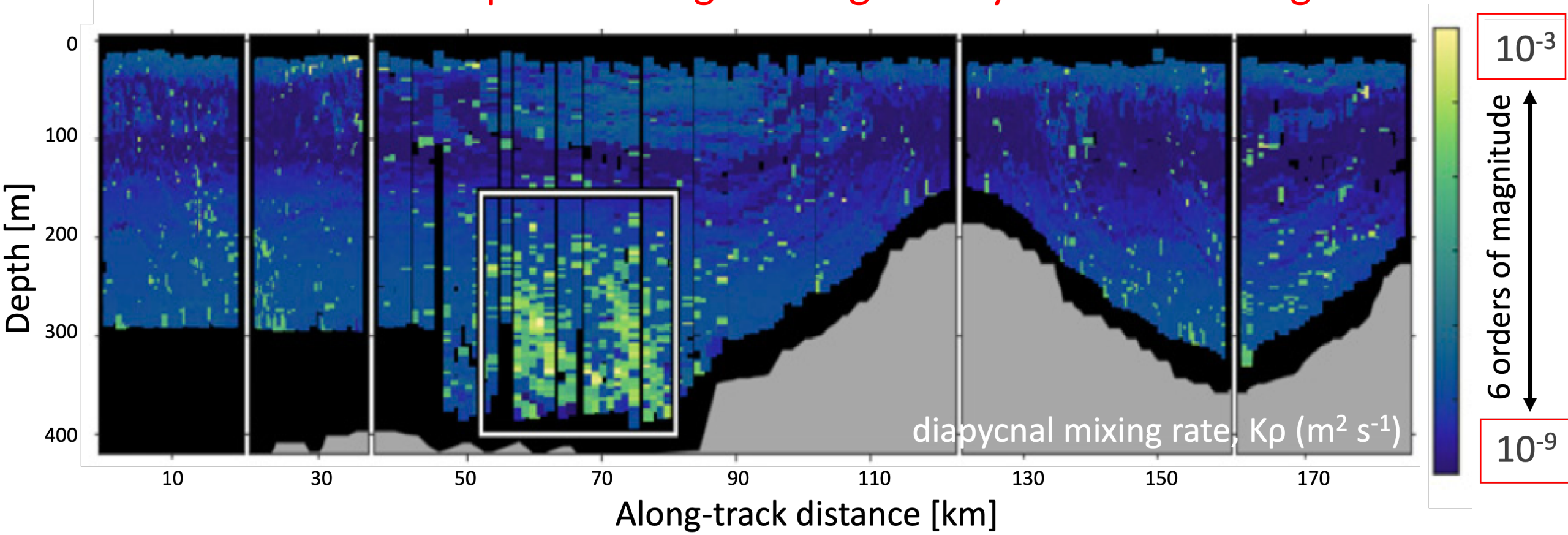


Scheifele* et al. 2021

Key Result 1:

… rare outliers play the dominant role in net mixing fluxes.

7% of estimates draw up the average mixing rate by 3 orders of magnitude!



Scheifele* et al. 2021

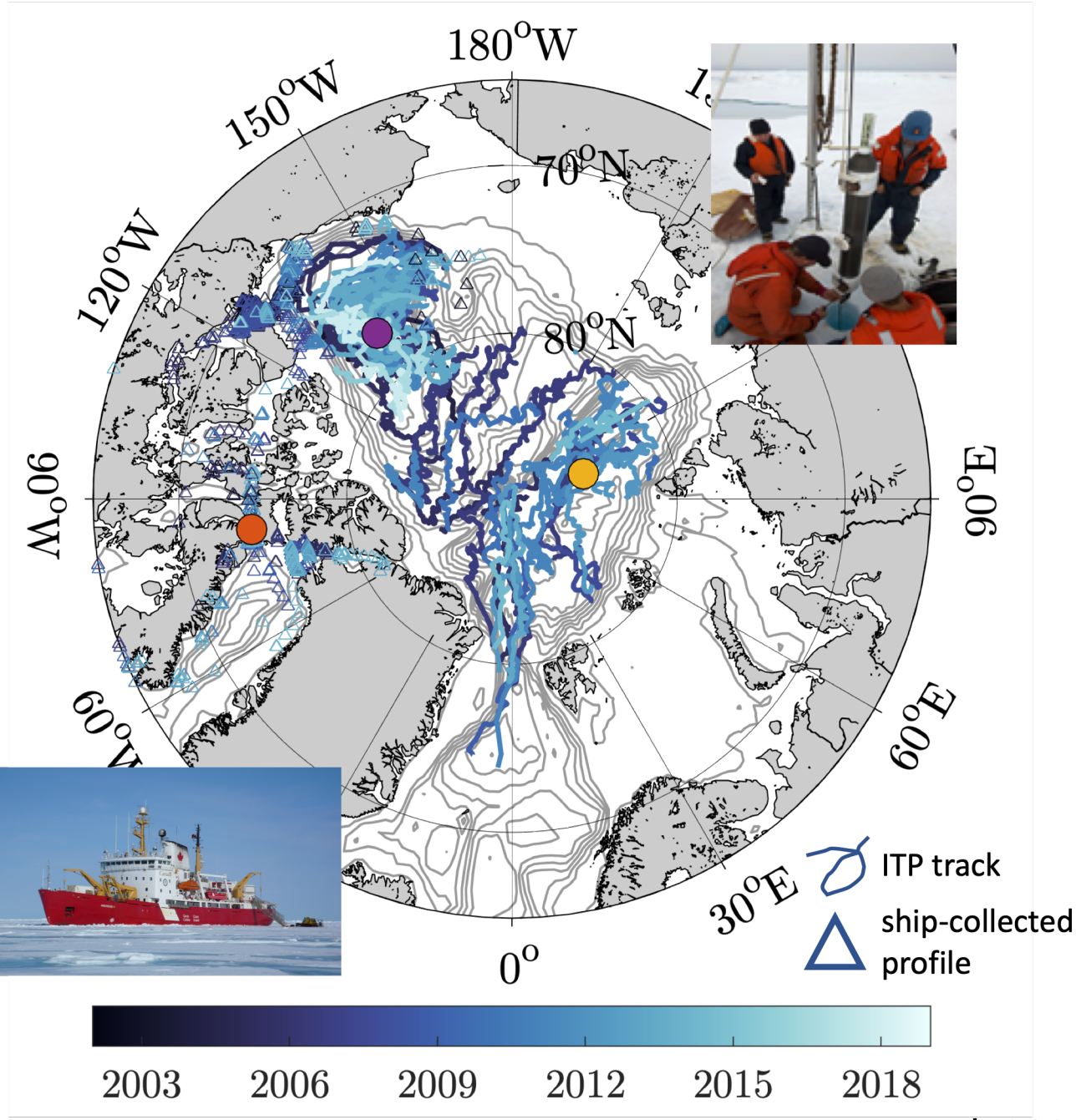
Key Result 2:

Turbulence is highly variable on the pan-Arctic scale…

Key Result 2 brought to you by:

the historic data record …

- 29,074 hydrographic profiles from 89 ITPs that sampled the central Arctic Ocean year-round 2004 - 2019
- 3,084 hydrographic profiles collected by ship-based programs in Canadian Arctic shelf & slope waters 2002 - 2014



Access the data at:
ftp.whoi.edu/whoinet/itpdata & www.polardata.ca

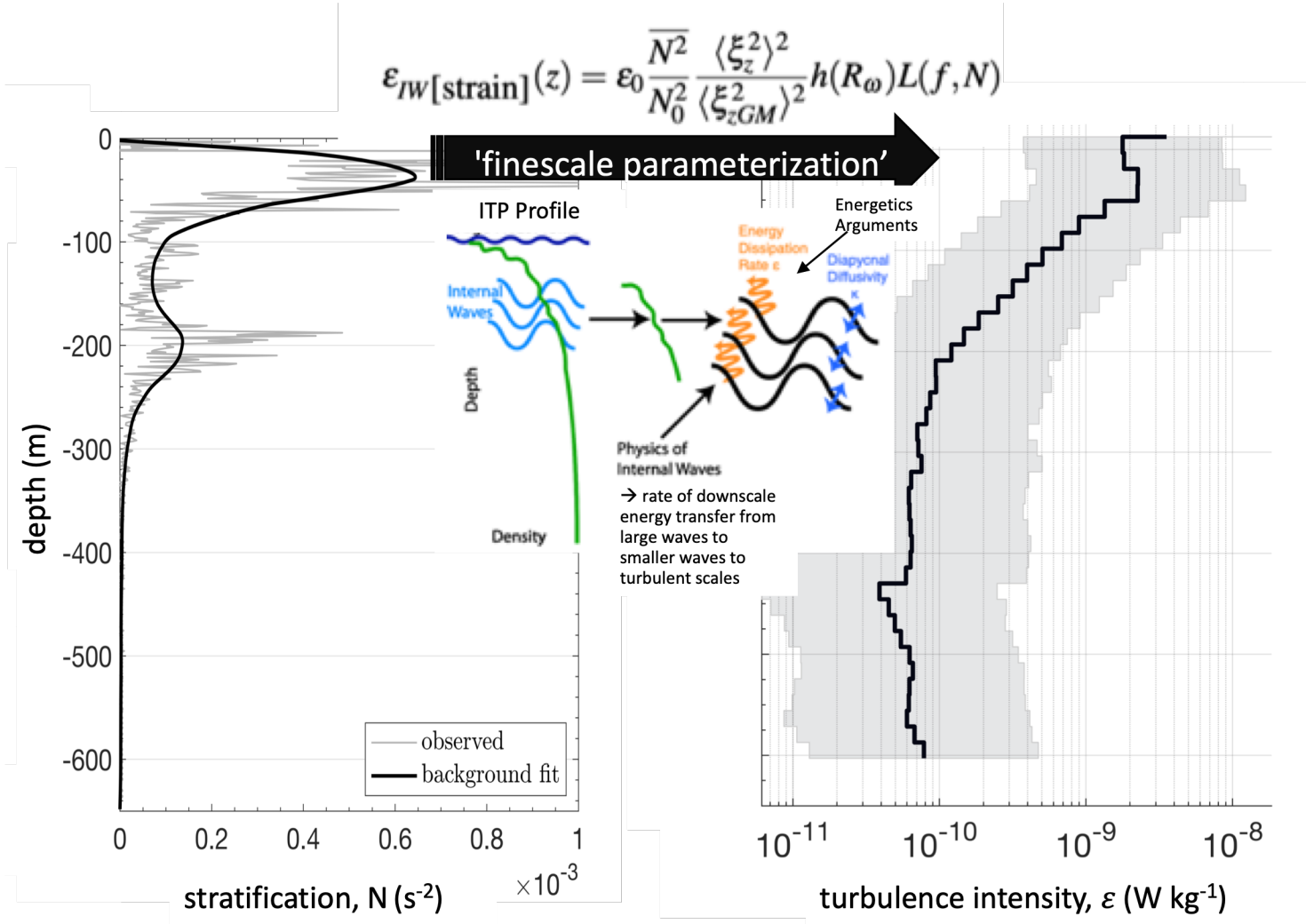
see Dosser et al. 2021

Key Result 2 brought to you by:

the historic data record + a parameterization model

- 29,074 hydrographic profiles from 89 ITPs that sampled the central Arctic Ocean year-round 2004 - 2019
- 3,084 hydrographic profiles collected by ship-based programs in Canadian Arctic shelf & slope waters 2002 - 2014
- → the finescale parameterization to infer turbulence intensity based on a model of how energy cascades from wave- to turbulent-scales

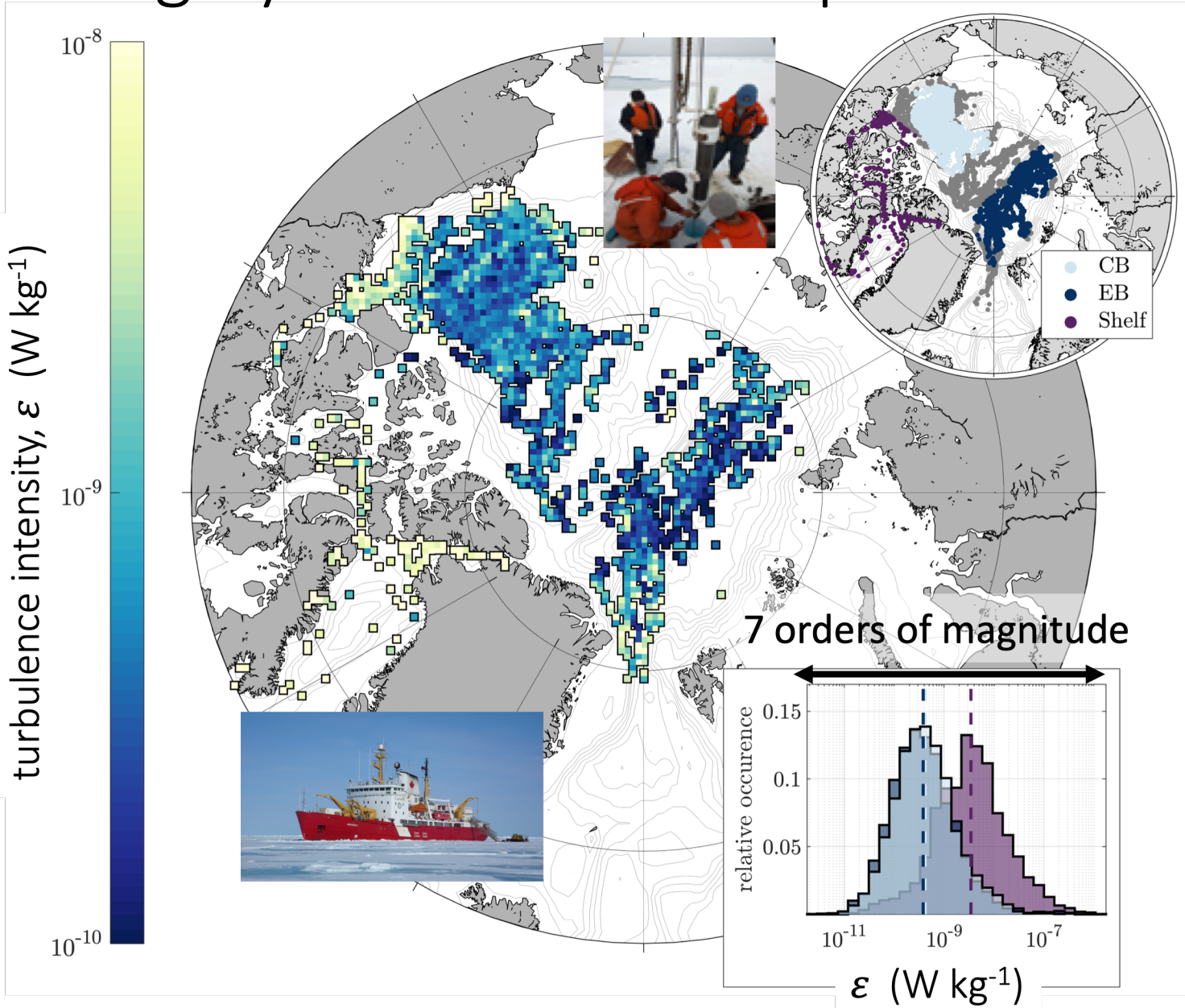
see Polzin et al. 2014



M. Chanona*

Key Result 2:

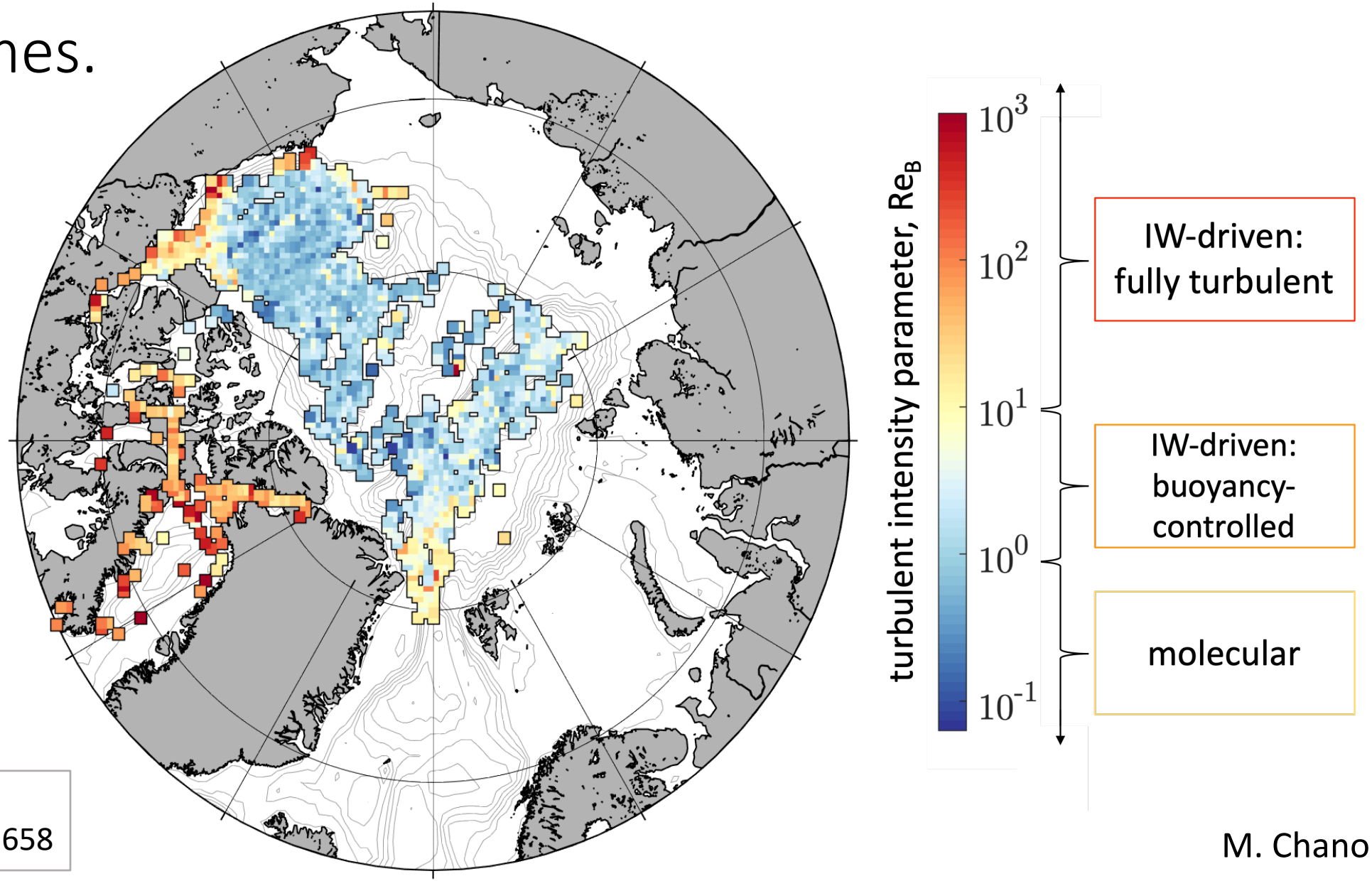
Turbulence is highly variable on the pan-Arctic scale…



Dosser* et al. 2021

Key Result 2:

but there are large-scale patterns that give insight into different mixing regimes.



For more see:
EGU Abstract: EGU23-12658

M. Chanona*

Key Result 3:

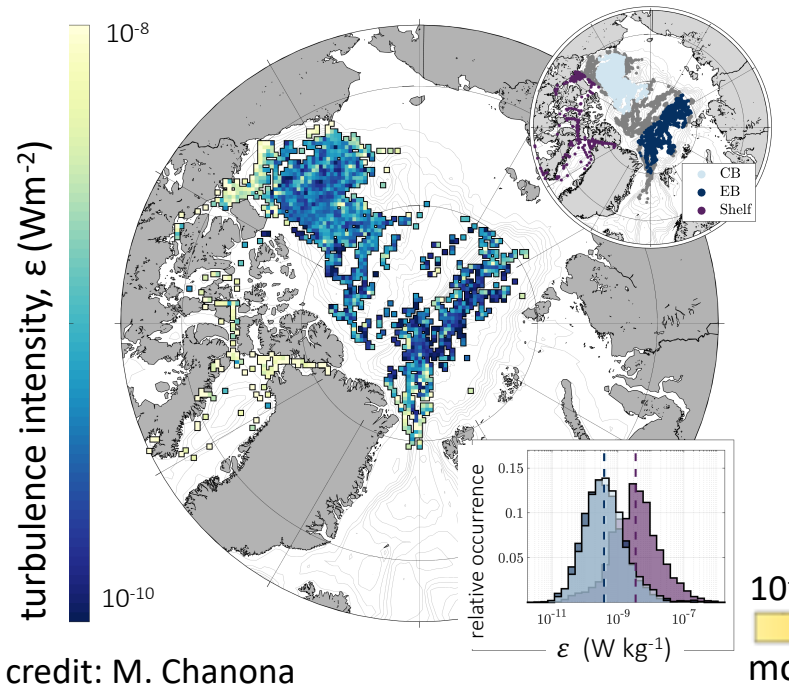
Variable mixing rate geography can lead to important changes in the modelled Arctic Ocean state & exports.

Key Result 3 brought to you by:

climate model “thought experiments”

- use an intermediate complexity regional model of the Arctic Ocean
- prescribe a map of background vertical diffusivity with horizontal & vertical variations informed by observational estimates
- interpret in the context of model runs that ↑ or ↓ the diffusivity uniformly in space

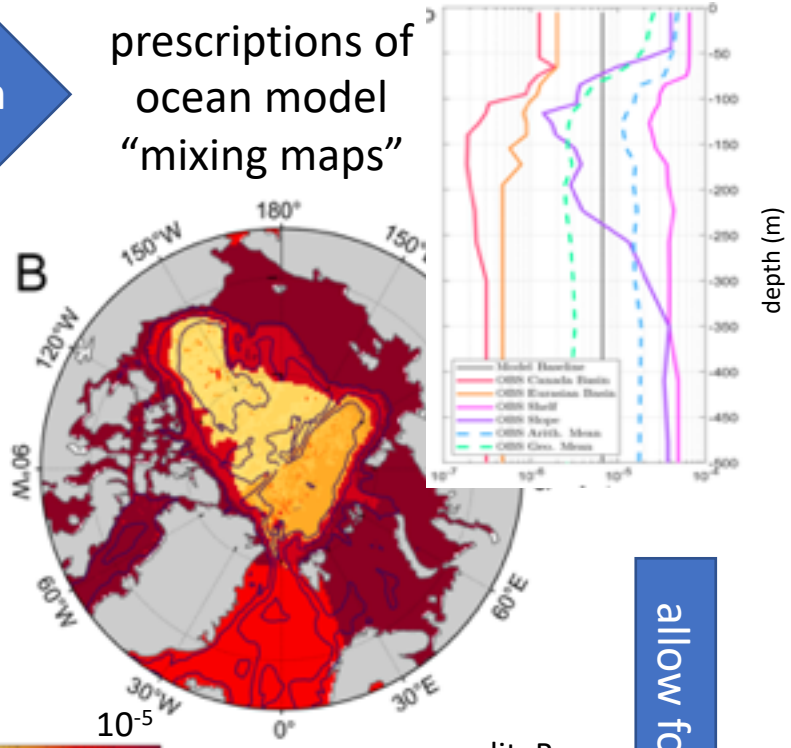
Observational estimates of ocean turbulence…



credit: M. Chanona

inform

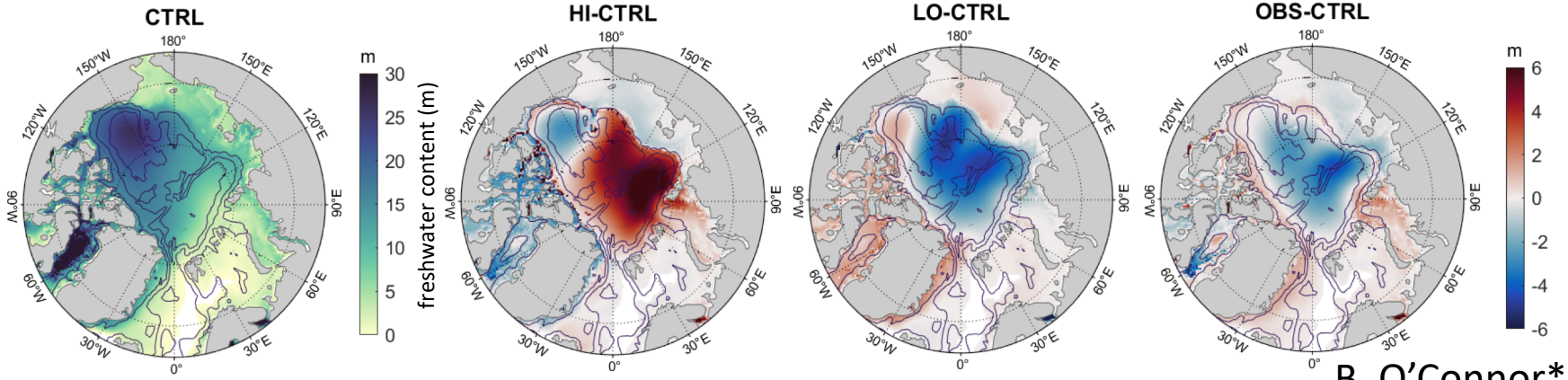
prescriptions of ocean model “mixing maps”



credit: B. O’Connor

allow for

climate model “thought experiments” that systematically vary the ocean mixing rate



B. O’Connor*

Key Result 3:

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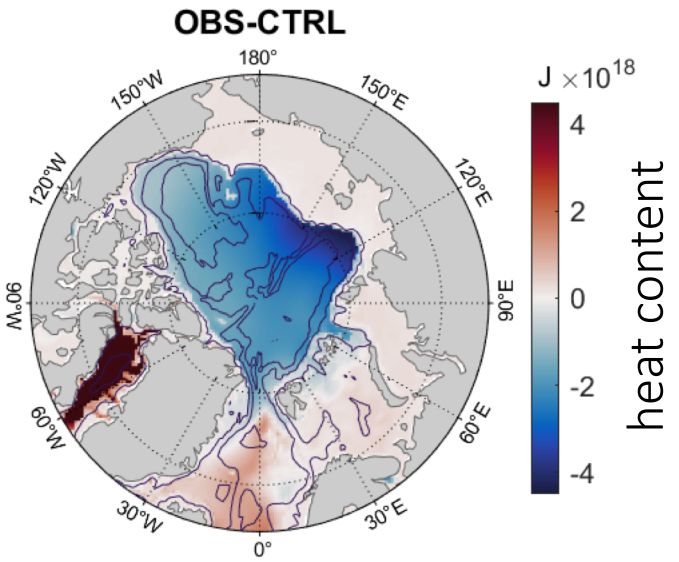
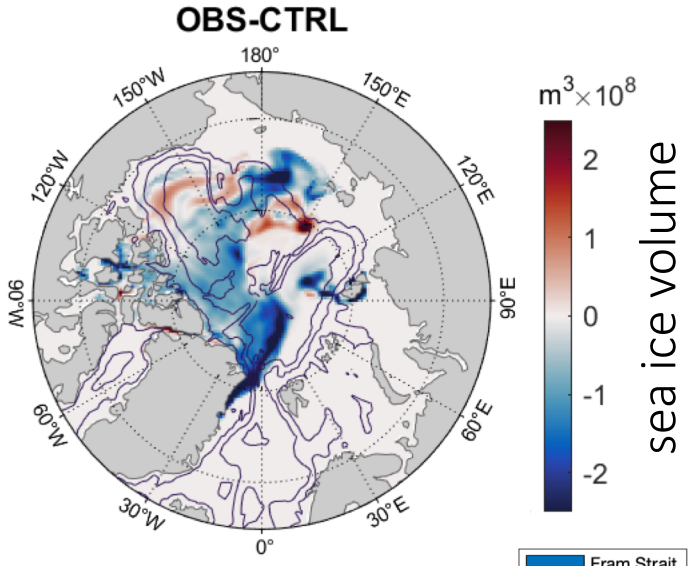
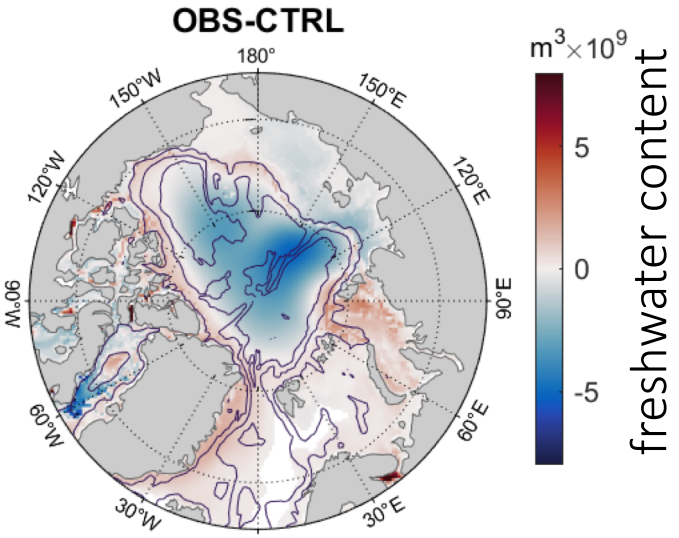
In OBS relative to CTRL:

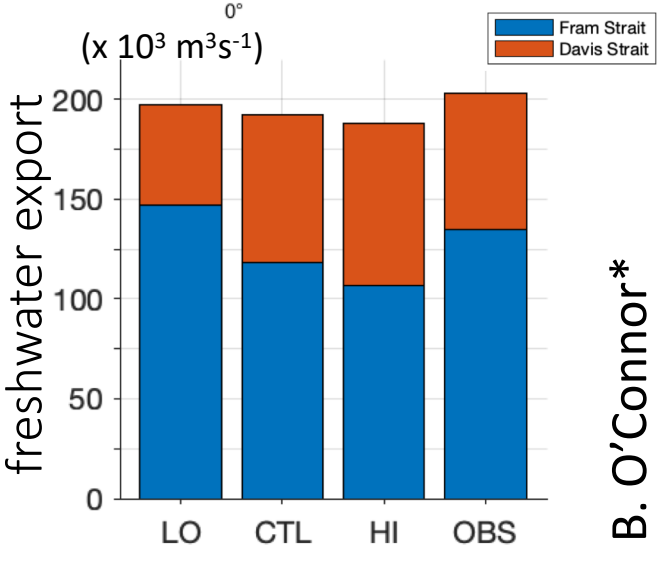
- ↓ heat storage
- ↓ sea ice volume
- ↓ freshwater storage
- ↑ freshwater export to the N. Atlantic
- changing export pathways

For more see:
EGU Abstract: EGU23-13560



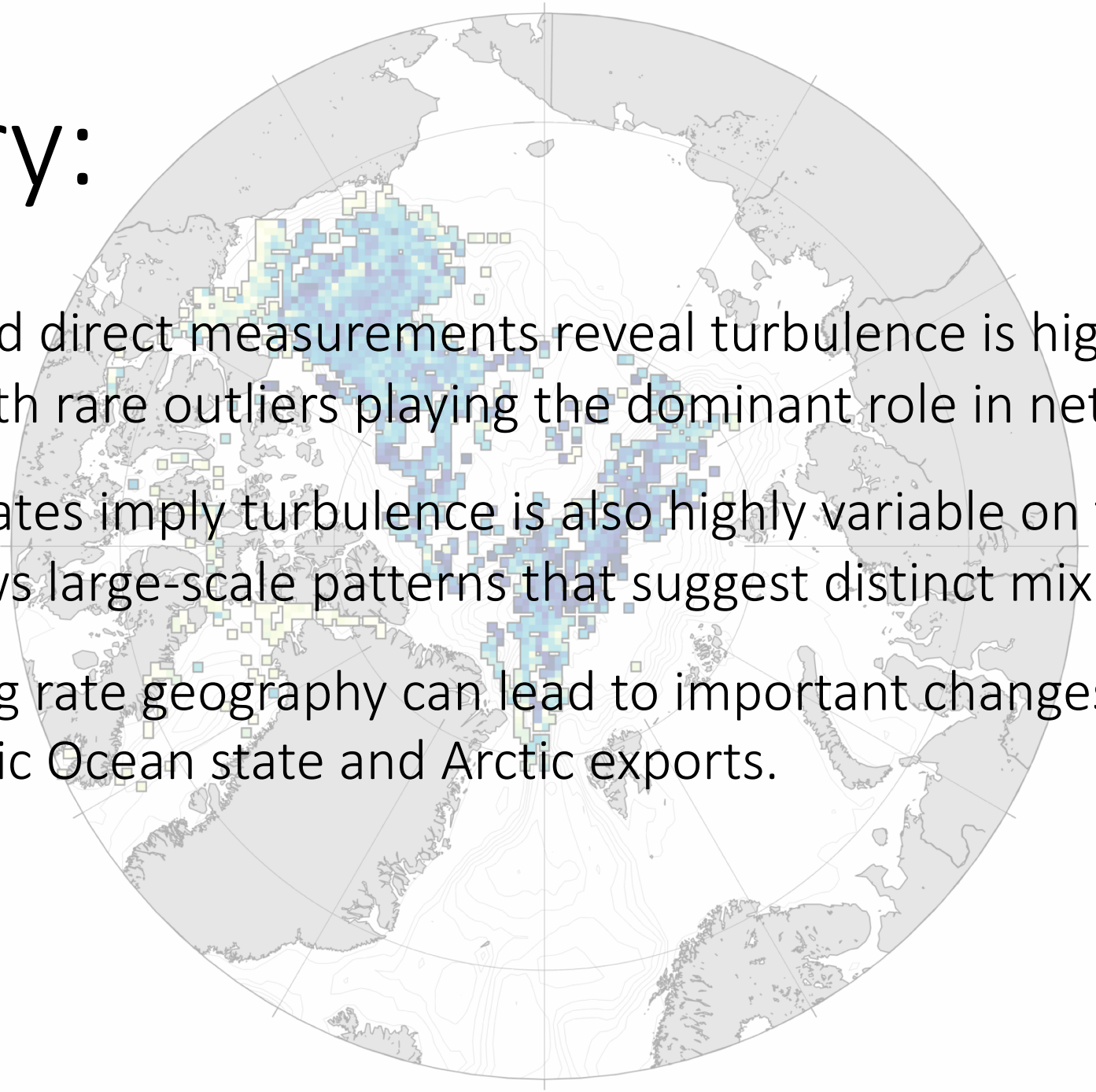






B. O'Connor*

Summary:



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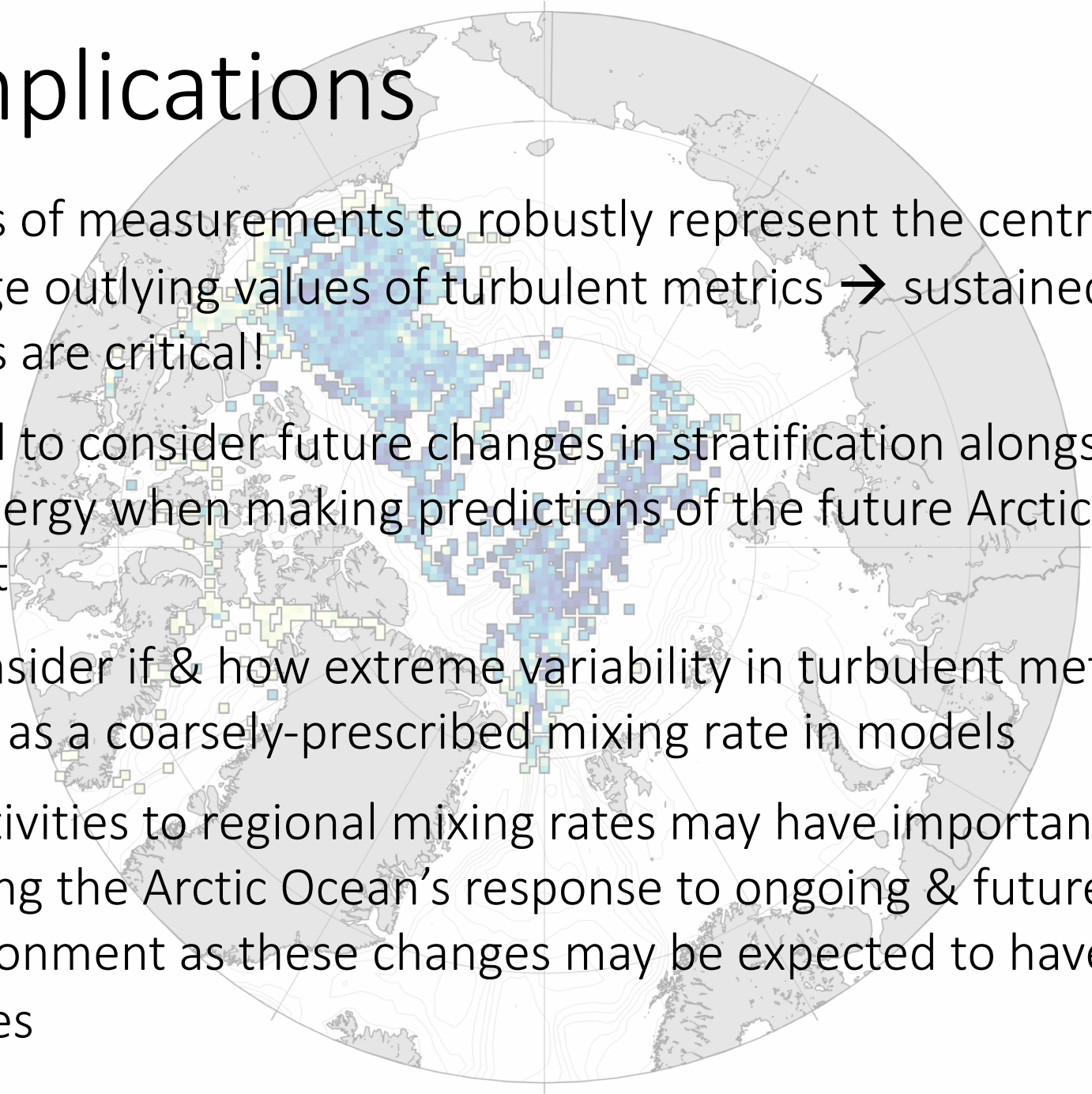
(Select) Implications



1. we need lots of measurements to robustly represent the central tendency & extreme large outlying values of turbulent metrics → sustained, autonomous observations are critical!
2. it is essential to consider future changes in stratification alongside changes in turbulent energy when making predictions of the future Arctic Ocean mixing environment
3. we must consider if & how extreme variability in turbulent metrics should be represented as a coarsely-prescribed mixing rate in models
4. varied sensitivities to regional mixing rates may have important implications for understanding the Arctic Ocean's response to ongoing & future changes in the mixing environment as these changes may be expected to have distinct regional dependencies

Questions?

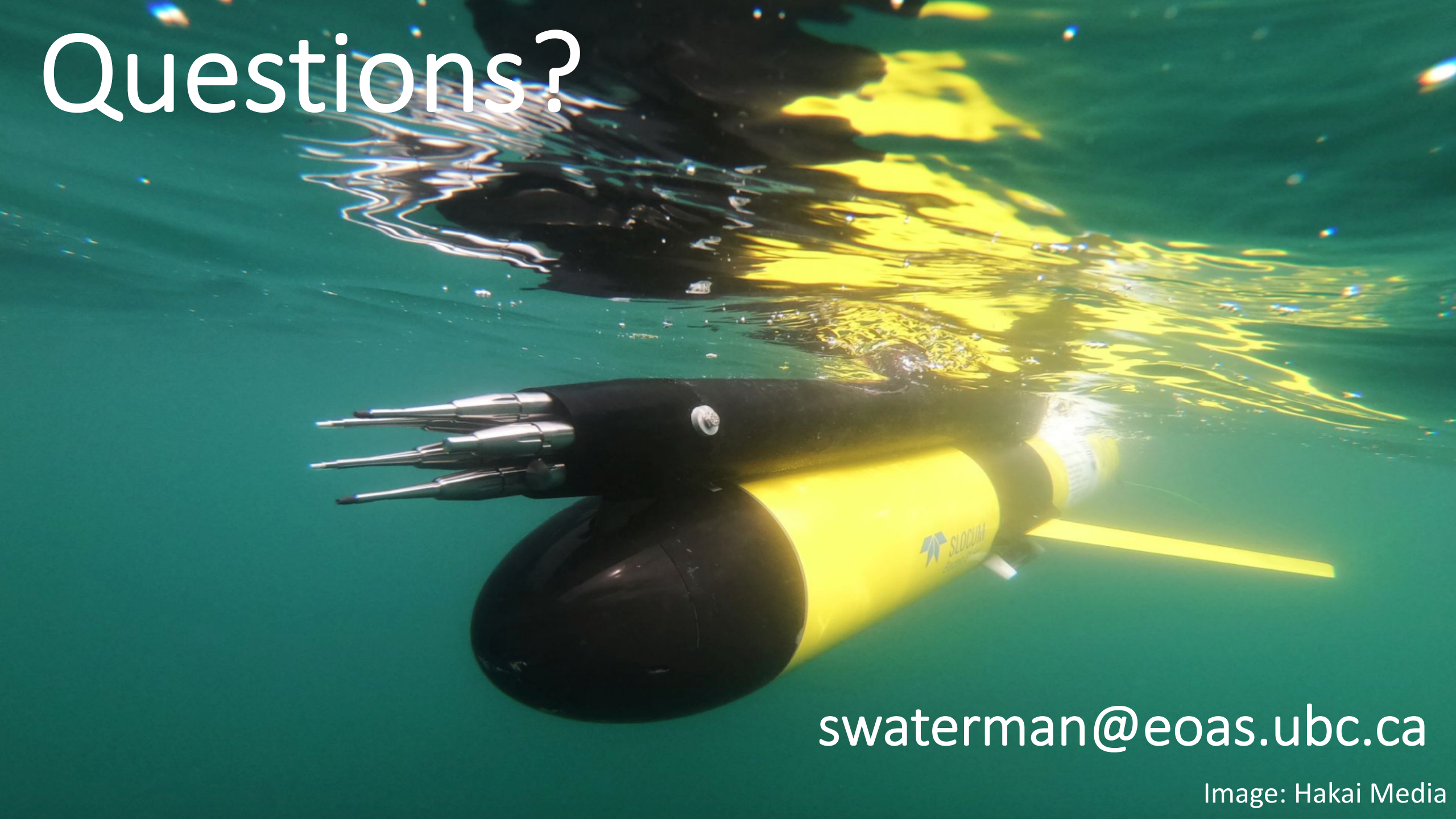


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Image: Hakai Media