OAFlux2: Satellite-Based Ocean Surface Stress in Ice-Free and Ice-Covered Polar Oceans

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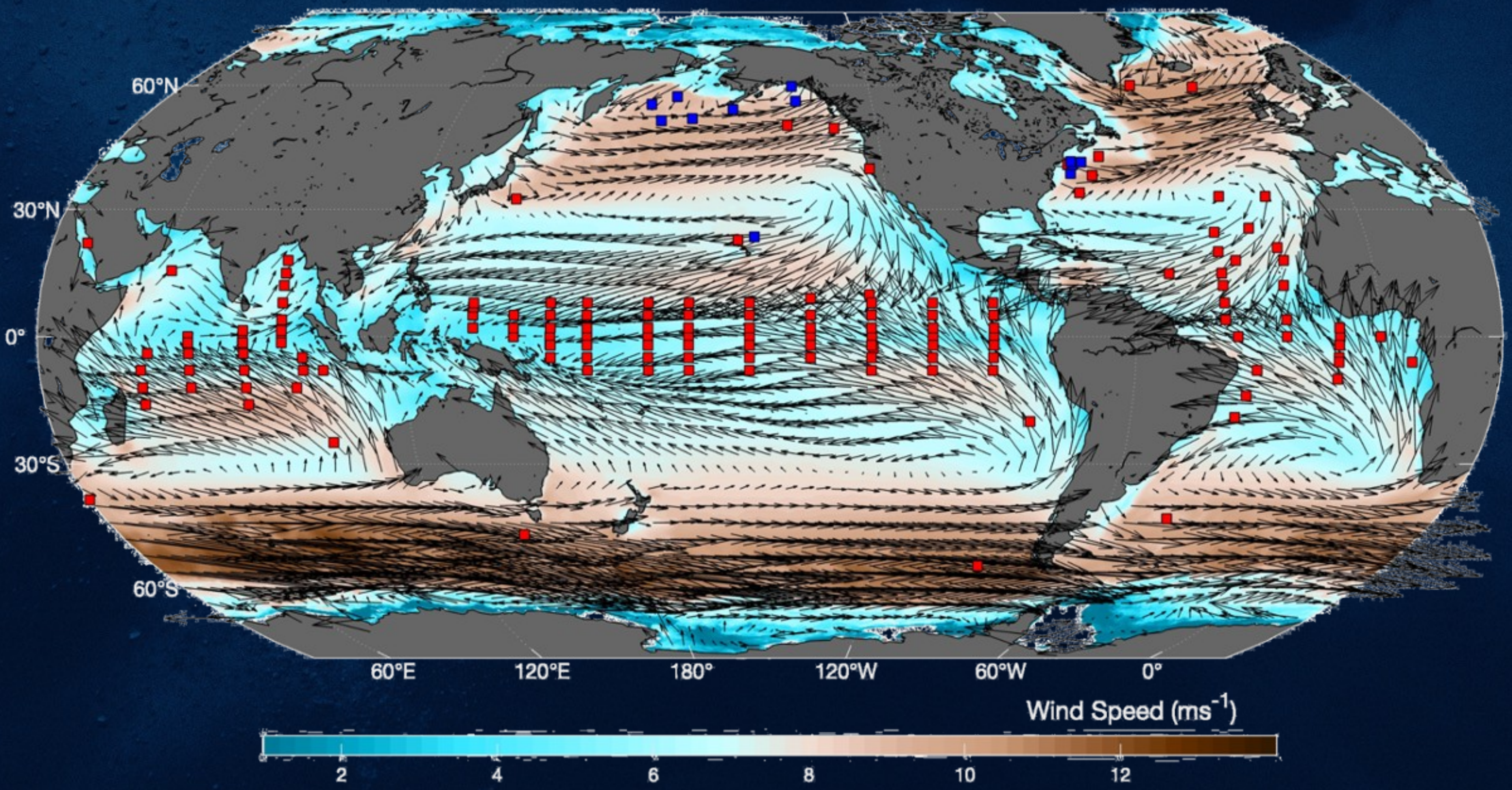
OAFlux2 – NASA MEaSUREs:
The 2nd generation of Objectively Analyzed Air-Sea Fluxes (1988 -)

- **Wind speed & vector** (0.25º, daily, 1988-present) are derived from 19 sensors, including SSM/I, SSMIS, AMSR-E, AMSR2, WindSat, NSCAT, QuikSCAT, SeaWinds, OSCAT, ASCAT A, B, & C.
- Daily mean is merged from 6-hourly fields with missing gaps filled by ML predicted values.
- Wind Stresses are calculated using COARE v3.6 algorithm.
- OAFlux2 is fully validated using a total of 160 buoys, including active, archived, and NDBC buoys.

Mean (1988-2024)



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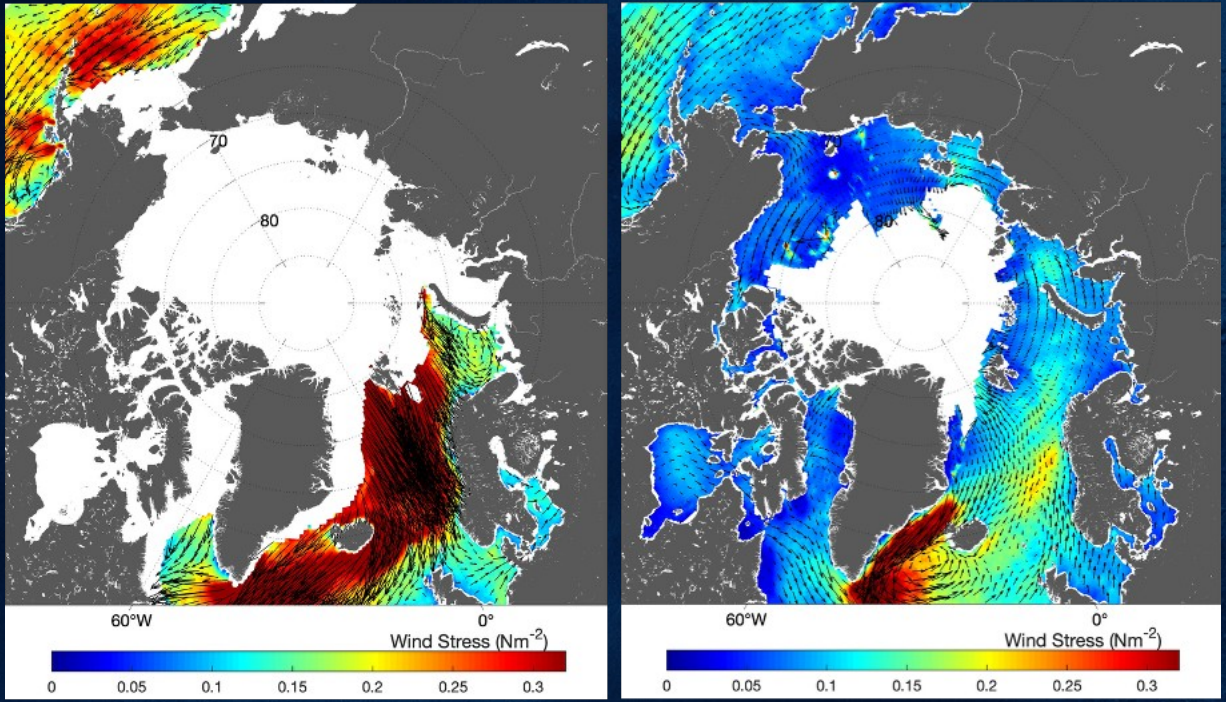
Scatterometer-derived wind datasets contain gaps in ice-covered polar seas

NSIDC Satellite-derived Ice Motion

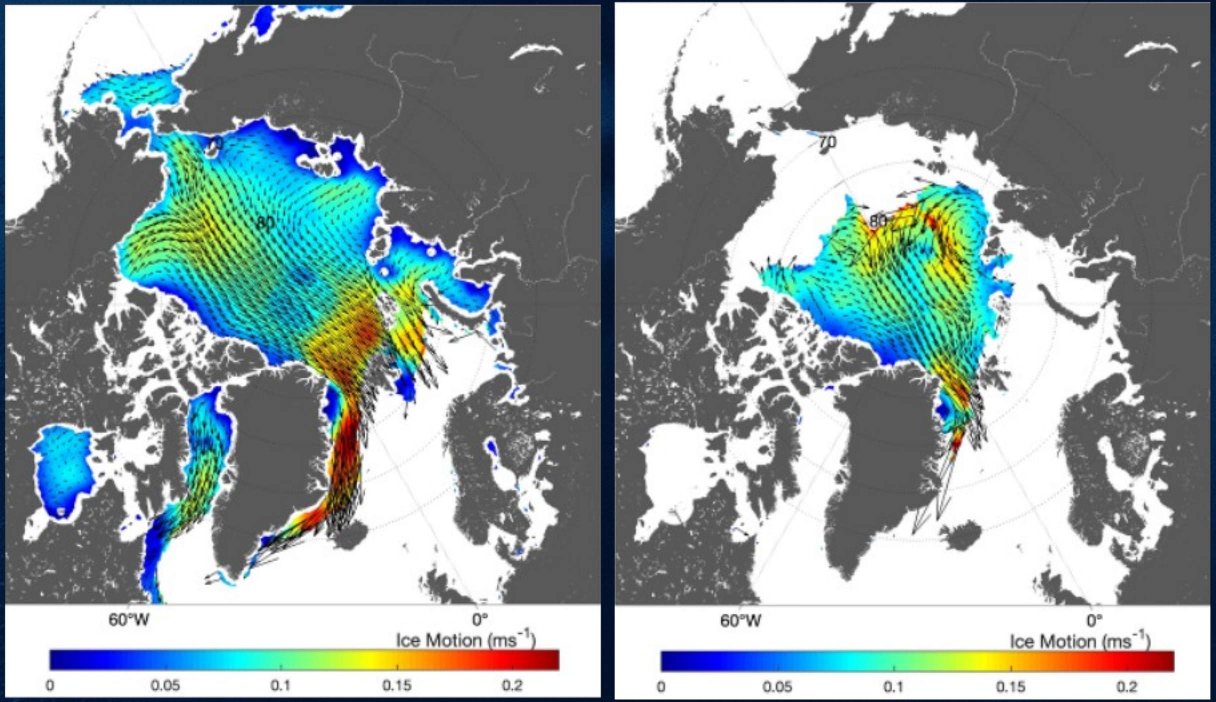
March 2023

Sept 2023

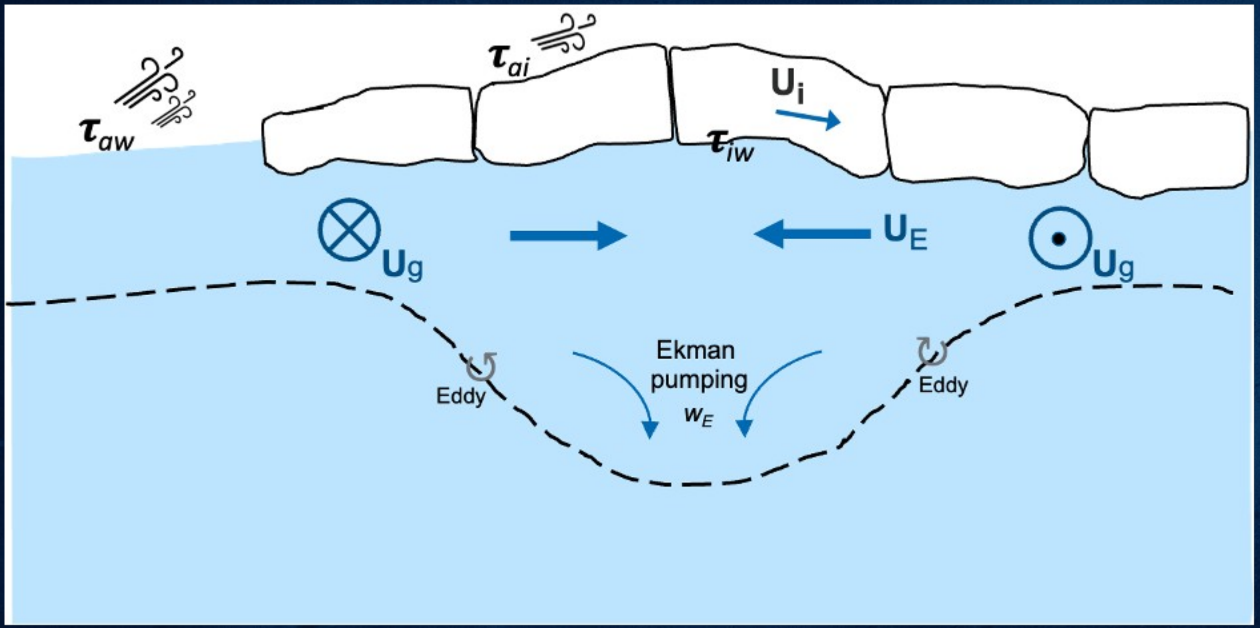


March 2023

Sept 2023



Ocean-Surface Stress in the Polar Seas and its Derivation



- $\tau_{aw,}$ the air-water stress for the open water:

$$\tau_{aw} = \rho_a C_{D,aw} |U_{10}| U_{10}$$

- $\tau_{iw,}$ the ice-water stress for the water covered by ice:

$$\tau_{iw} = \rho_w C_{D,iw} |U_{ice} - U_E - U_g| (U_{ice} - U_E - U_g)$$

- The total ocean-surface stress: $\tau_o = \alpha\tau_{iw} + (1-\alpha)\tau_{aw}$, where α is sea ice extent.

- Ekman velocity: $U_E = \dfrac{\sqrt{2}e^{-i(\pi/4)}}{f\rho_w D_e}\tau_o$

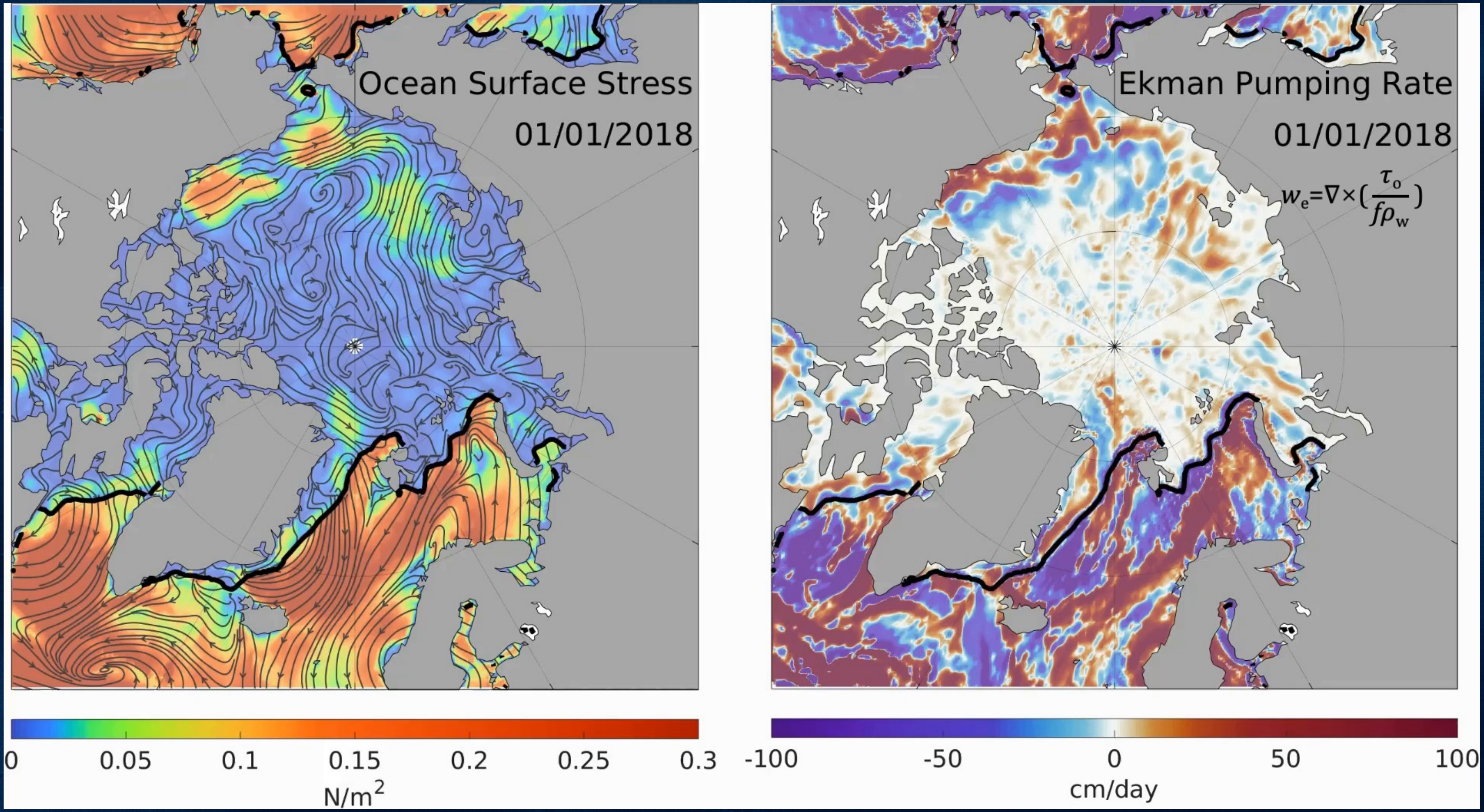
- Richardson iteration method is applied to solve τ_o and U_E iteratively.

Input datasets

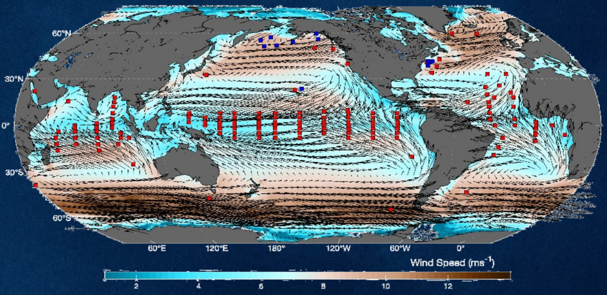
Variable	Product	Resolution
U_{10}	OAFlux2 Satellite Ocean-Surface Winds	Daily 0.25°, 1988-present
U_{ice}	Polar Pathfinder Sea Ice motion V4	Daily 25 km, 1978-present
U_g	CLS multi-mission Ocean Altimeter SSH	3-Day 25 km, 2011-2021
	Goddard/NSIDC Sea Ice Concentrations V2	Daily 25 km, 1978-present

Liu, C. & Yu, L. (2025a):Satellite-based Analysis of Ocean-Surface Stress across the Ice-free and Ice-covered Polar Oceans. Earth Syst. Sci. Data Discuss. https://doi.org/10.5194/essd-2025-14, in review.

Daily Maps of Arctic Ocean Surface Stress and Ekman Pumping Rates



Ocean-Surface Stress from the Tropics to Polar Seas



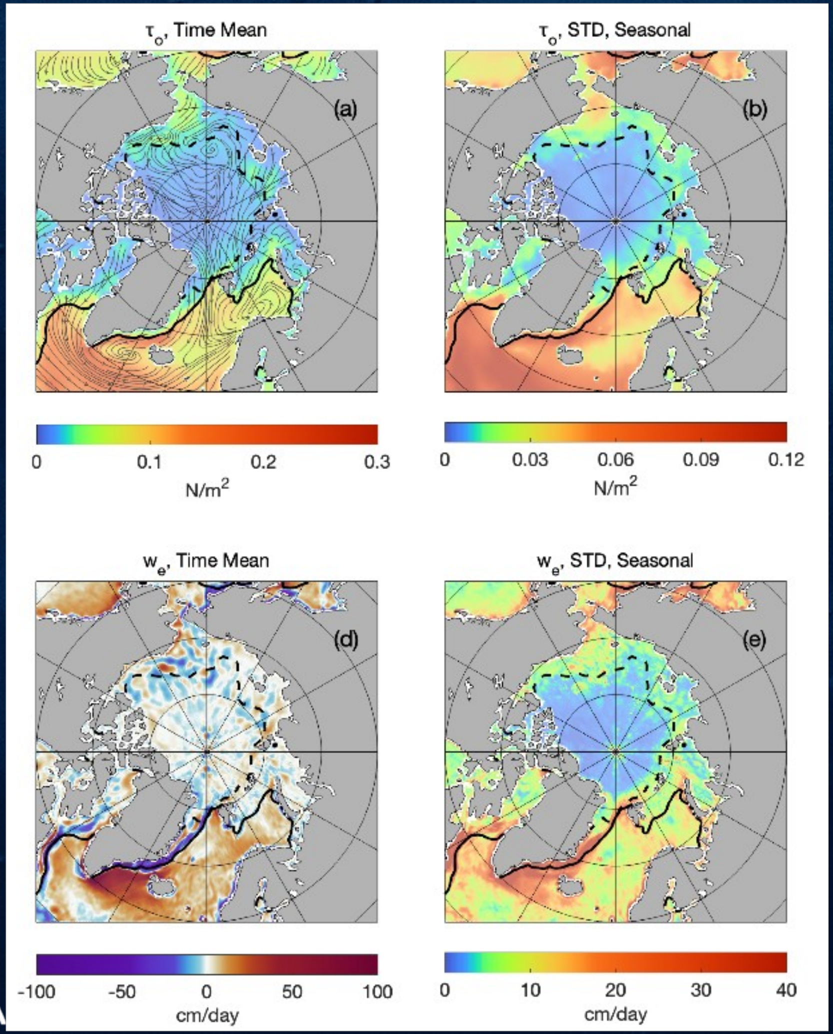
Arctic

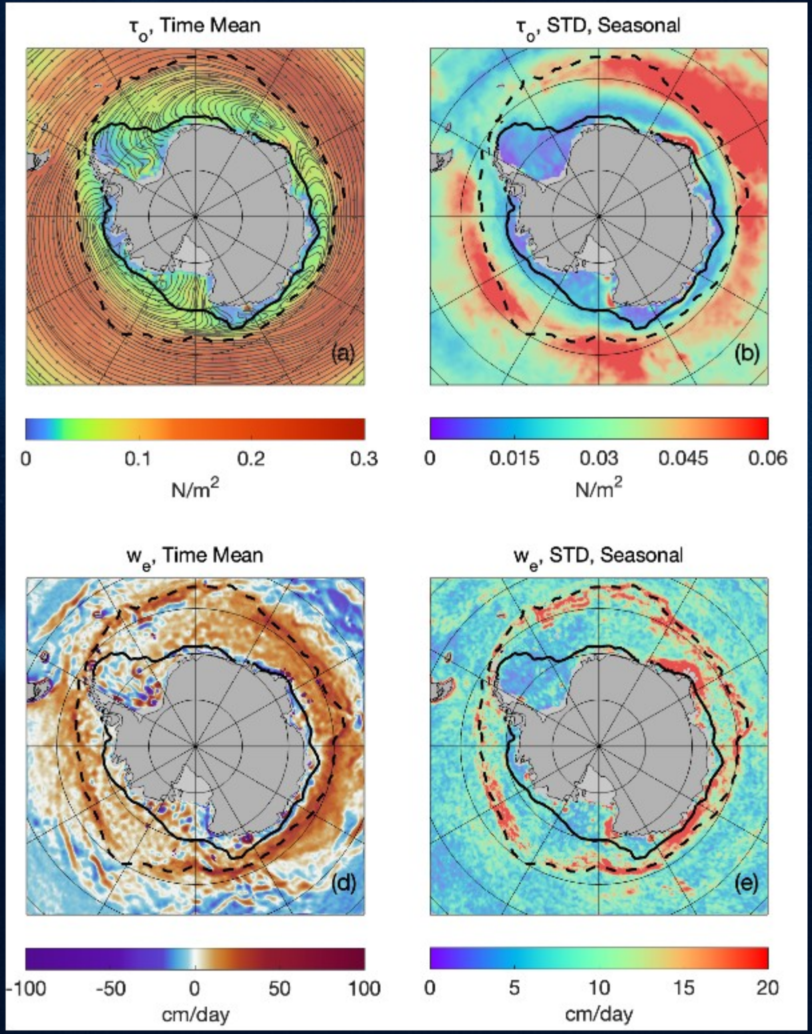
Antarctic

Mean (2011-2018)

Ocean Surface Stress

Ekman Pumping

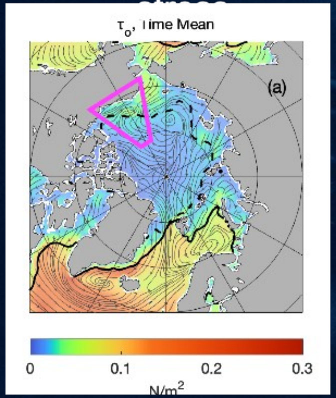




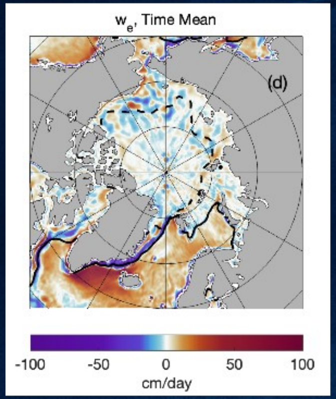
Solid and dashed black lines represent the March and September sea ice boundaries, respectively, defined by 15% sea ice concentration averaged over 2011-2018.

Science Applications: I. Understanding ITP current measurements

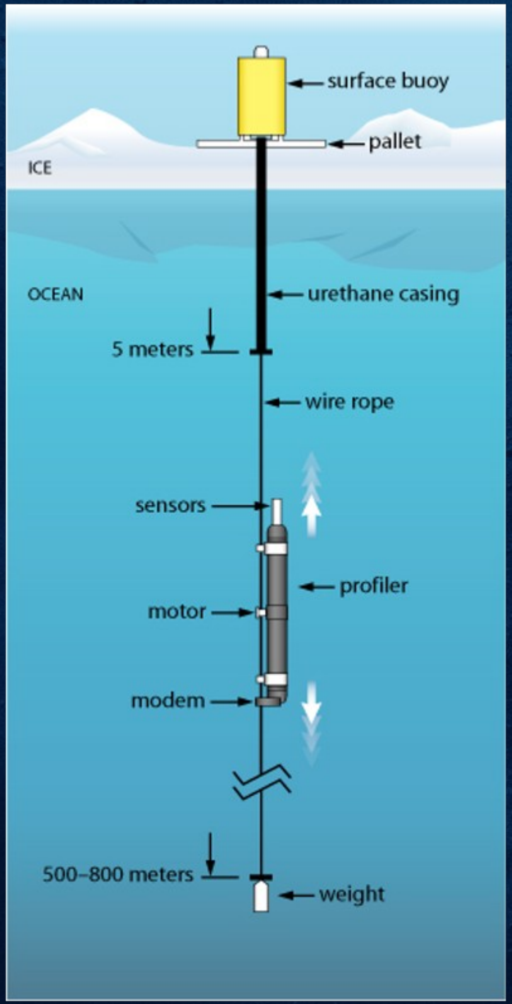
Ocean-surface stress

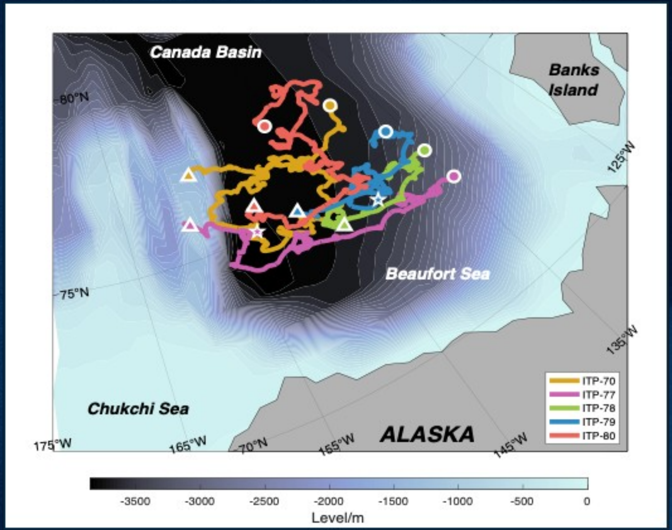


Ekman pumping



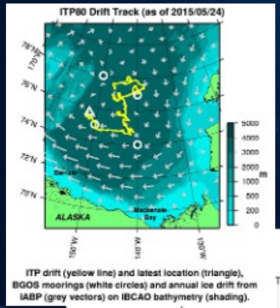
Ice-Tethered Profilers
(http://www.whoi.edu/itp)

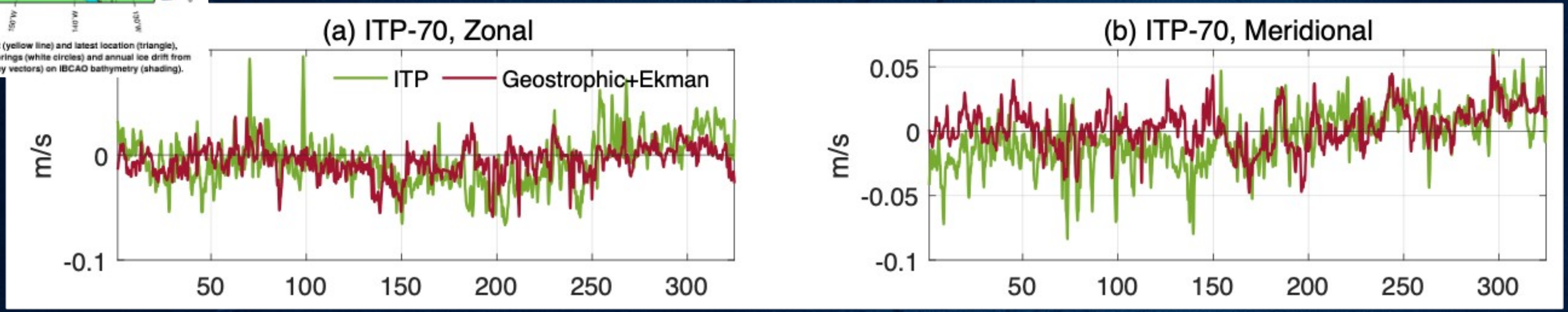


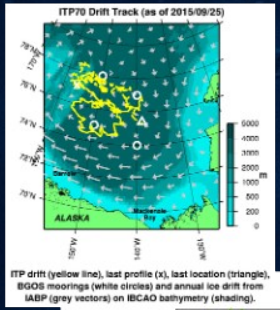


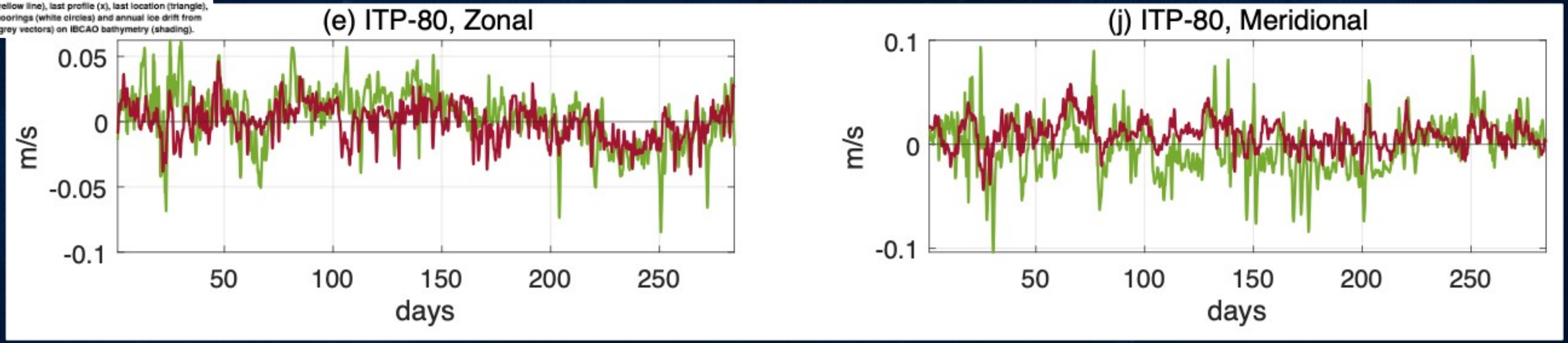
Unit ID	Start		Last		# of Days	# of Profiles
	Position	Date	Position	Date		
ITP-70	76.81°N 138.89°W	8/26/2013	77.11°N 156.51°W	7/15/2014	324	3713
ITP-77	73.37°N 134.99°W	3/11/2014	75.89°N 158.50°W	10/2/2014	206 (153*)	2367 (1800*)
ITP-78	74.36°N 135.14°W	3/12/2014	74.08°N 145.43°W	8/6/2014	148 (130*)	1694 (1500*)
ITP-79	75.38°N 136.50°W	3/22/2014	75.02°N 148.37°W	9/30/2014	193 (143*)	1694 (1636*)
ITP-80	77.36°N 146.15°W	8/14/2014	75.68°N 151.79°W	5/24/2015	284	3260

$(\vec{U}_{EK} + \vec{U}_{geo})$ vs $\vec{U}_{ITP}$ Measurements





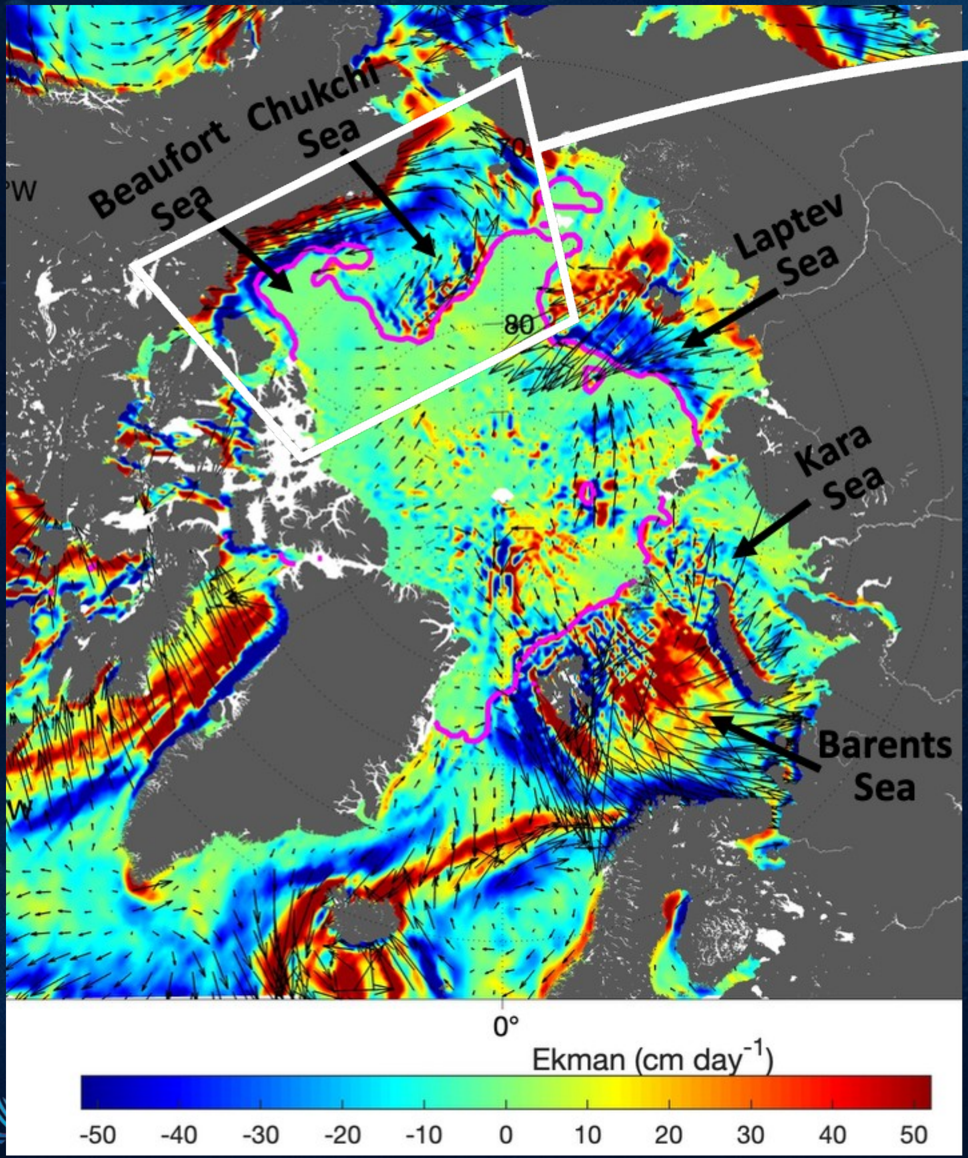




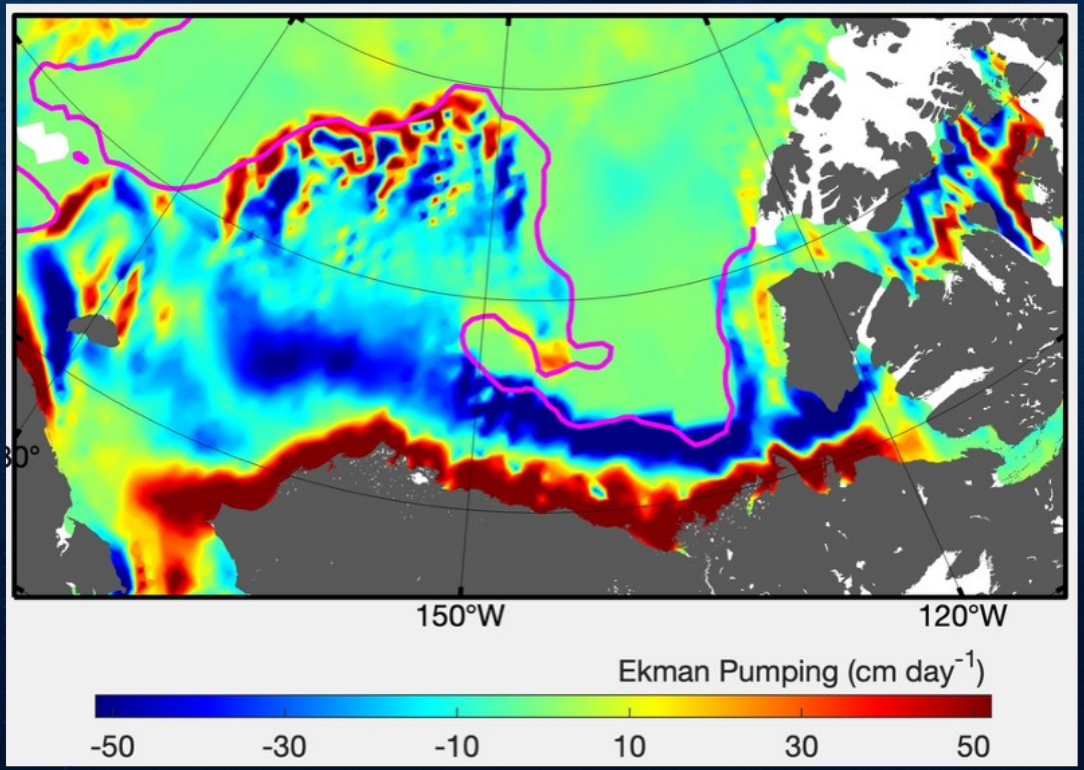
R_squared

ITP ID	R^2	
	$U_{EK} + U_{geo}$	$V_{EK} + V_{geo}$
ITP 70	0.58	0.36
ITP 77	0.36	0.23
ITP 78	0.80	0.44
ITP 79	0.39	0.73
ITP 80	0.65	0.20

Science Applications:
II. Mesoscale ocean processes at the ice edge

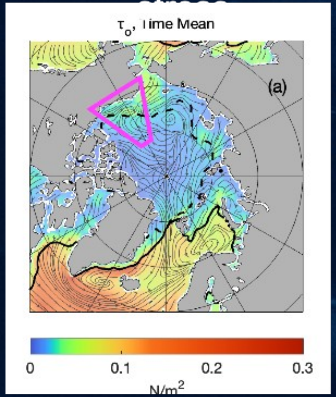


Sept 10, 2022

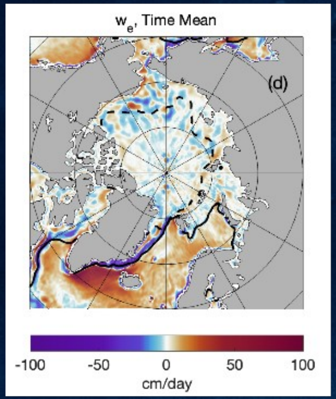


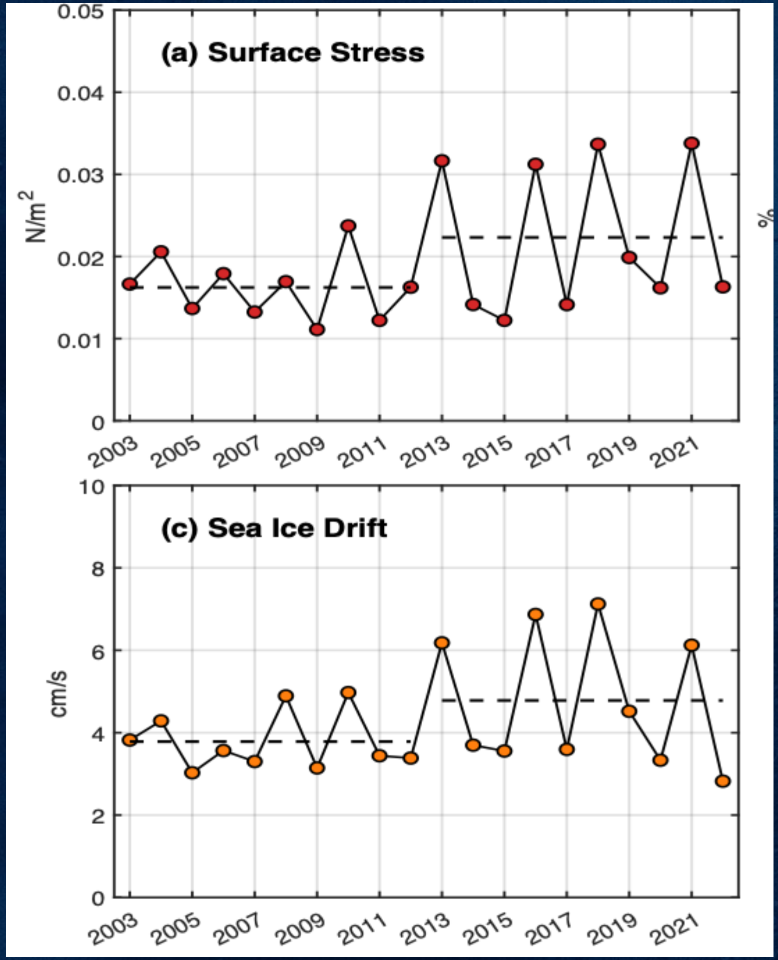
Science Applications: III. Wintertime (DJFM) ocean-surface stress changes in the Beaufort Sea

Ocean-surface stress



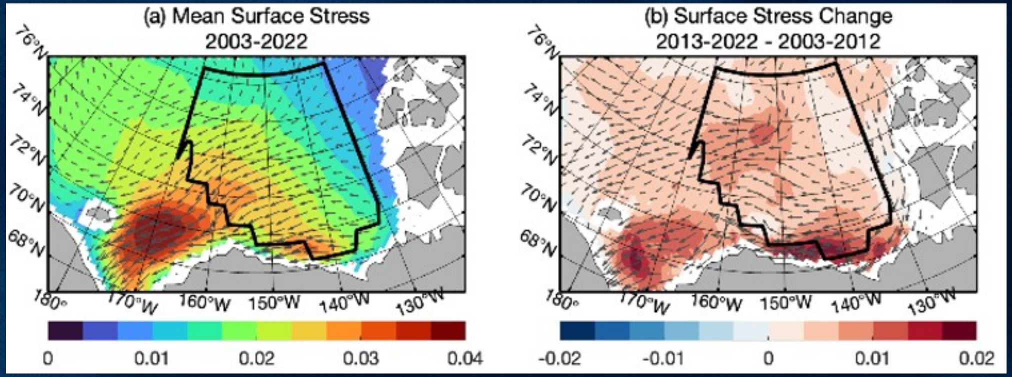
Ekman pumping

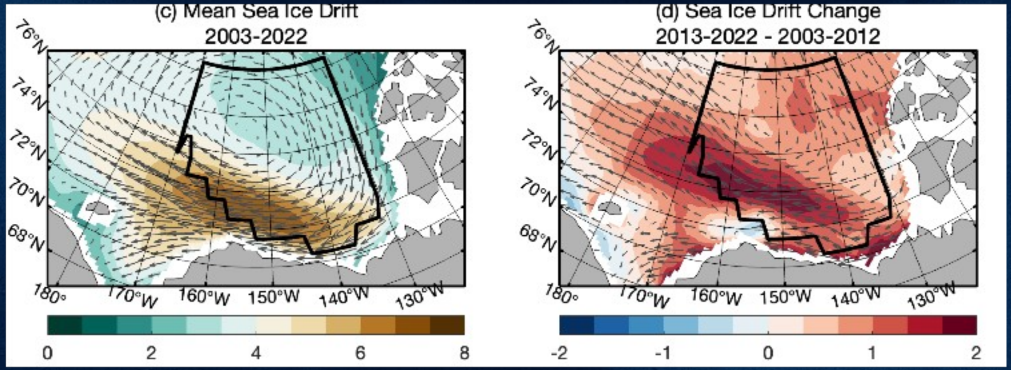


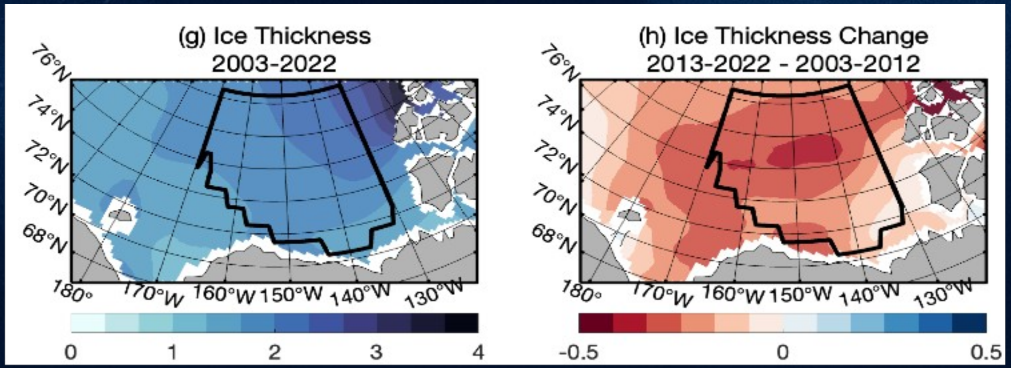


Mean

2010s - 2000s



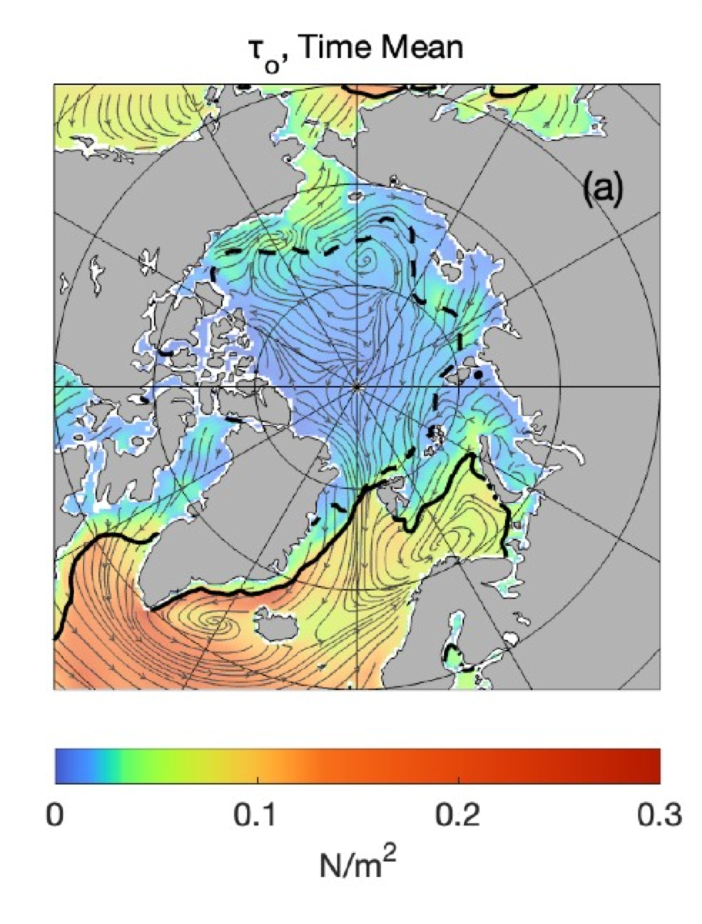


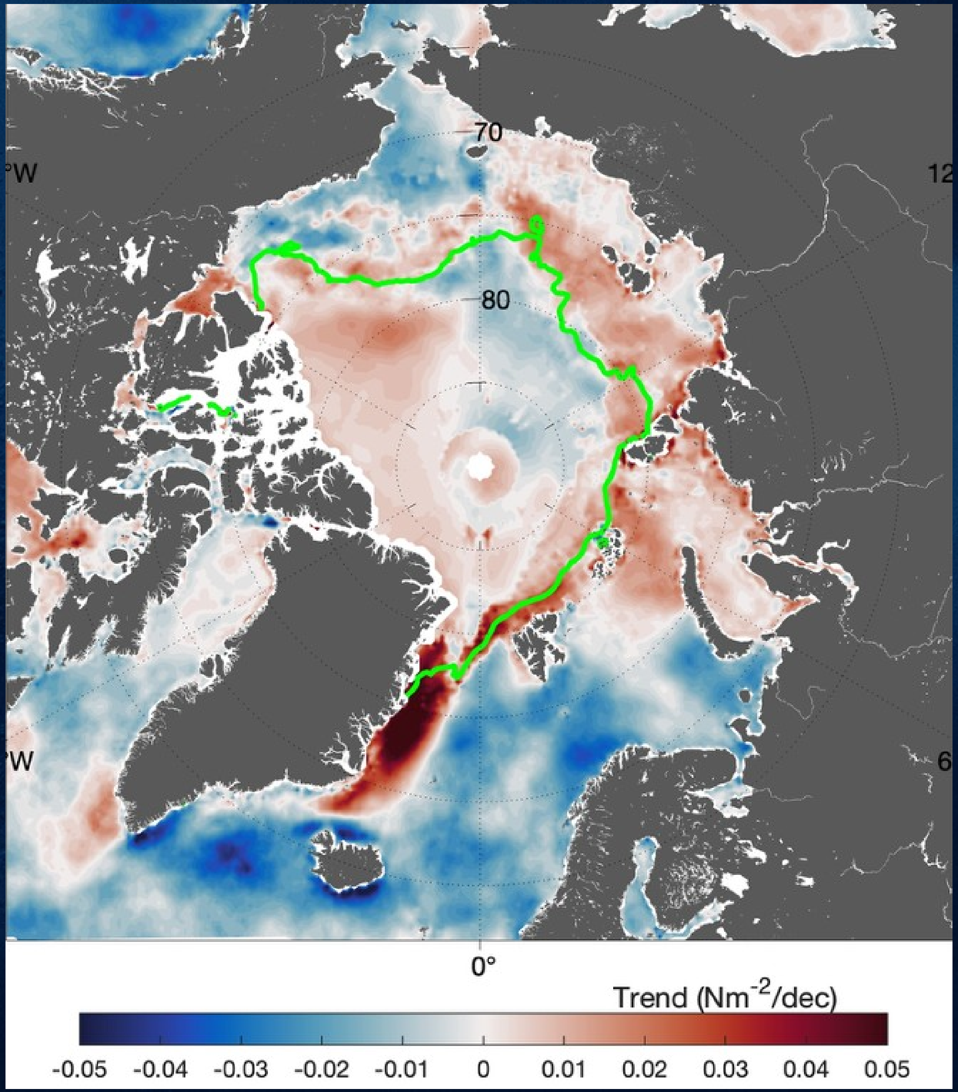


Liu, C. & Yu, L. (2025b) Winter Intensification of Ocean Surface Stress Drives Ekman Downwelling in the Beaufort Gyre Since the 2010s. JGR – Oceans. In review.

The reduction in ice thickness enhances air-ice-ocean coupling, increasing the sensitivity of ocean stress beneath the ice to changes in surface winds.

Science Applications:
IV. Changes in September ocean-surface stress





Summary

- We have developed a new dataset for ocean-surface stress across both ice-free and ice-covered regions in the Arctic and Antarctic seas.
- The dataset is derived from satellite-based ocean-surface winds, ice motion vectors, and geostrophic velocities, providing a first-order description of the spatial and temporal variability in surface stress, offering insight into air–ice–ocean interactions across polar regions.
- The resulting ocean current velocities are compared with ITP measurements, showing good alignment on monthly mean scales, though less so for day-to-day variability.
- Arctic ice has been decreasing in both extent and thickness, which affects air-ice-ocean coupling. As a result, the ocean-surface stress becomes more sensitive to changes of atmospheric circulation pattens.
- The most significant changes occur near the ice edge, where mesoscale variability is high and surface stress responds directly to retreat in sea ice extent.