Ocean Predict

SYMPOSIUM OP'24

In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Polar Ocean Predictions: Opportunities and Challenges in a Rapidly Changing Environment

Gregory Smith

Env. Canada

Heather Regan,

NERSC

Disclaimer:

- if you want to hear about sea ice, you are too late!
- IICWG-DA workshop was in Frascati 5-7th Nov.
- Heavy Arctic bias in this presentation... (100%)

Polar regions are warming

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Climate crisis

This article is more than **2 years old**

New data reveals extraordinary global heating in the Arctic

Temperatures in the Barents Sea region are 'off the scale' and may affect extreme weather in the US and Europe

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Two women removed BA flight 'after altercat over Maga cap'

The Barents Observer

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Temperatures are getting warmer in the whole world, including the Arctic. Photo: Elizaveta Vereykina

The spring temperatures in Russia and Norway break records

May 2024 has been a few degrees warmer than normal.

Polar oceans are changing

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OCTOBER 22, 2024
Editors' notes

Polar bears are sustaining ice-related paw injuries in a warming Arctic

by Hannah Hickey, University of Washington

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Fisheries

Study: Ocean warming is driving wild Pacific salmon into Canadian Arctic

10 June 2024
By Responsible Seafood Advocate

Study finds that more Pacific salmon are migrating into the Canadian Arctic due to ocean warming

The Barents Observer
Русский
Video Podcast Opin

Arctic tundra on the shores of Kongsfjorden near Ny-Ålesund at Norway's Svalbard archipelago. A recent ... summer CO2 uptake, permafrost areas lose more CO2 the rest of the year, contributing to greenhouse ga...
Photo: Thomas Nilsen

Warming climate changing CO2 balance in northern ecosystems

...l that climate change is significantly altering how ...CO2) in permafrost and non-permafrost areas, s... ...ations for the global carbon balance.

Climate change: World's oceans suffer from record-breaking year of heat

8 May 2024
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Matt McGrath, Mark Poynting and Justin Rowlatt
BBC News Climate & Science

Unusually warm seas may also have taken a direct toll on one of the most beloved ocean-going creatures in the coldest continent, the emperor penguin.

"There have been examples of the sea-ice collapsing before emperor chicks have properly fledged, and there have been mass drowning events," says Prof Meredith.

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Warming is not helping smoother navigation through the Arctic

SHREYA DASGUPTA
25 JUL 2024 ARCTIC
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Temperatures are getting warmer...
The spring ... break recor...
May 2024 has been a few degrees warmer than normal.

Los Angeles Times
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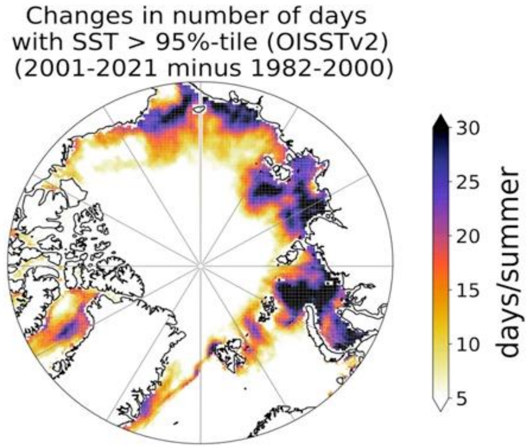
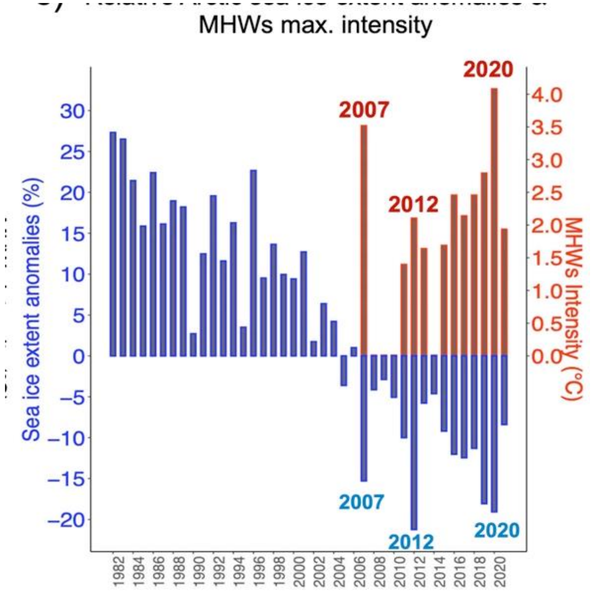
CLIMATE & ENVIRONMENT

Arctic ocean may absorb less CO2 than projected due to coastal erosion

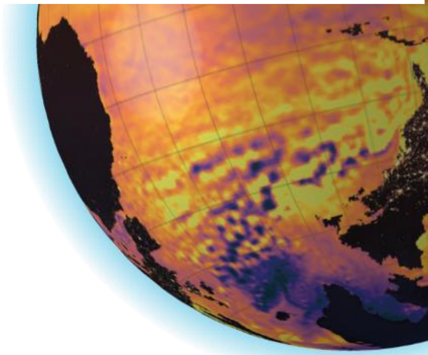
Consequences…

- Rapid changes in atmosphere coincides with sea ice losses and ocean warming
  - Significant increase in occurrence and intensity of marine heat waves
  - Impacts on marine habitats and species migration
  - Driving new needs for ocean predictions



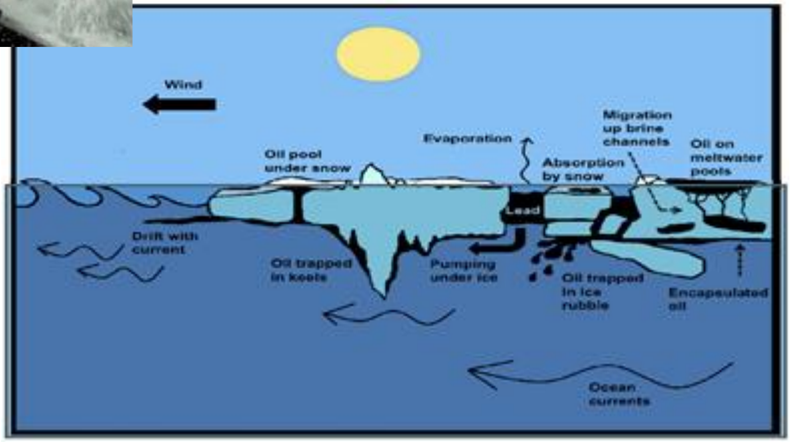


Barkhordarian et al., 2024 (https://www.nature.com/articles/s43247-024-01215-y)



The growing need for improved polar predictions

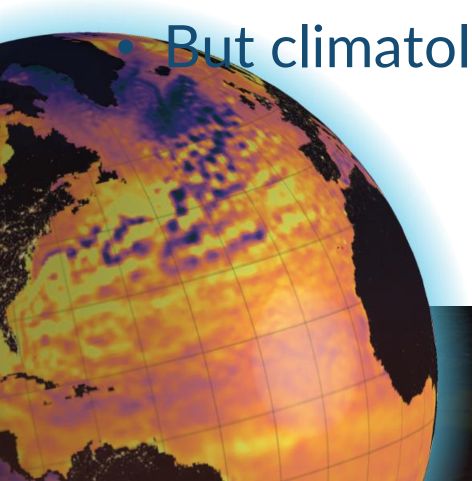
Oil spill in ice: Is the OceanPredict community ready?



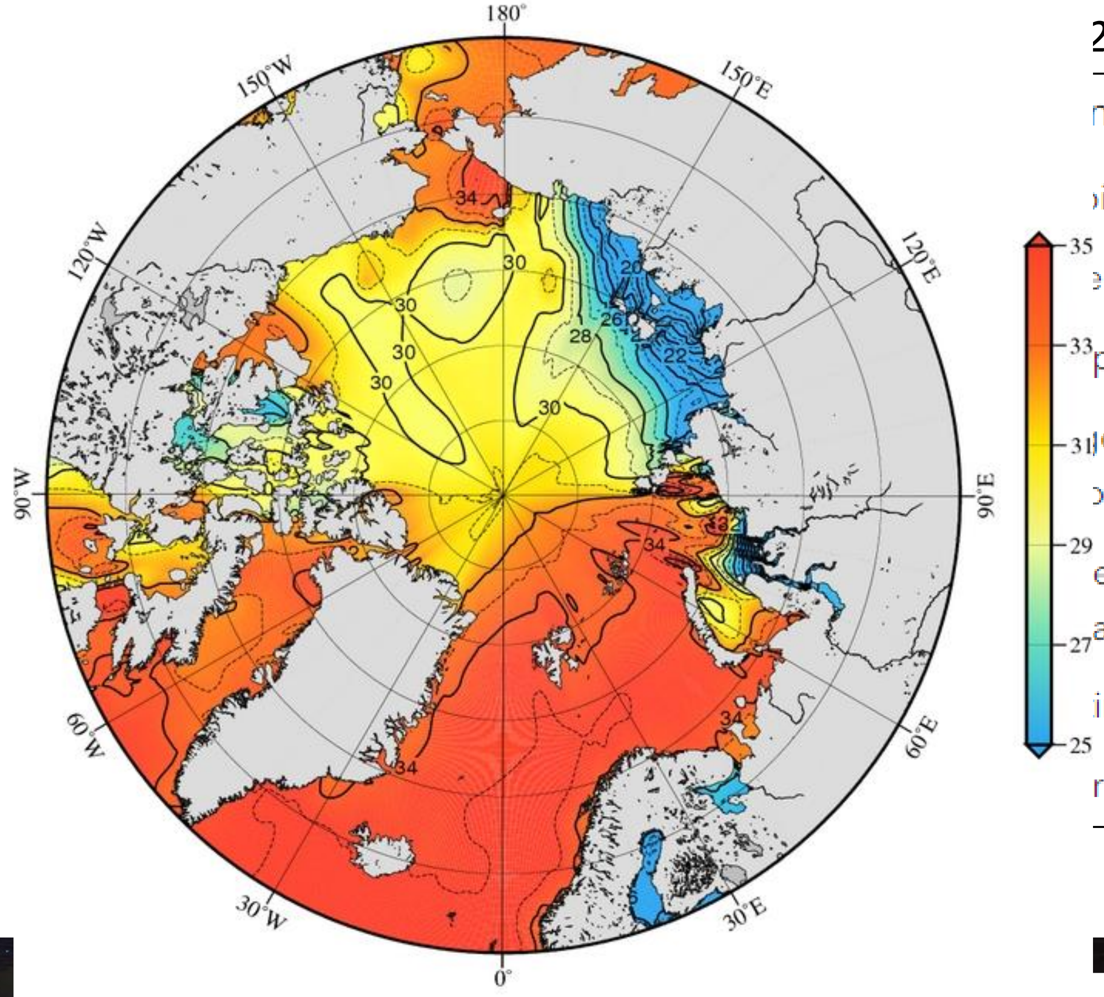
- Increase in maritime traffic and exploitation of marine resources in the Arctic
- Predictive power of traditional knowledge is breaking down
- Support for Antarctic operations and understanding of ice shelf stability
- More open water leading to greater need for "traditional" ocean prediction products (e.g. currents, storm surge, waves)

...but gaps in observations

- Ice cover hinders use of traditional remote sensing measurements (SST, SLA)
- In situ coverage extremely sparse compared to other regions
- Yet, need for accurate predictions of water mass properties and mesoscale circulation (like other regions in the world)
- Some important improvements over recent years....
- But climatology remains unreliable



World Ocean Atlas Regional Climatology: Arctic Region
Contour Interval=1



February salinity [PSS] at the surface (quarter-degree grid)

24-11-11)

ng Systems

bile systems

e floats - Argo

p floats - Argo

geochemistry floats -

erwater gliders -

anGliders

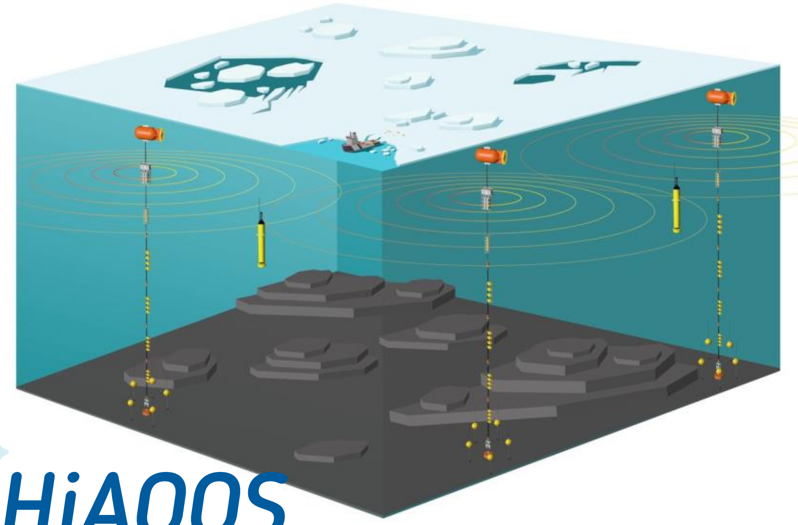
ing buoys - DBCP

r buoys

Various international efforts underway to address gaps in Arctic ocean observations

- EU4oceanobs (www.eu4oceanobs.eu)
- Arctic Passion (https://arcticpassion.eu/
    - *Pan-Arctic Observing System of Systems - pan-AOSS*
- ArcticROOS
- EuroArgo (www.euro-argo.eu)
- ARCGOOS (Lee et al., 2019)
- HiAOOS (hiaoos.eu)

ArcticROOS
EuroGOOS Arctic Regional Ocean Observing System



HiAOOS

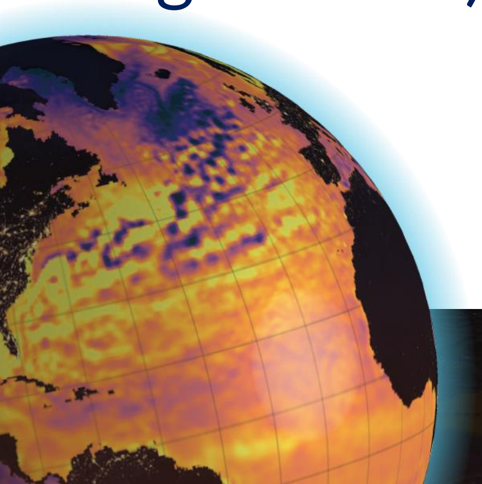
Increasing open water areas could be opportunity for more observations

In situ

- Saildrones
- Marine mammals
- Underwater cables*
- Ships of opportunity
- Profiling floats (ALAMO, Argo, gliders …)

Satellites

- Altimeters (SSH, winds, waves, sea ice)
- Passive microwaves (sea ice, SST, SSS, winds)
- SAR (sea ice, winds, waves, doppler currents…)
- Infrared (SST)
- Visible (Ocean colour)

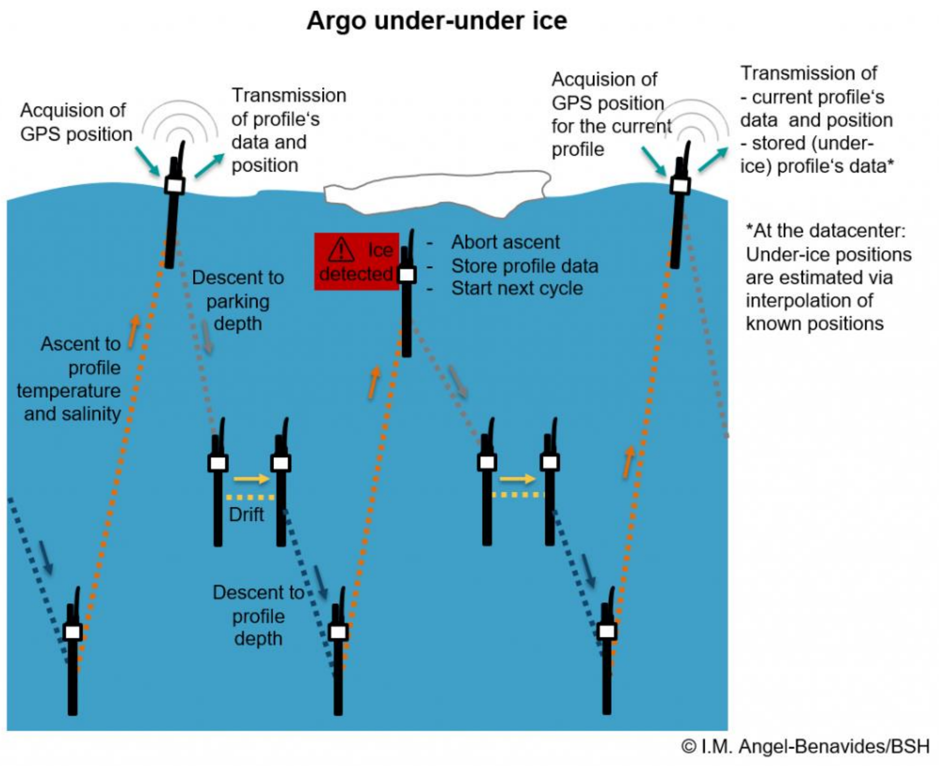


*Note also potential use of underwater cables for tomography, geolocation of Argo floats,...

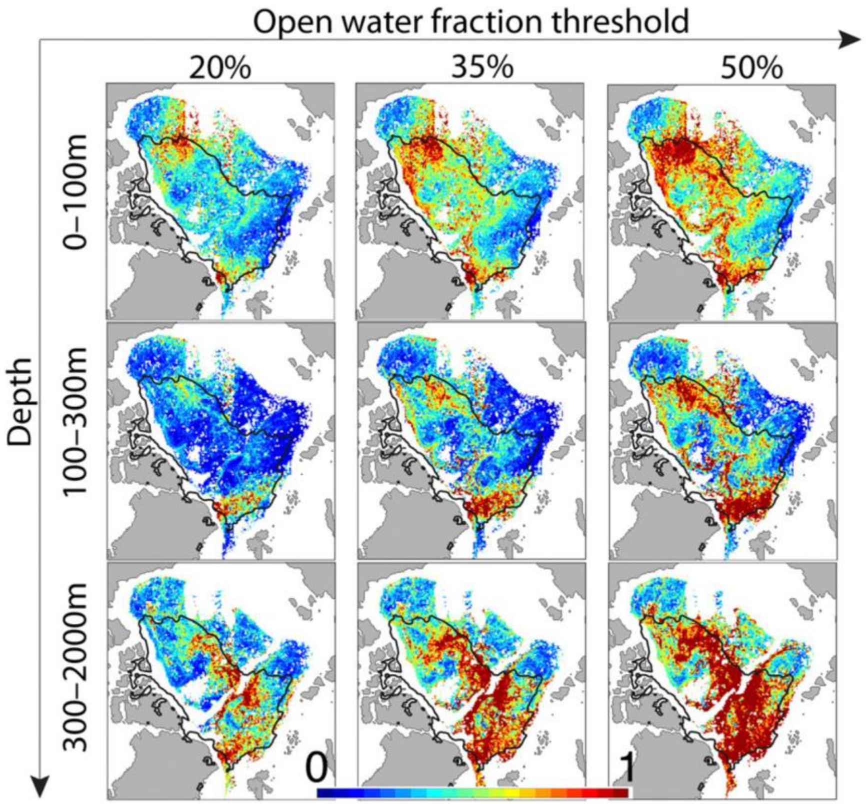
Numerous efforts to address polar gap

- PolarArgo: New Argo technologies
  - e.g. Le Traon et al. (2020)
  - More robust hardware to resist ice damage
  - Ice detection (ability to abort float asscent)
  - Storage of under-ice profiles
  - Float localization under-ice

- OneArgo Decade project
  - see OP24 talk by B. King



Potential impact of Argo floats on Ocean State Estimate

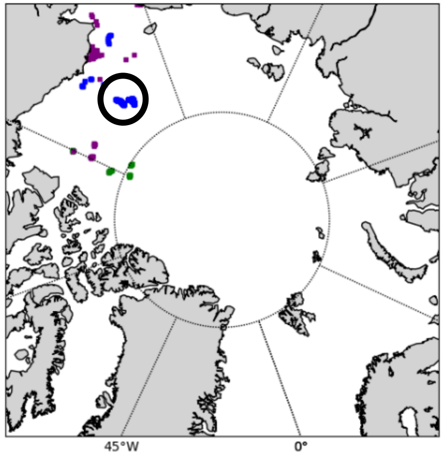


Mean normalized temperature error (Nguyen et al., 2020)

Arctic Observing System Simulation Experiments (OSSEs)

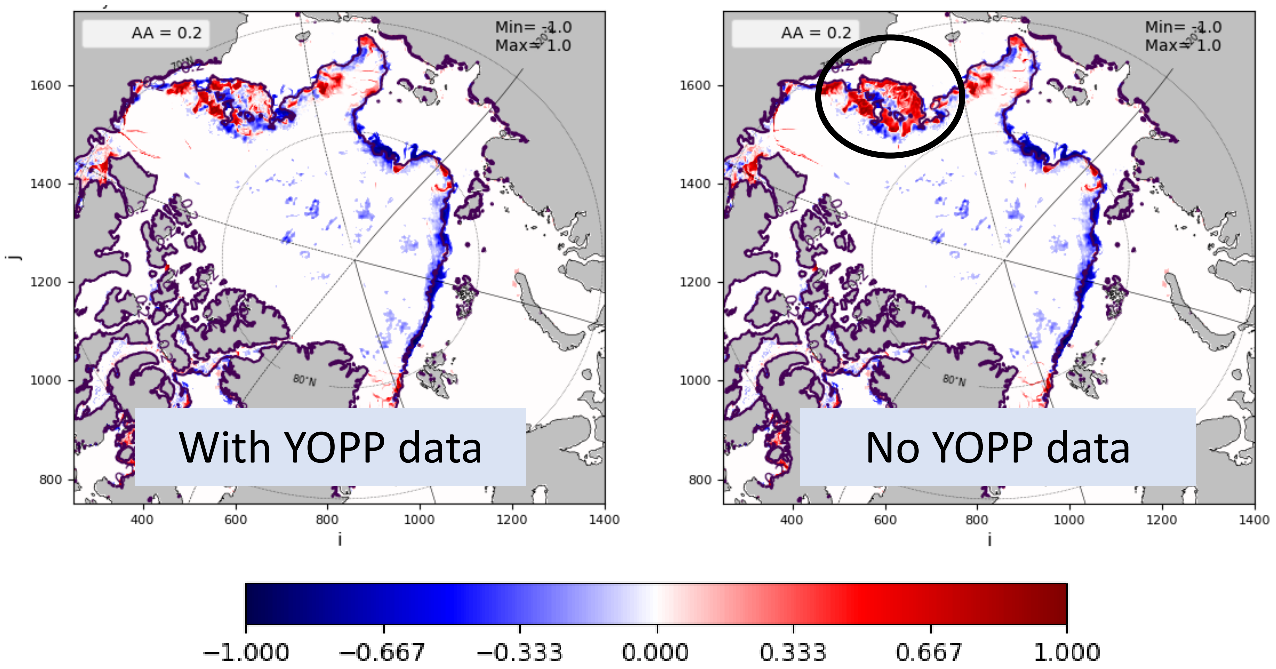
- Lyu et al. (2021):
  - 1x1° Arctic profiling array could substantially improve watermass properties
- Nguyen et al. (2020):
  - OSSE with Argo floats seeded in the Arctic basin
  - Impact strongly sensitive to ability of floats to surface

Arctic OSE results



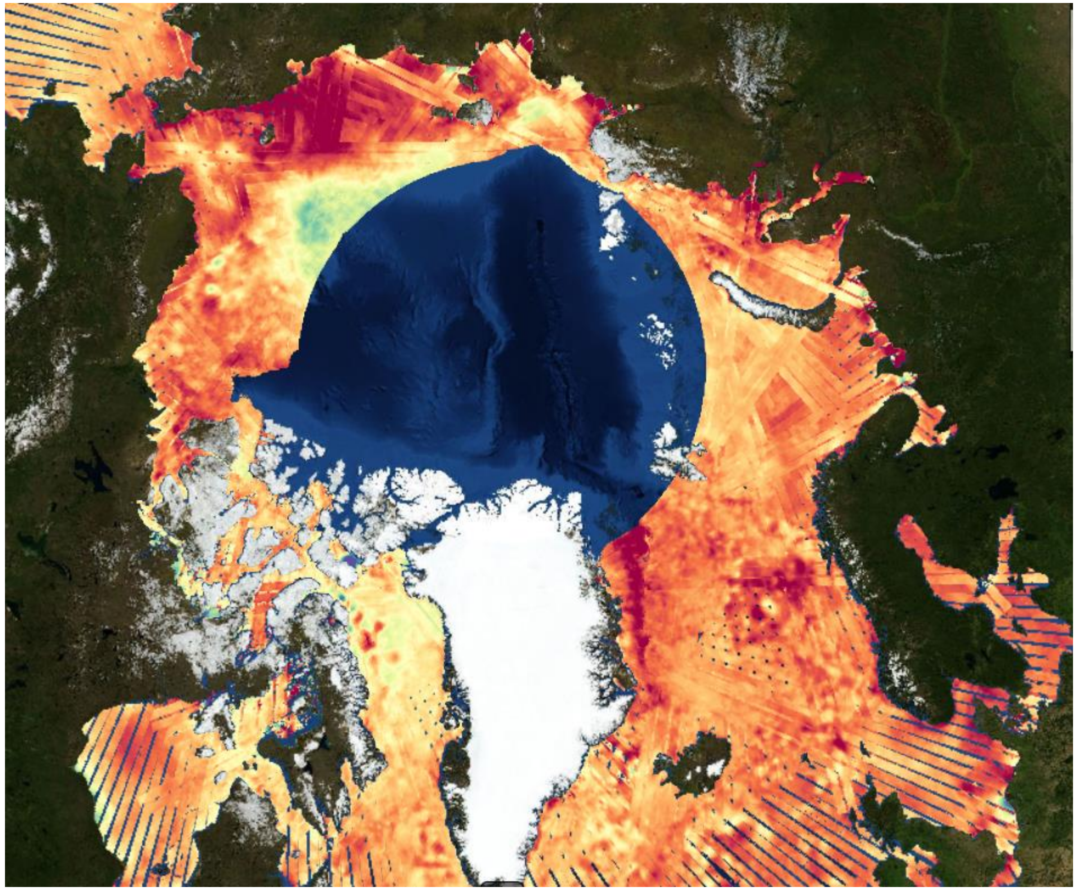
- Data withholding experiments performed using YOPP in situ observations over summer 2018 using regional ocean analysis system (RIOPS).
- With YOPP data, sea ice increments are smaller for a rapid freeze up event suggesting 7d trial fields provided a more accurate estimate of conditions.
- Salinity increments using YOPP data freshen and stratify mixed layer allowing faster surface cooling leading to **better representation of rapid ice formation** event in Beaufort/Chukchi Sea
- Impact of in situ observations strongly affected by satellite altimetry

Sea ice concentration increment for 2018-10-17

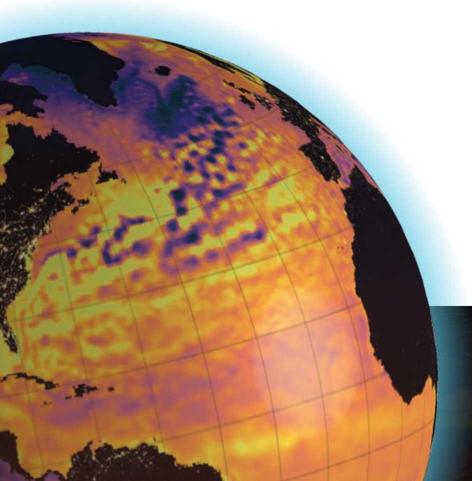


Satellite altimetry

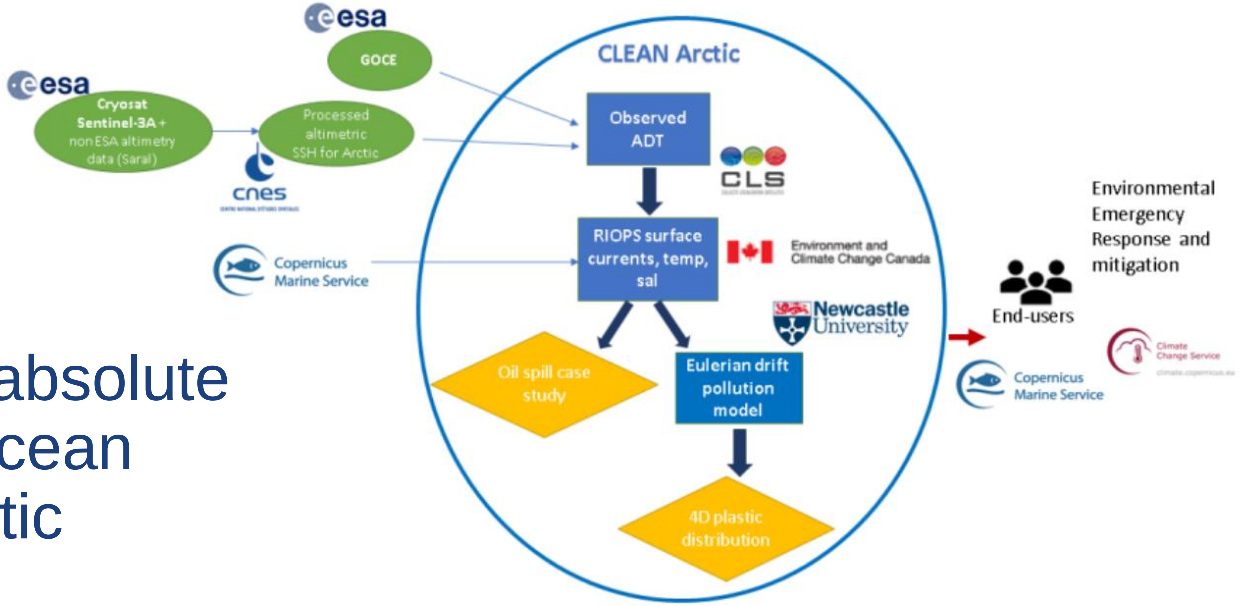
- Increasing open water areas provide greater potential impact of altimetry
- SWOT has potential to improve constraint on smaller scales present in the Arctic
  - Lots of cross-overs near 79N
- Also, altimetry in leads (Prandi et al., 2021)
- However, inaccuracies in MDT due to short observation period an issue (Pujol et al., 2018)



14 days of SWOT data from NERSC virtual laboratory (20240915)

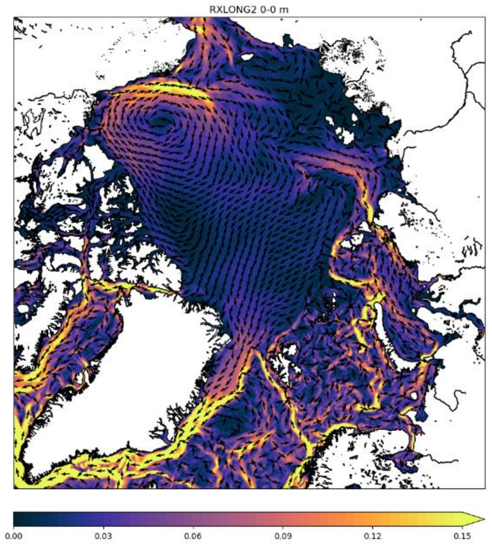


Project Clean Arctic: Assimilation of absolute dynamic topography data in an ocean assimilation system for the Arctic

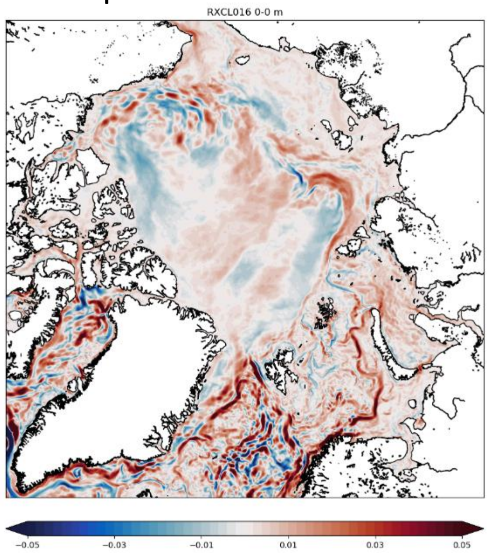


- Developed new Absolute Dynamic Topography (ADT) dataset over the Arctic.
  - Avoids the need for Mean Dynamic Topography (as for SLA assimilation)
- Assimilated ADT in Regional Ice-Ocean Prediction System
  - Required various adaptations for spatial scales and under-ice assimilation
- Significant impact on basin-scale sea level and transports through key Arctic gateways

Mean sfc currents



Impact of ADT assim



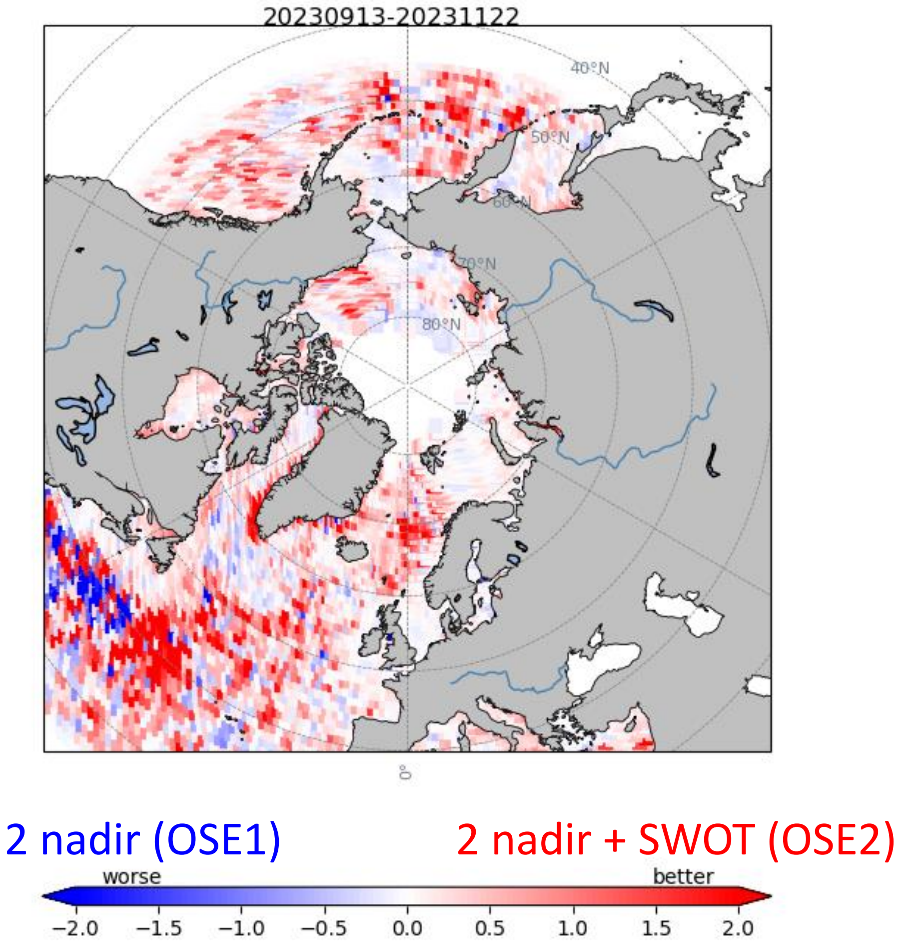
Smith et al. (2024)

Preliminary results of assimilation of early SWOT observations

- Assessed the impact of assimilation both real and synthetic SWOT observations in Regional Ice Ocean Prediction System (RIOPS)
- 4-km resolution over the Arctic (inc. tides)
- SWOT data: AVISO Level 3, release v0.3
- Evaluated for 2023-09-13 to 2023-11-22
- OSE1: Assimilate only 2 altimeters (Cryosat2, Jason3)

- OSE2: Impact of SWOT+2 nadir
- Reduction of RMS differences in GIN and Beaufort Seas

RMS difference compared to all SLA observations

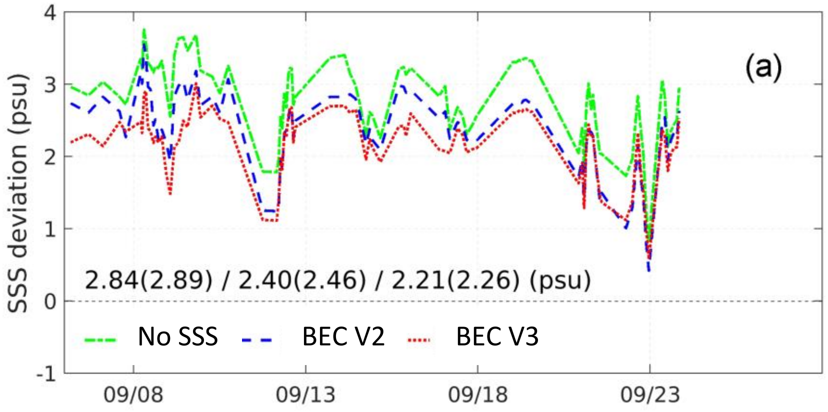


Liu et al., Front. in Mar. Sci., 2024

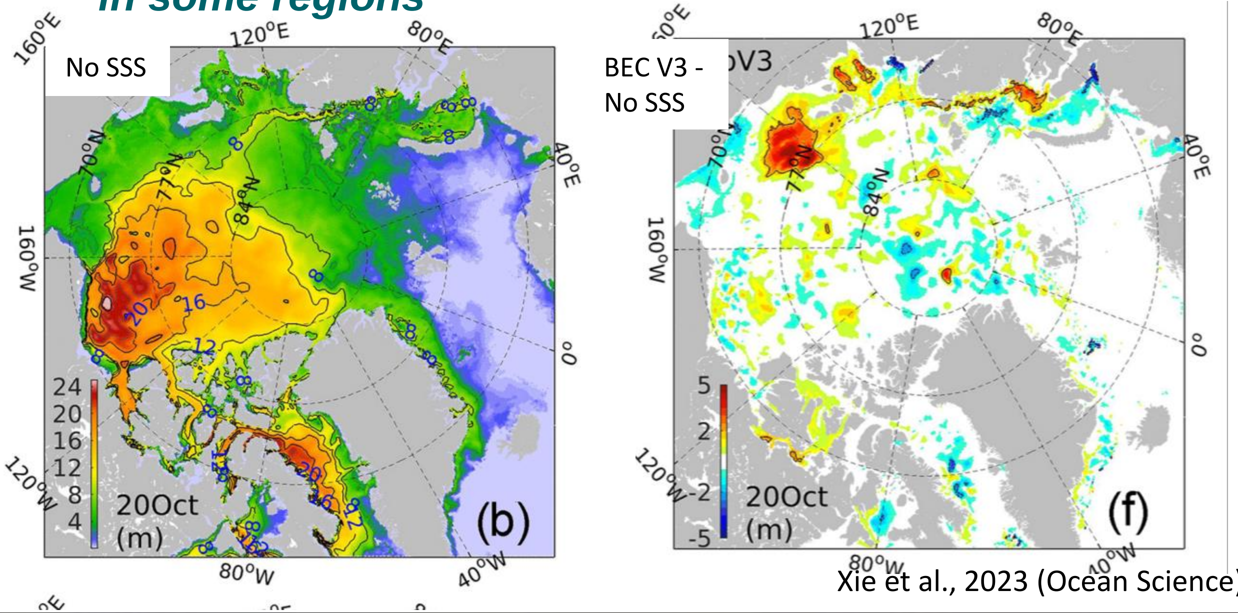
Effect of assimilating SSS from SMOS

- Assimilating sea surface salinity can reduce biases
  - This could have important effects for ocean stratification and sea ice freeze/melt
  - However, sources of uncertainty leading to the differences remain

Assimilating SMOS SSS can reduce errors compared to CTD data…



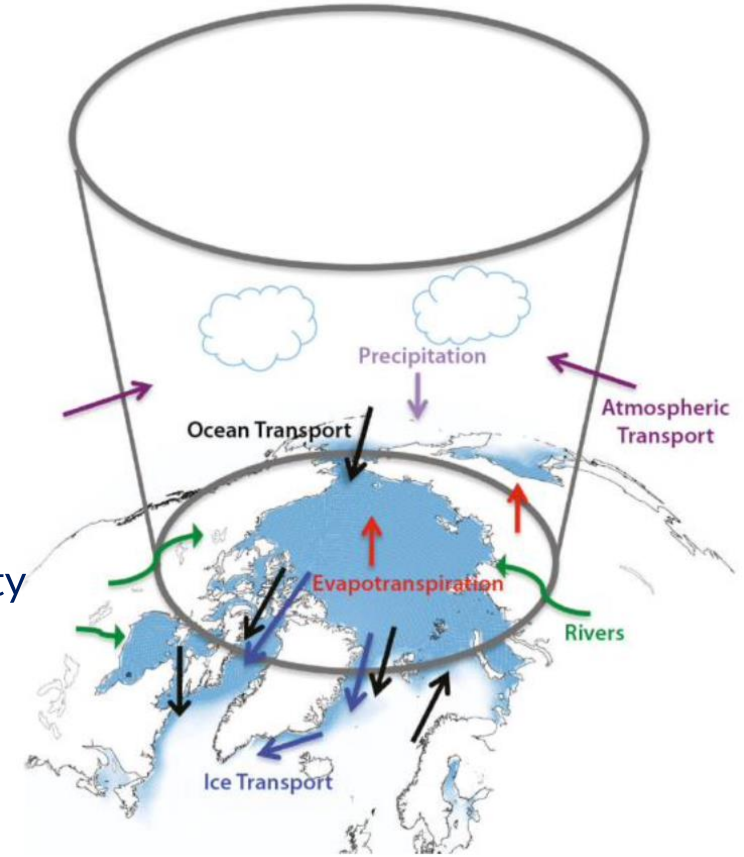
… and can have large effects on Freshwater content in some regions



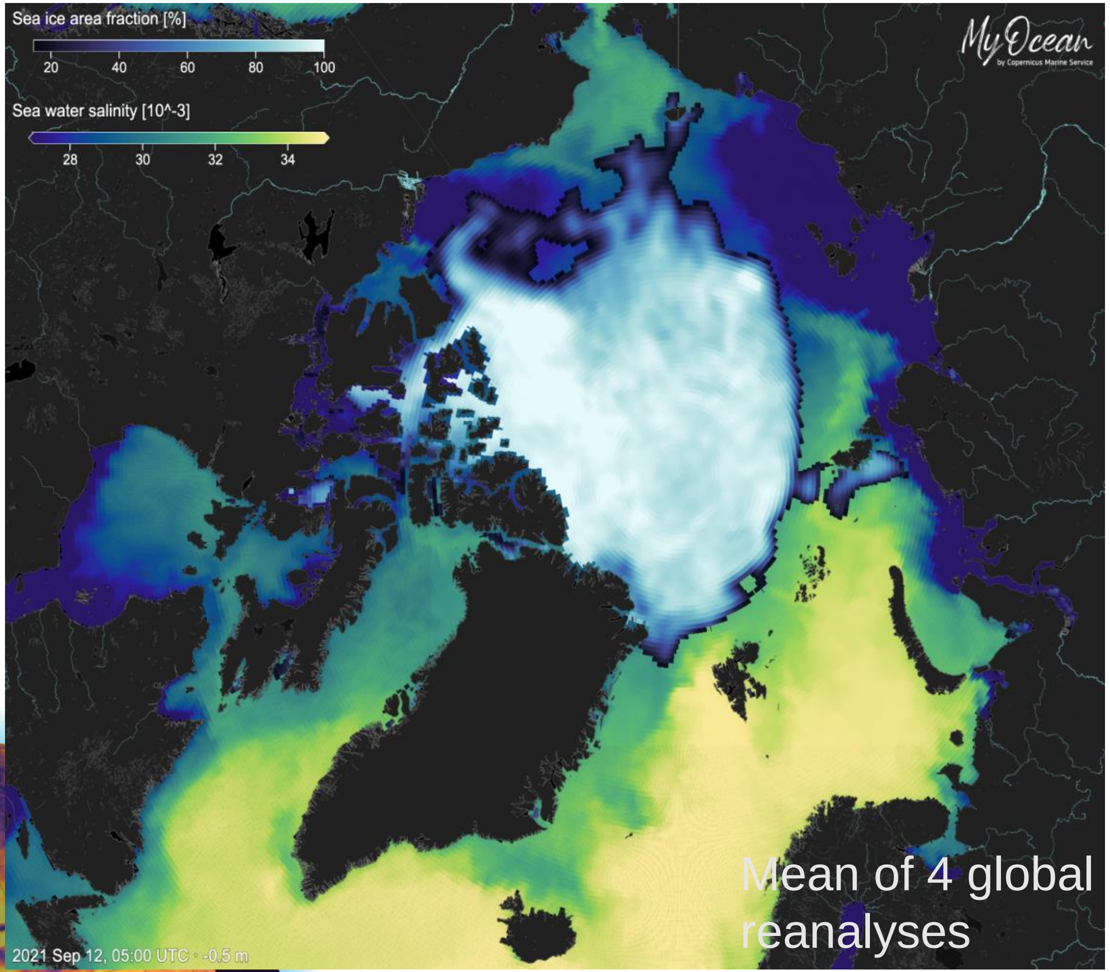
Xie et al., 2023 (Ocean Science)

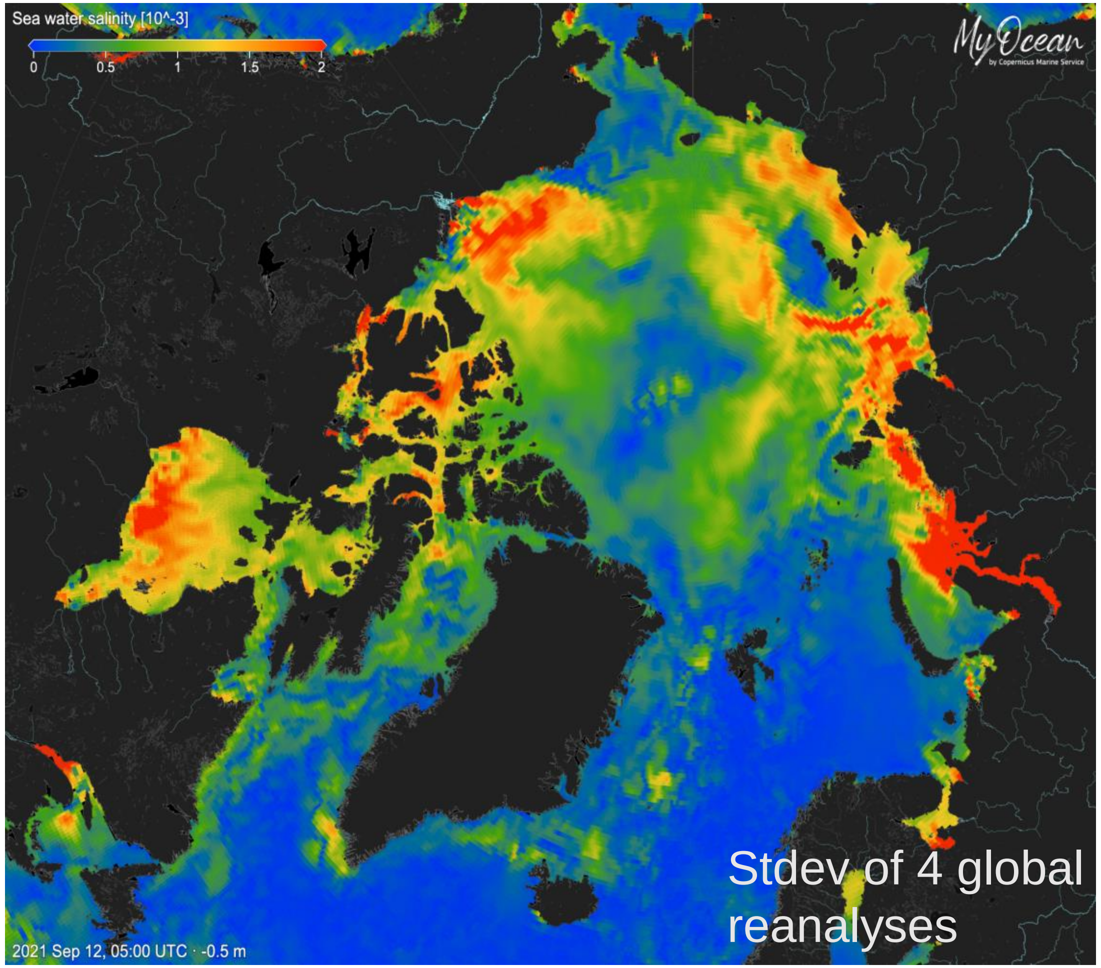
SSS is impacted by:

- Pacific / Bering Strait (2.500 km3/yr)
  - Moorings: 0.8 Sv, increasing (Woodgate et al. 2018)
  - Often 1.4 Sv in models
- Rivers (2.900 km3 / yr)
  - Increasing …
- Glacial melt
  - Lacks streamflow measurements
  - Mostly going to North Atlantic, not Central Arctic
- Sea ice melt (300 km3 / yr, Edel et al. 2024)
  - Reduced ice thickness abruptly in 2007
    - Uncertainties: Lacking observations of snow depth and sea ice density
  - Export in Fram Strait is reducing
- Precipitations – evaporation
  - Increase moisture flux (correlated with the AO)
    - North of 60N: 8.500 km3/yr -> 9.000 km3/yr
  - Reduced evaporation
  - Lacks observations of snowfall à la Edel et al. 2020 (CLOUDSAT)



Big spread in modelled SSS…

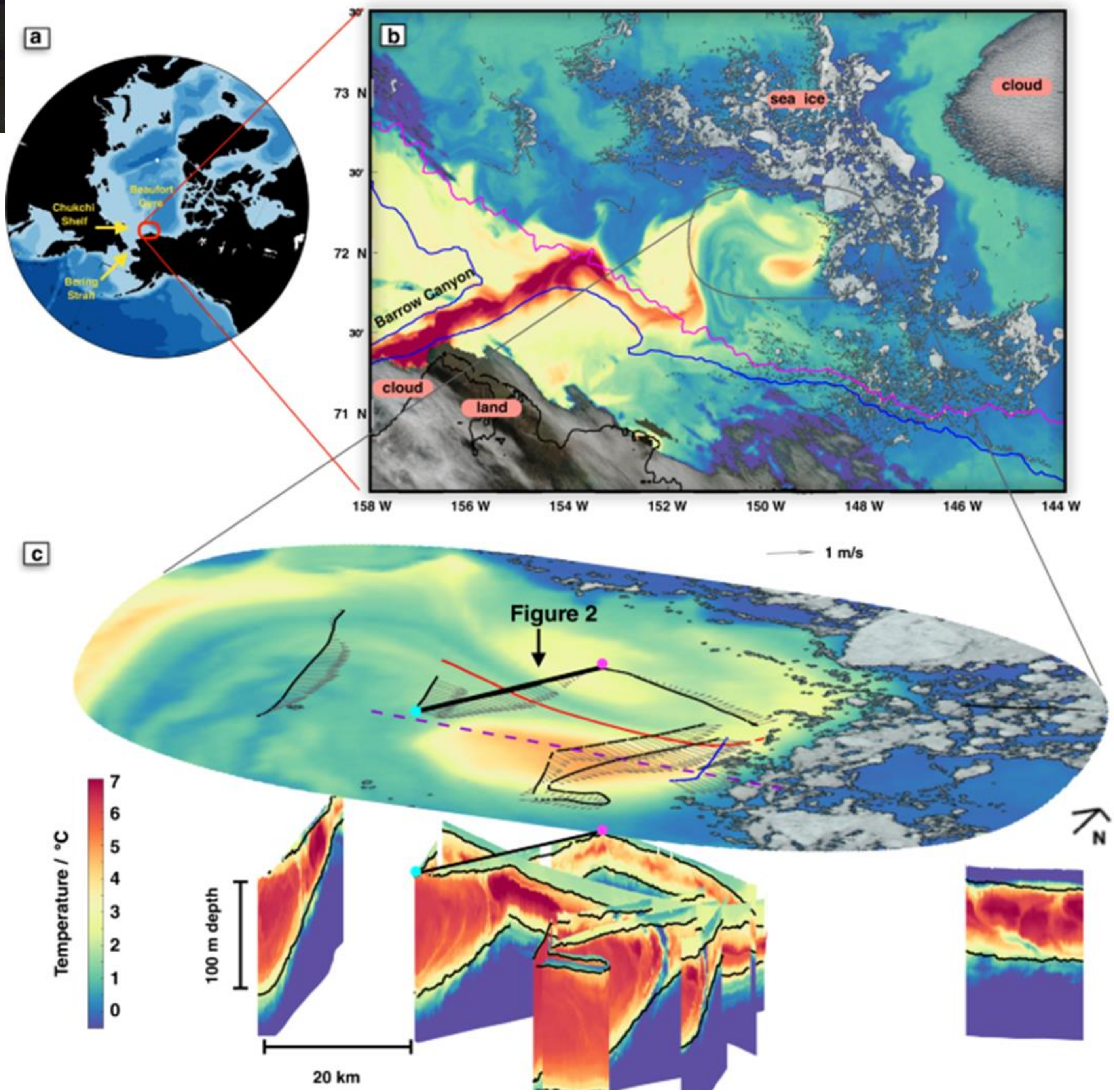




Ocean Predict

Challenges in Ocean Modelling: small scale

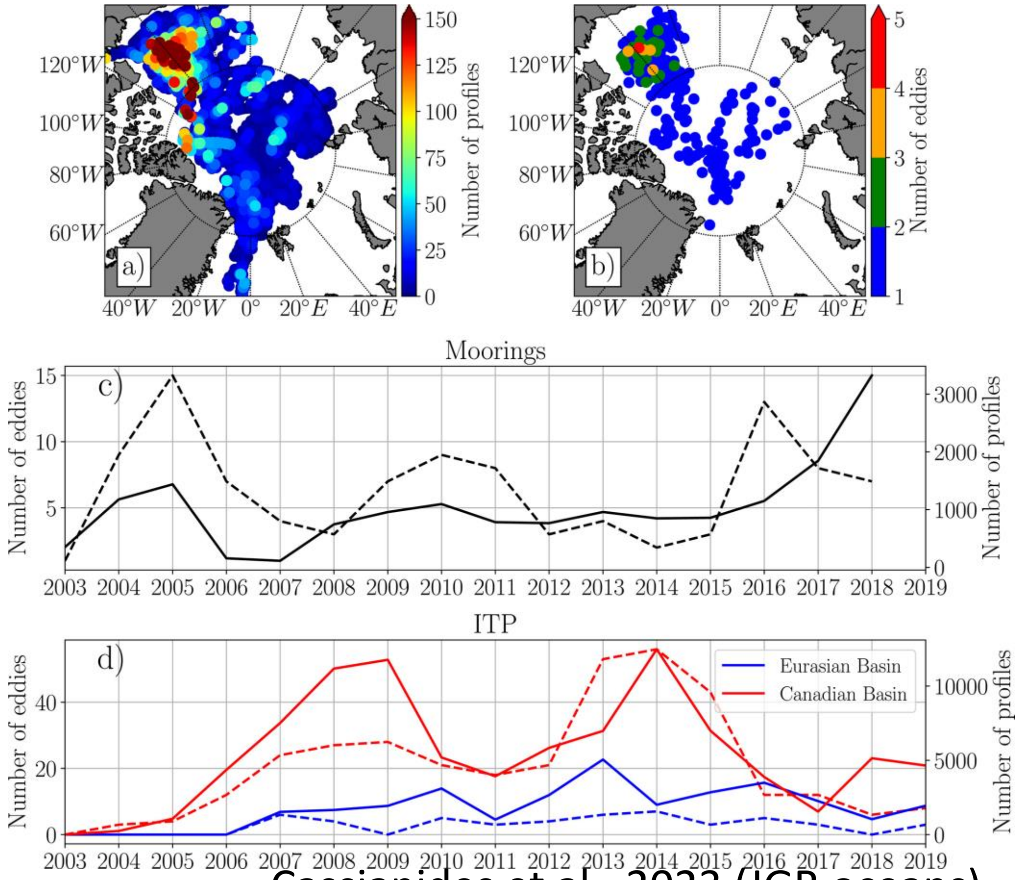
- Importance of small scales in the Arctic and important exchanges through open boundaries and between shelf and interior.
- e.g. MacKinnon et al. (2021): Processes affecting heat redistribution associated with subduction of warm(er) Pacific waters in Beaufort Gyre
- Demonstrates example of processes affecting heat exchange and driving submesoscale circulation that ocean models need to capture.



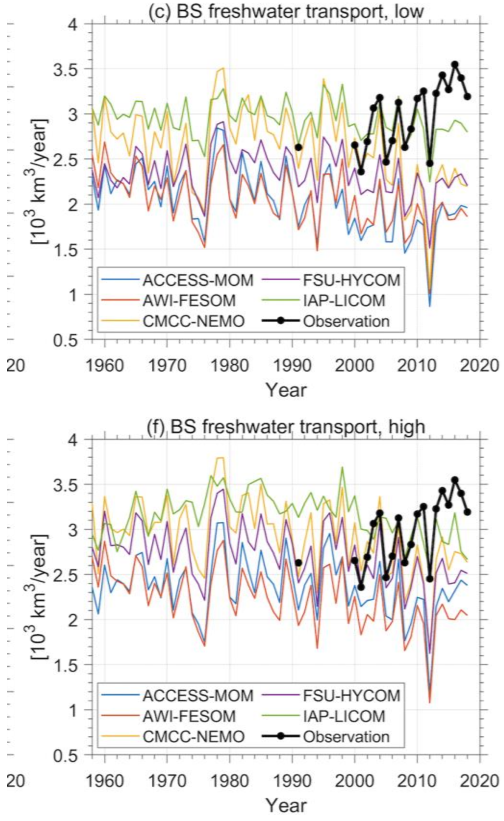
Presence of eddies

can affect transports through key gateways

Eddies are detected in observations...

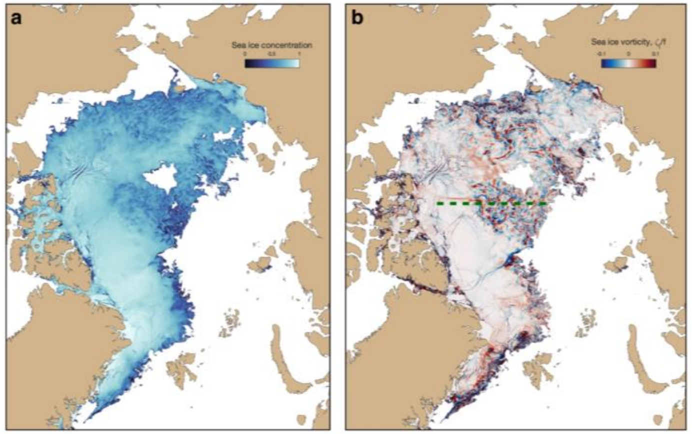


Cassianides et al., 2023 (JGR oceans)



Wang et al., 2024 (GMD)

High-resolution simulations also show imprint of eddies on sea ice



Manucharyan and Thompson, 2022 (Nature)

The Arctic is a "quiet" ocean, but how quiet should it be?

New possibilities to inform model processes in the MIZ from satellites

- e.g. using Doppler shift to retrieve surface currents in the MIZ, or detecting waves under floes
- Multisensor approaches to diagnose contributions and reduce uncertainty

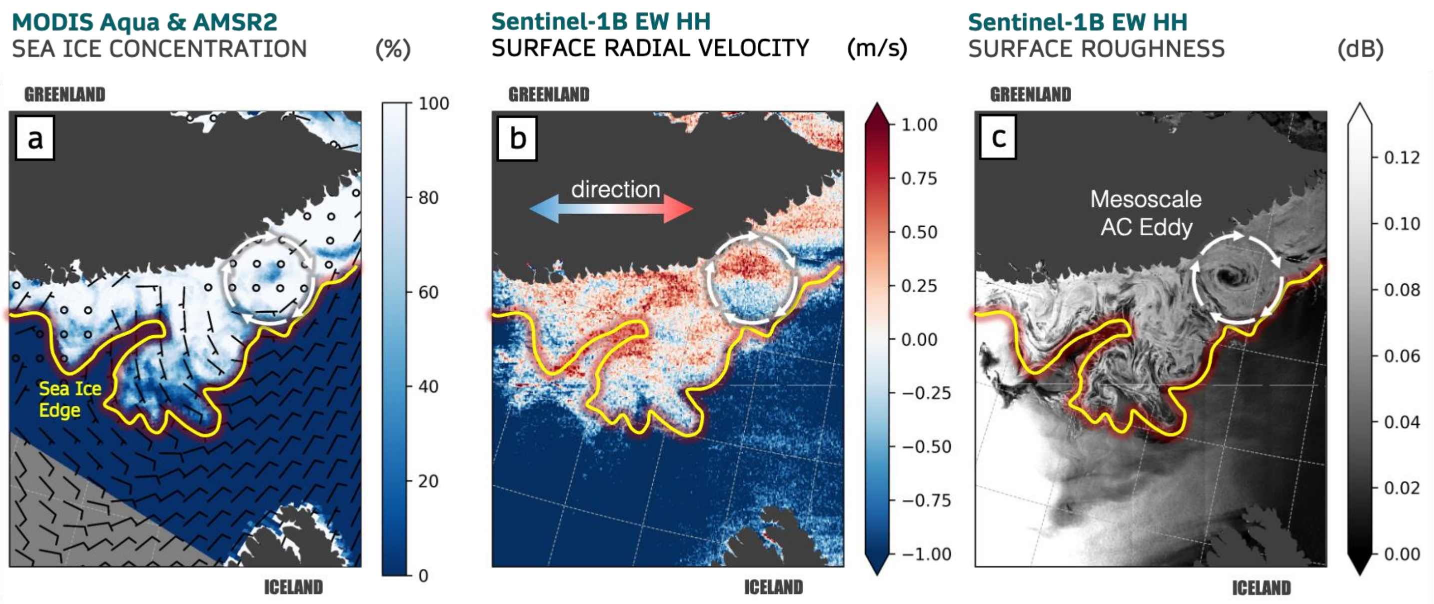
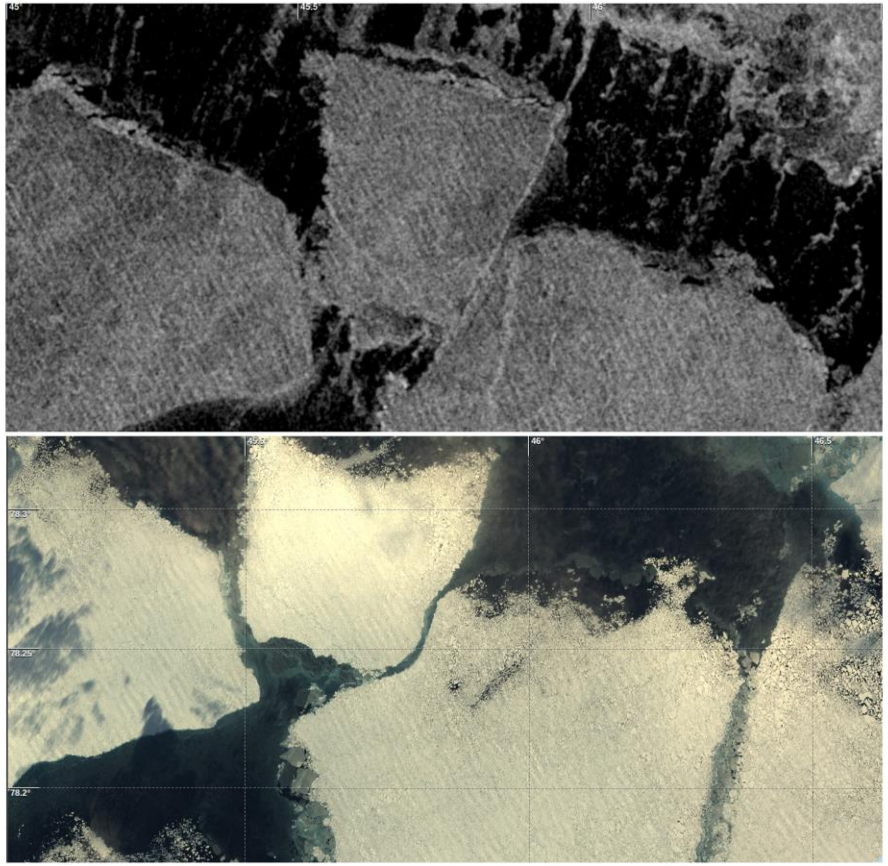


Figure 1.1. MIZ structures in the Denmark Strait on 14th November 2020: (a) Sea ice concentration derived from the thermal infrared sensor (MODIS) and passive microwave radiometer (AMSR2) observations (Ludwig et al. 2020), black barbs indicate wind field at 10m height at time of SAR acquisition from ECMWF; (b) Sea ice and Ocean surface radial velocities derived from the Sentinel-1B Doppler Centroid Anomaly - negative/positive values indicate motion to the left/right; (c) Surface roughness from Sentinel-1B. The yellow curves display the sea ice edge derived in the left image. The presence of a clockwise rotating mesoscale eddy is marked with white arrows. All datasets are provided at a 1 km grid resolution.

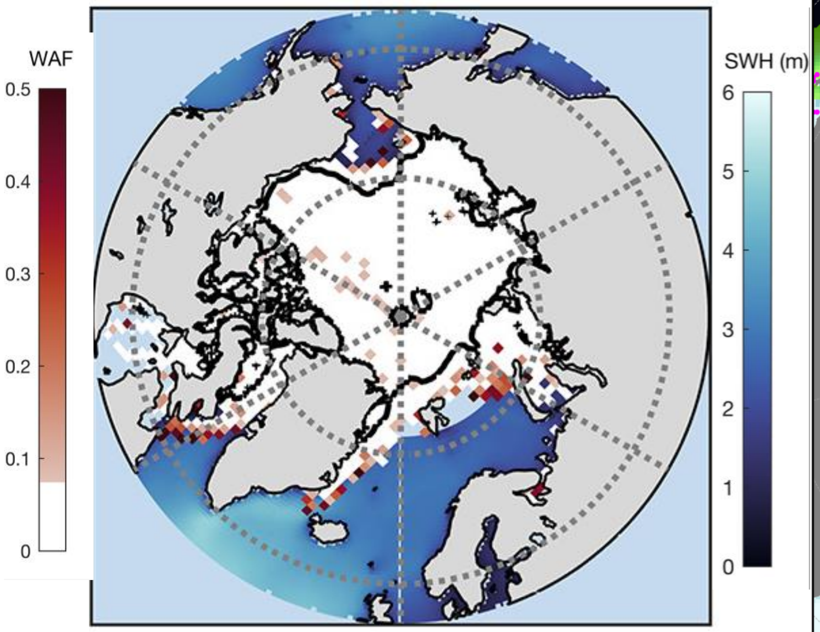
Figure courtesy of A. Moiseev



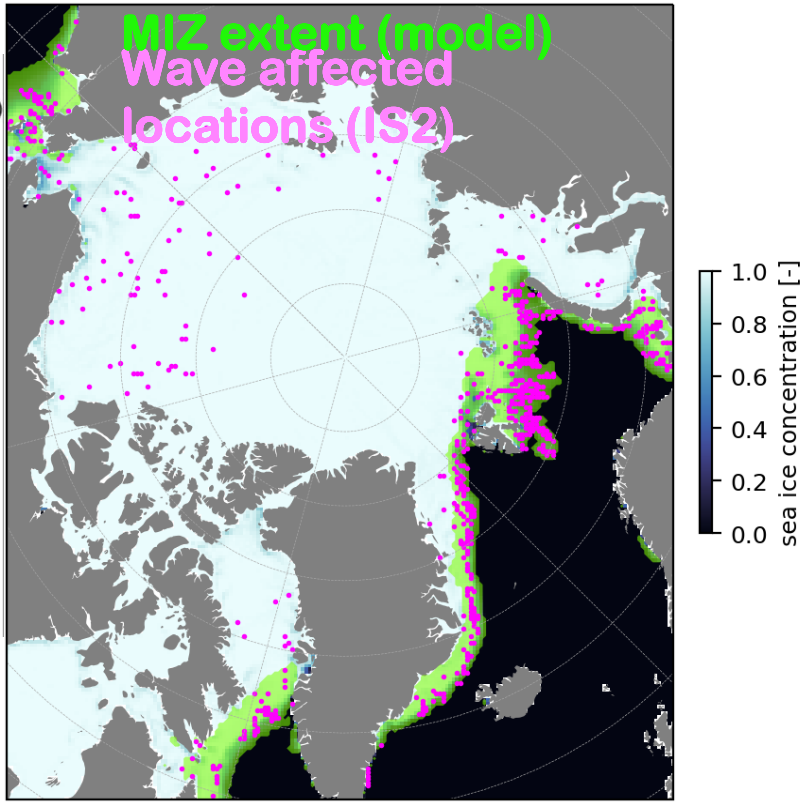
Collard et al. (2022)

Waves increasingly important in Arctic?

- Models suggest strong effects on sea ice growth, melt and mobility in MIZ, and potential growth in wave-affected area in sea ice
- **How to validate such models?**
- Altimetry detection of wave-affected area:
    - Horvat et al. 2020: IceSat-2 (detection of wave trough in-ice)
    - Zhu et al. 2023: CryoSat-2 (from waveform power and the waveform stack statistics)
- Main challenge: How to link this wave-affected area to more quantitative (and measurable) properties of the ice/wave state? (like wave height, floe size…)



Horvat et al. (2020)

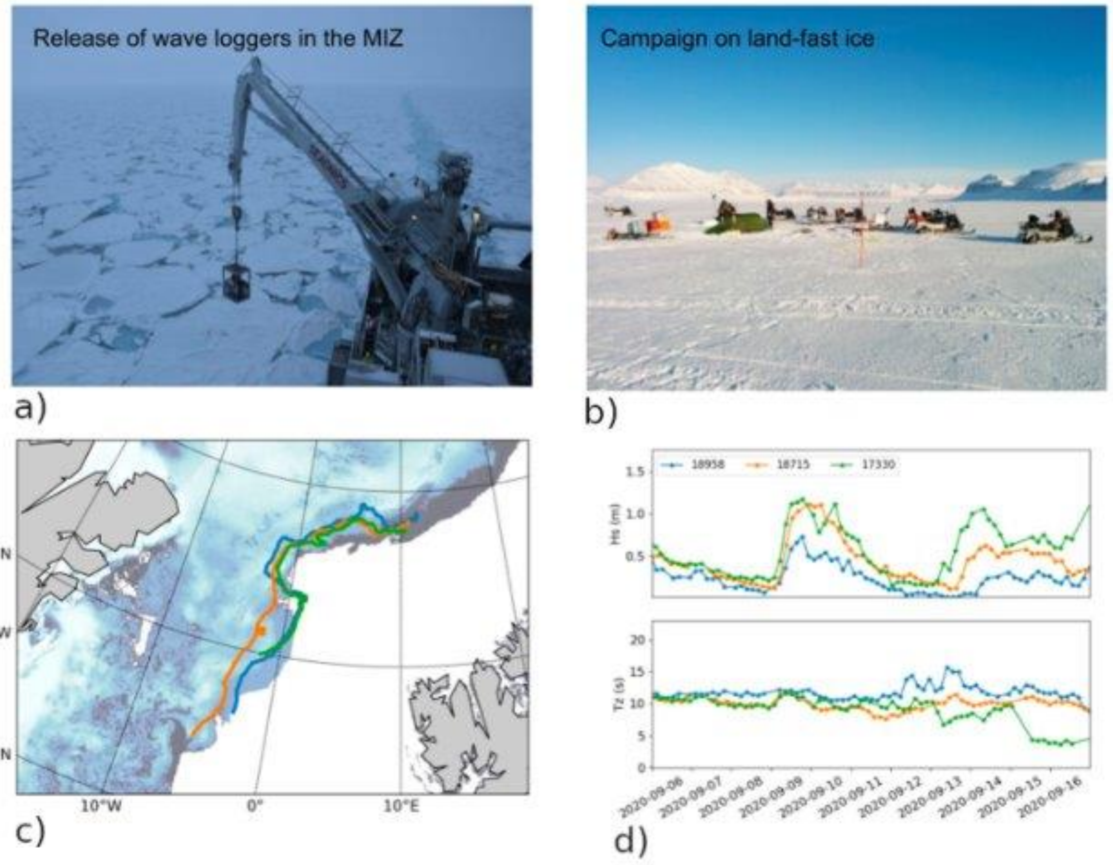


Boutin et al. (2022).

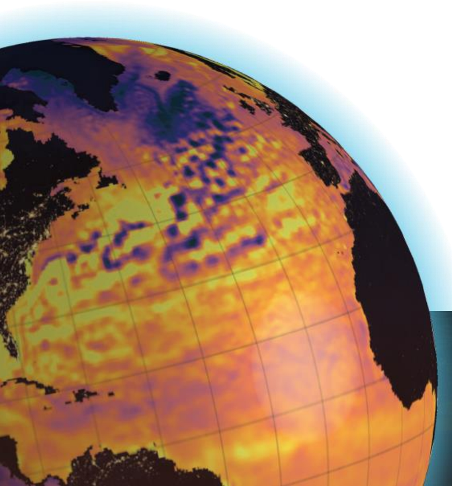
Limited available in-situ wave observations

Historically, few in-situ data collected, even less available

- Open Met Buoy program: cheap & light buoys
  - Almost 200 publicly trajectories available since 2018 (mostly Barents/Greenland area); Rabault et al (2023)
- And also "Swift" buoys and moorings from APL-UW (mostly for the Beaufort area); Thomson et al (2023)



Note: no operational forecast model currently has two-way coupling with waves and sea ice (very costly...)




scientific **data**

Check for updates

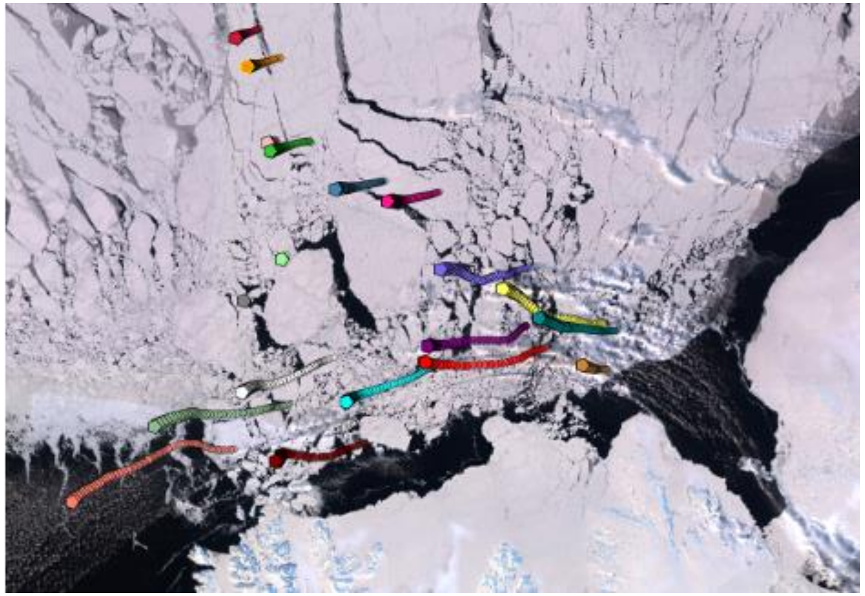
OPEN
DATA DESCRIPTOR

A dataset of direct observations of sea ice drift and waves in ice

Jean Rabault[1], Malte Müller[2,3], Joey Voermans[4], Dmitry Brazhnikov[5], Ian Turnbull[6], Aleksey Marchenko[7], Martin Biuw[8], Takehiko Nose[9], Takuji Waseda[9,10], Malin Johansson[11], Øyvind Breivik[12,13], Graig Sutherland[14], Lars Robert Hole[12], Mark Johnson[5], Atle Jensen[15], Olav Gundersen[15], Yngve Kristoffersen[16], Alexander Babanin[4], Paulina Tedesco[1,17], Kai Haakon Christensen[2,3], Martin Kristiansen[8], Gaute Hope[12], Tsubasa Kodaira[9], Victor de Aguiar[11], Catherine Taelman[11], Cornelius P. Quigley[11], Kirill Filchuk[18] & Andrew R Mahoney[19]

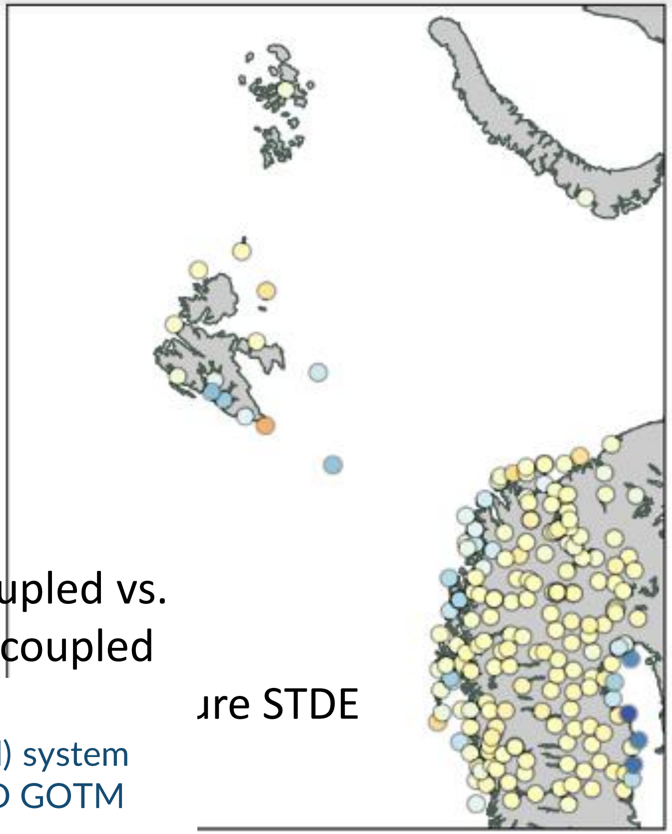
MIZ highly coupled: dedicated campaigns useful

Observed cold air outbreak and southerly storm event in Svalbard, 2024



Courtesy M. Muller, MET Norway

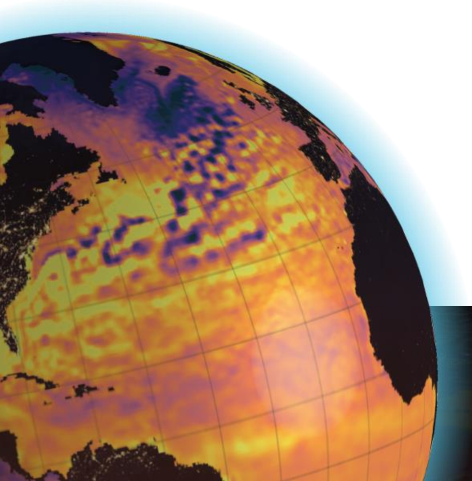
Coupling experiment, May 2023



Coupled vs. Uncoupled

ure STDE

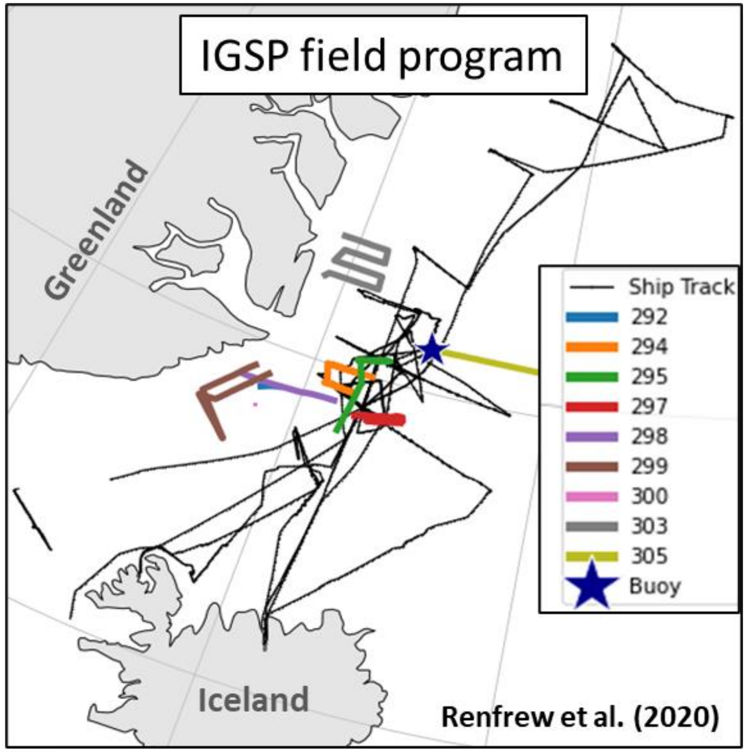
Courtesy Y. Batrak, MET Norway

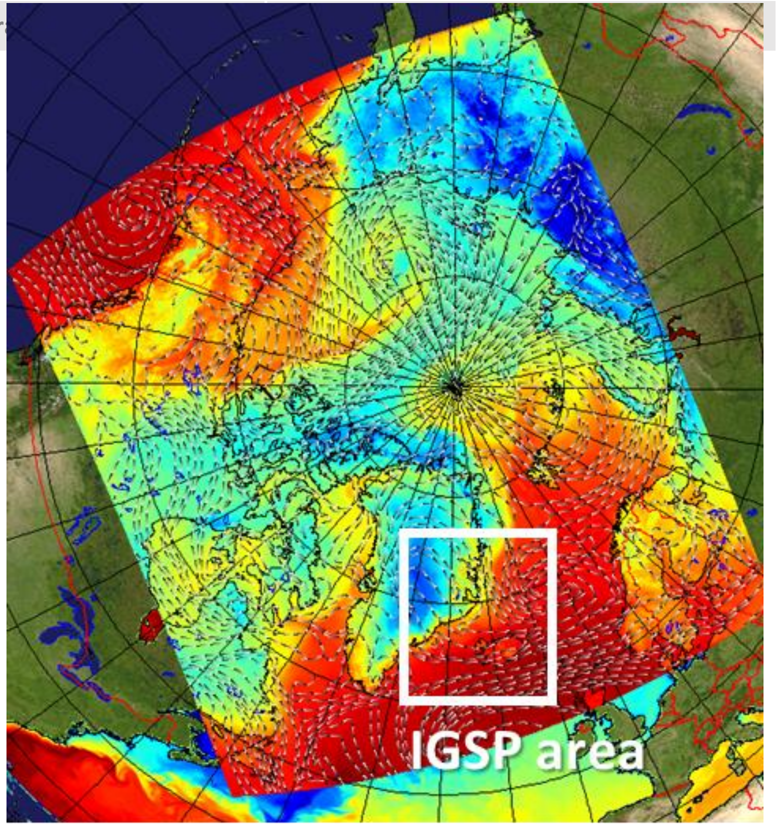


Important for weather forecasting...

- Coupled atm-ocean vs operational (non-coupled) system
  - Only coupling ocean mixing processes (1D GOTM water column)
  - Ocean currents neglected for efficiency
- Positive impact on air temperatures through coupling, especially for the coastal stations.

Uncertainty in surface fluxes- Example





Iceland Greenland Sea Project

OBSERVATIONS

- Multiplatforms atmospheric & ocean
  - met buoy, research ship, radiosondes & aircraft
- Captures multiple Greenland *cold air outbreaks*

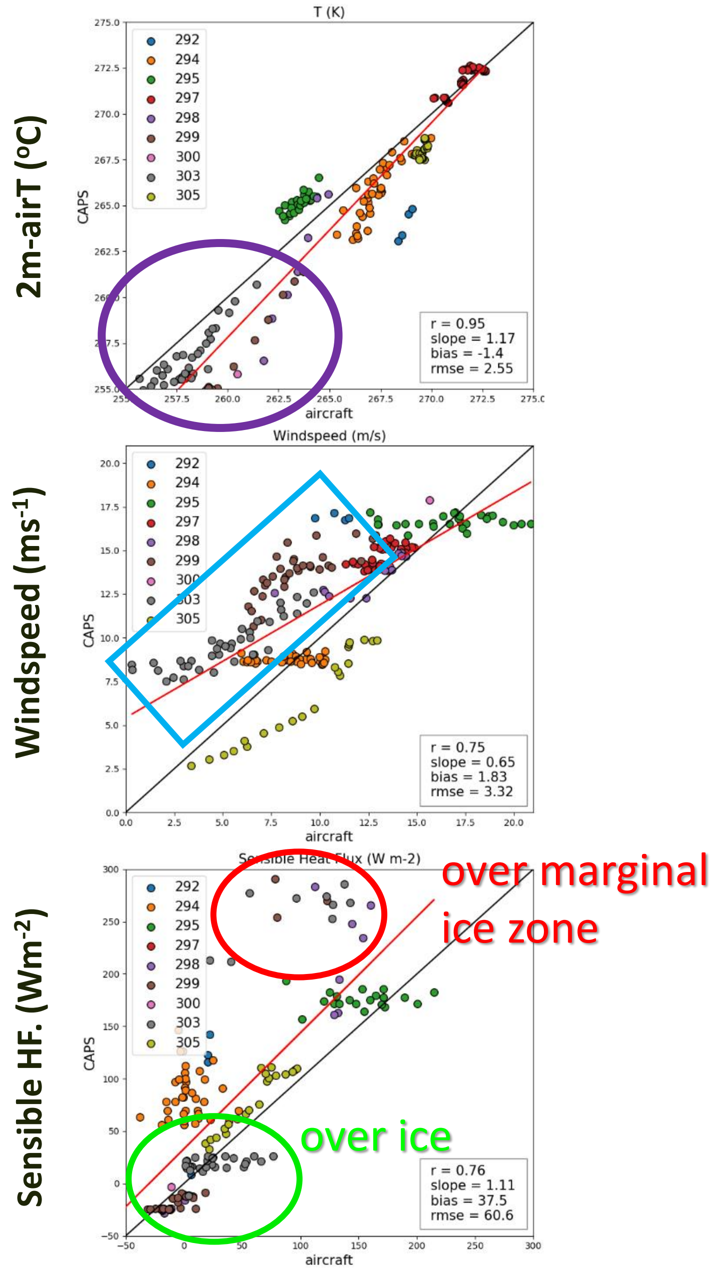
CAPS operational (2018)

- Uncoupled version running in operations starting Feb 2018 and fully coupled starting in June 2018. Currently being reinstalled.
  - 48h forecast (2x per day)
- Initialized with daily SST & ice analysis at 25km res.

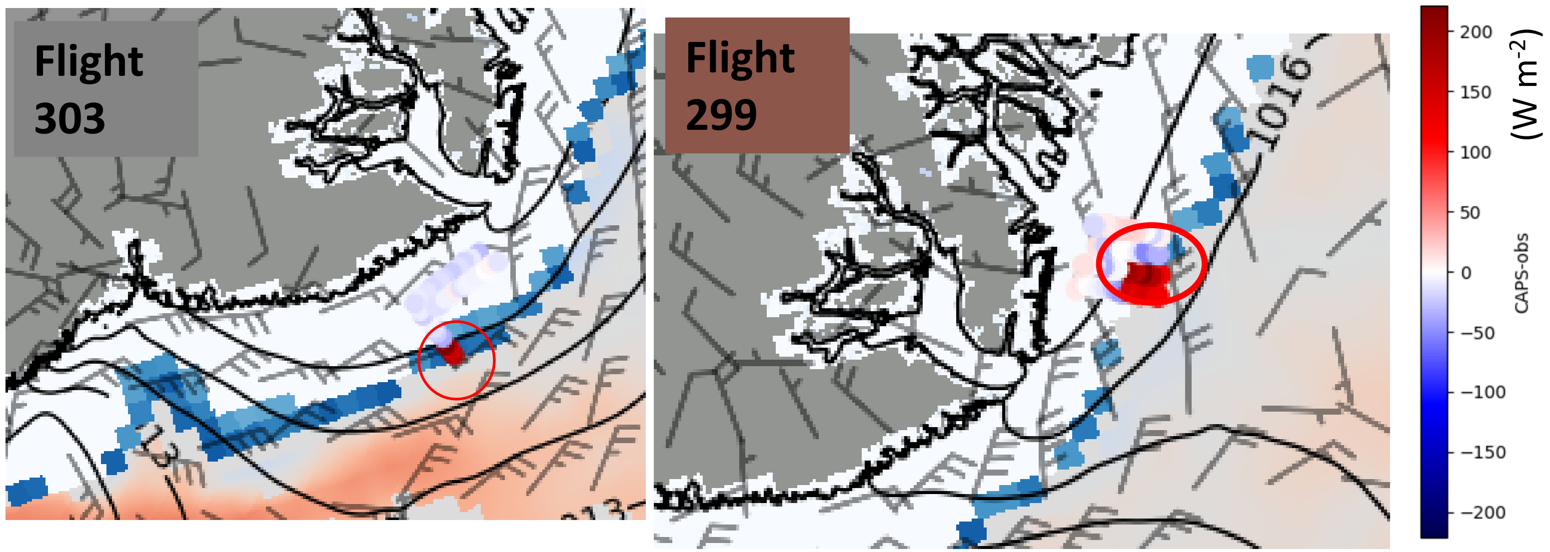
YOPP YEAR OF POLAR PREDICTION

CAPS (uncoupled) vs IGSP YOPP Observations

YOPP YEAR OF POLAR PREDICTION



Sensible Heat flux differences along flight paths



- Cold biases over the ice (lack of leads)
- Overestimated wind speeds over ice
- Sensible heat fluxes
  - Underestimated sensible heat flux over the ice (too few leads)
  - Overestimated sensible heat fluxes at ice edge
    - abrupt transition vs. observations
    - overestimated against ship data (>100 Wm^{-2} differences)
- Biases all highly dependent ice edge location & representation

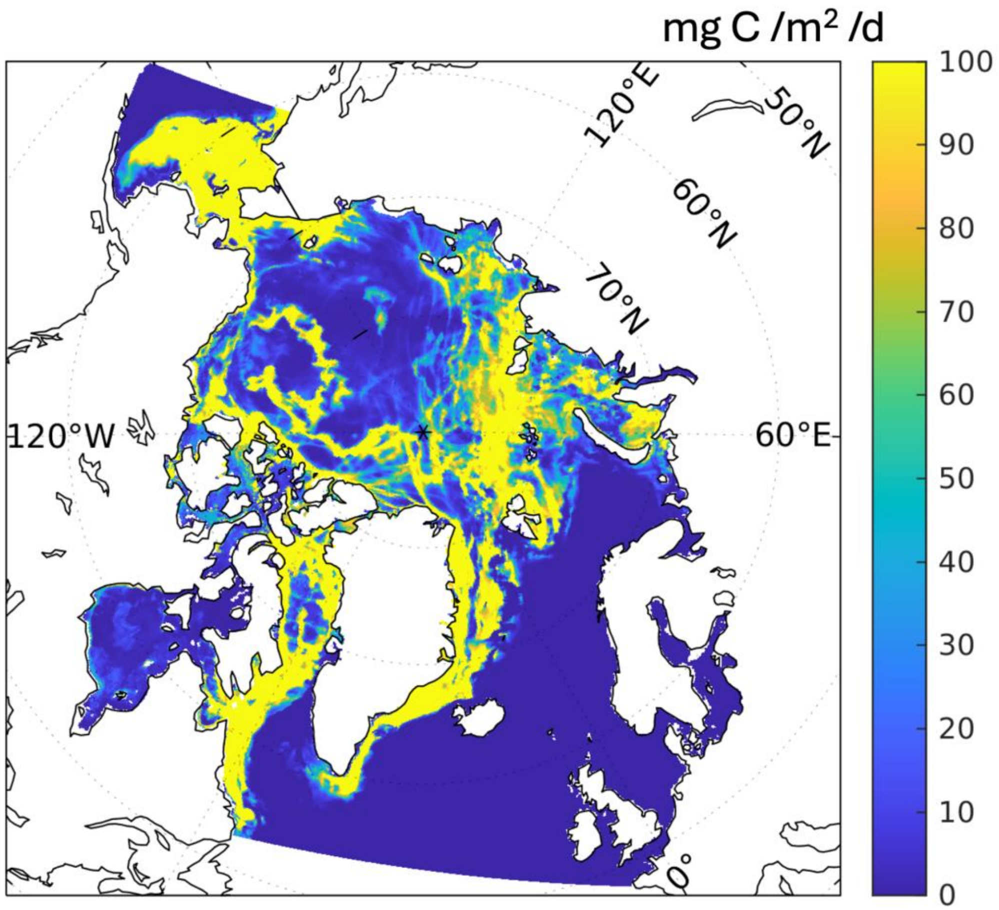
See presentation by F. Dupont for details

JP Paquin, M. Gheta, F Dupont, ECCC

Physical properties at all scales must be accurate in order to accurately model biology in models

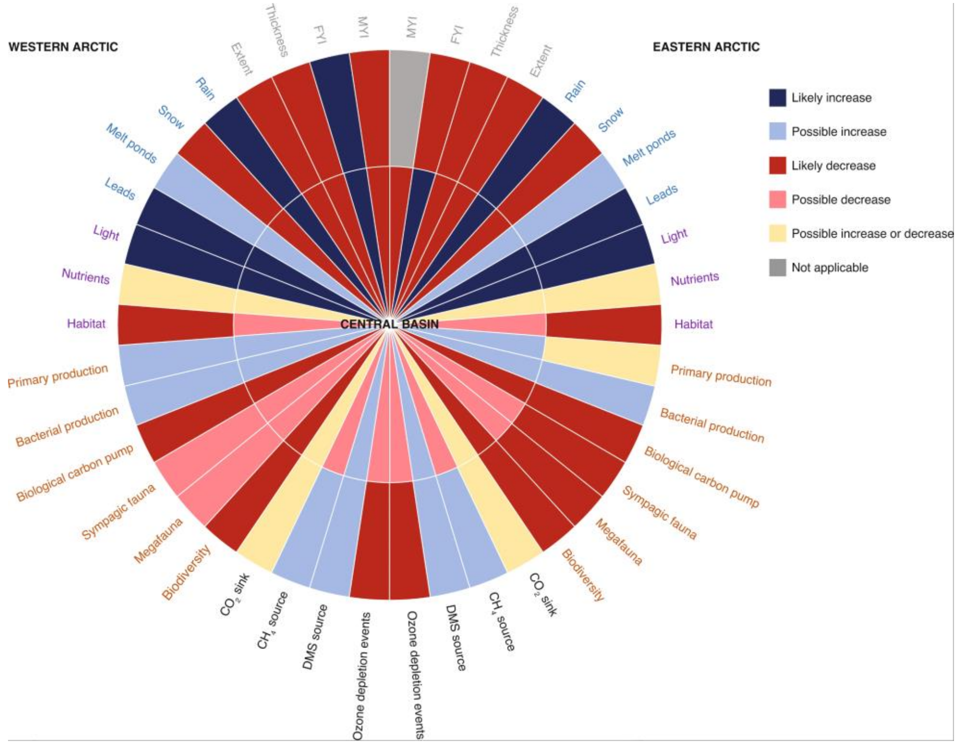
- Ice algae grows earlier than ocean algae
- Very important for zooplankton

Ice algae: *Melosira arctica*
Photo: Oliver Müller (UiB)



Ice algae biomass 2013-04-30

Biogeochemistry expected to change...



Lannuzel et al., 2020 (Nature)

...but uncertainties and simplifications in ecosystem models are compounded by errors and uncertainties in modelled physical properties (sea ice, T, S, transports...)

- Assimilation of surface chlorophyll changes modelled values in top 100 metres...

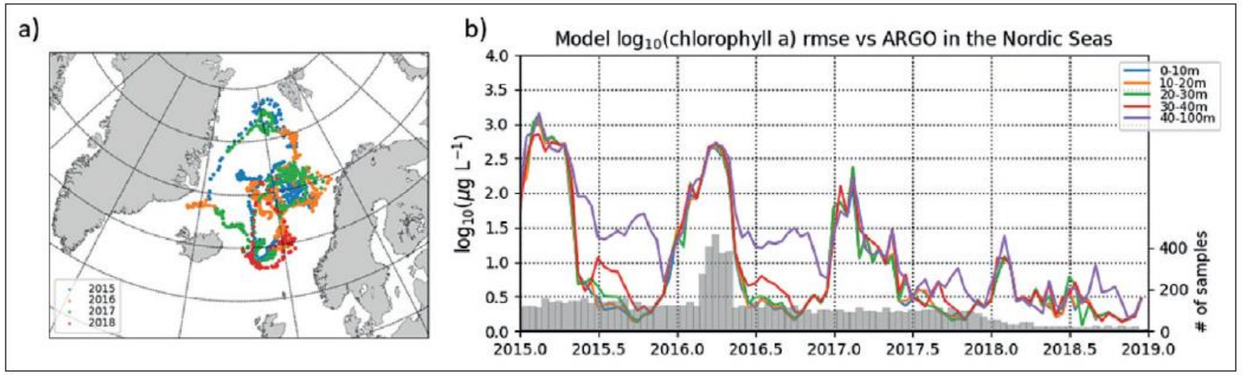
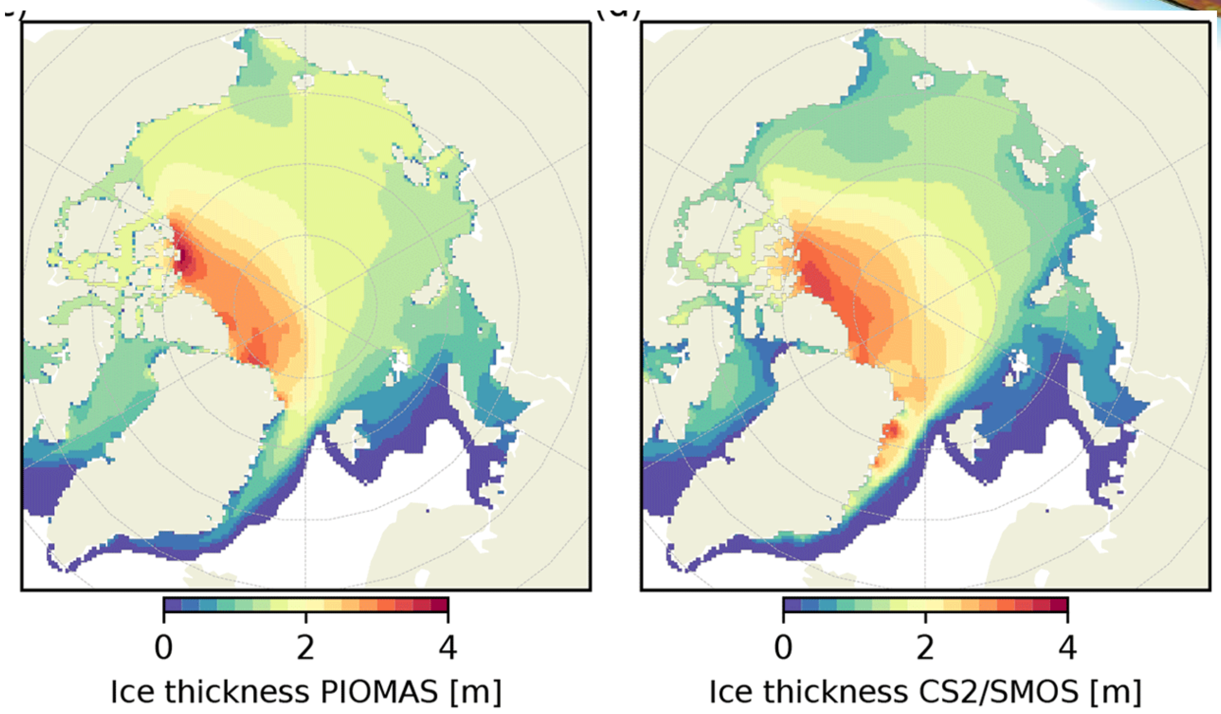


Fig. 3. Comparison of simulated Chlorophyll profiles to BGC-Argo buoys (panel a). The model root mean square error (RMSE) is shown in panel-b, note the inclusion of surface chlorophyll from satellite in January 2017 and the logarithmic scale for concentrations.

Bertino et al., 2021 (EUROGOOS)

Sea ice impacts on upper ocean

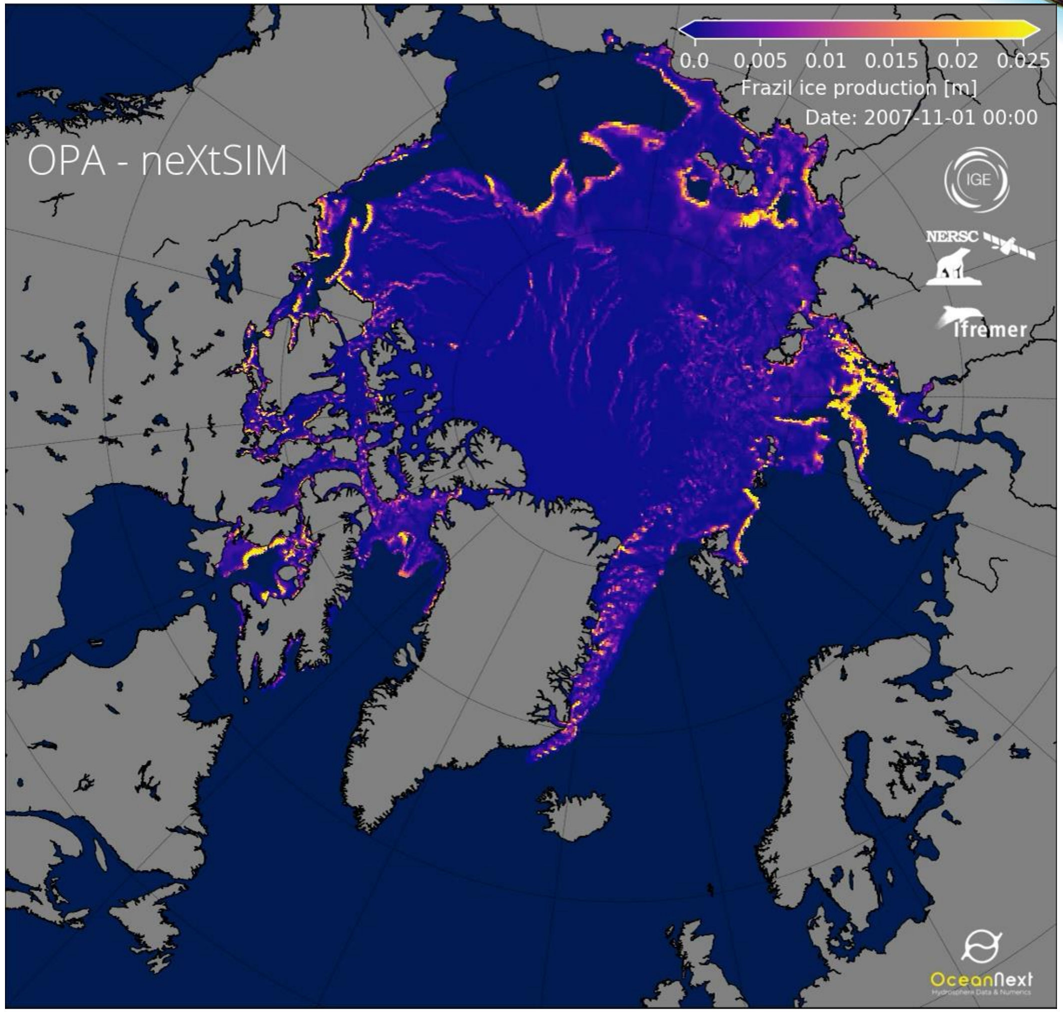
- Accurate sea ice thickness – distribution, not just total!
  - Freshwater inputs and stratification
  - Heat budget
  - Momentum transfer
  - SIN'XS project is a nice example of coordinated database of sea ice thickness



Boutin et al. (2023)

Sea ice impacts on upper ocean

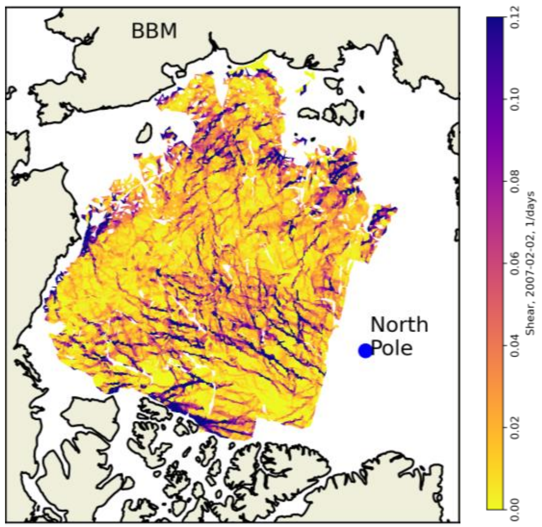
- Accurate sea ice thickness – distribution, not just total!
  - Freshwater inputs and stratification
  - Heat budget
  - Momentum transfer
  - SIN'XS project is a nice example of coordinated database of sea ice thickness
- Dynamic sea ice response to storms (leading to shear-induced mixing)
  - A dynamic ice cover gives increased heat, momentum, and gas exchanges
  - SIDFEx is a nice example of intercomparison of sea ice drift



Boutin et al. (2023)

Main novelties in sea ice developments

- Increasing diversity of rheologies (e.g. BBM, EAP), and intercomparisons (e.g. SIREX)
- Improved thermodynamics in forecasting systems
- Introduction of wave-ice interaction and floe-size distribution
- How much can AI help to reduce costs, improve accuracy, generate ensembles…



Olason et al (2022)

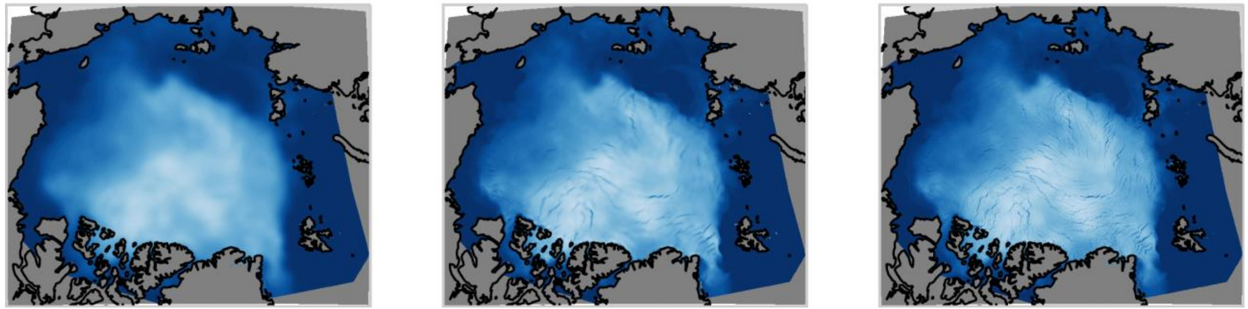
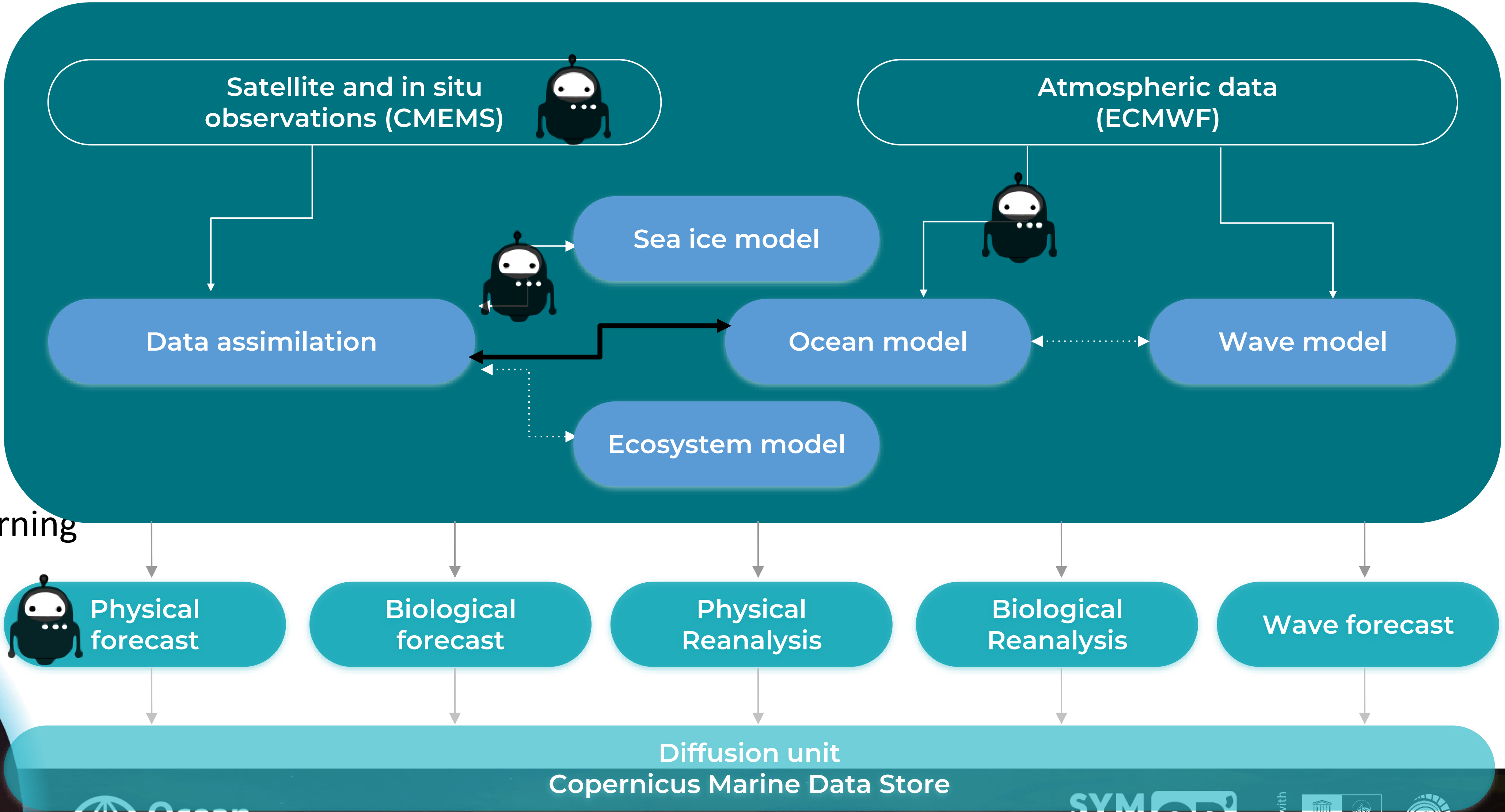


Figure courtesy of J. Brajard

AI for sea ice



= machine learning

What is the current status of Arctic forecasts?

Global: 10 models

Model	Domain	Coupling	Resolution	Availability	Website and/or reference
ECMWF	Global	IFS fully coupled	1/10 degree	Free for member states; fee for commercial users	https://www.ecmwf.int/en/forecasts/datasets/set-i
GIOPS	Global	NEMO-CICE	12 km	Data and visual	**Smith et al., 2016**
MOI	Global	NEMO-LIM2	3.5 km	Data and visual	https://data.marine.copernicus.eu/product/GLOBAL_ANALYSISFORECAST_PHY_001_024/description
GOFS3.1	Global	HYCOM-CICE	3.5 km	Data and visual	**Metzger et al., 2014**
GOFS16	Global	NEMO-LIM2	3.5 km	Visual	https://gofs.cmcc.it/backend/public/gofs/short-description.html
Met Office coupled DA	Global	UM-JULES-NEMO-CICE	12 km	Not readily available	https://www.metoffice.gov.uk/services/data/met-office-data-for-reuse/model
Met Office FOAM	Global	NEMO-CICE	3.5 km	Not readily available	https://www.metoffice.gov.uk/services/data/met-office-data-for-reuse/model
RTOFS	Global	HYCOM-CICE	3.5 km	Data and visual	https://polar.ncep.noaa.gov/global/data_access.shtml
NAVY-ESPC	Global	HYCOM-CICE-NAVGEM	1/25 degree	Limited availability as registered user	**Barton et al., 2021**
FIO-COM10	Global	MOM5-SIS with MASNUM wave	1/10 degree	Not readily available	**Shao et al., 2023**

Regional: 8 models

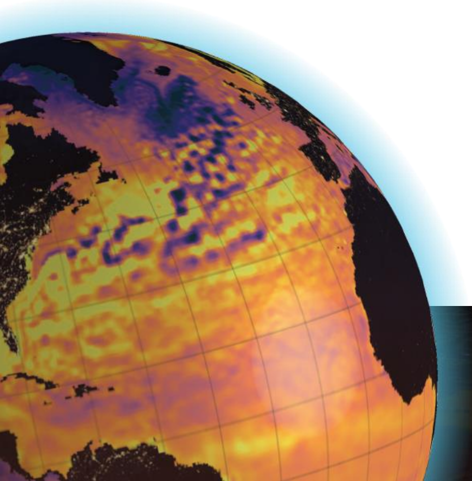
Model	Domain	Coupling	Resolution	Availability	Website and/or reference
ArcIOPS	Regional	MITgcm	18 km	Not readily available	http://www.oceanguide.org.cn/IceIndexHome/ThicknessIce; **Liang et al., 2019**
DMI	Regional and coastal	HYCOM-CICE	10 km	Visual	https://ocean.dmi.dk/models/hycom.uk.php; **Ponsoni et al., 2023**
neXtSIM-F	Regional	neXtSIM	7.5 km*	Data and visual	https://data.marine.copernicus.eu/product/ARCTIC_ANALYSISFORECAST_PHY_ICE_002_011/description; **Williams et al., 2021**
NIPR**	Regional	N/A	?	Visual	https://www.nipr.ac.jp/sea_ice/e/forecast/
NOAA PSL (CAFS)	Regional	POP2-CICE-WRF	10 km	Data and visual	https://psl.noaa.gov/forecasts/seaice/about.html
RIOPS	Regional	NEMO-CICE	3.5 km	Data and visual	https://science.gc.ca/eic/site/063.nsf/eng/h_97620.html; **Smith et al., 2021**
TOPAZ5	Regional	HYCOM-CICE (+ ECOSMO)	6km	Data and visual	https://data.marine.copernicus.eu/product/ARCTIC_ANALYSIS_FORECAST_PHYS_002_001_a/description
VENUS	Regional and coastal	IcePOM-WW3	2.5 km coastal	On demand	**Yamaguchi, 2013**

Coastal: 4 models

Model	Domain	Coupling	Resolution	Availability	Website and/or reference
Barents-2.5	Coastal	ROMS-CICE	2.5 km	Data and visual	https://ocean.met.no/models; **Röhrs et al., 2023**
CIOPS	Coastal	NEMO-CICE	5 km	Data	Paquin et al. (2024)
NOAA Ice Drift**	Coastal	N/A (free drift)	N/A; visual on 0.5 x 0.5 degree grid	Visual	**Grumbine, 1998**
Stormsurge	Coastal	ROMS barotropic	4 km	Data + warning	https://ocean.met.no/models

What do users want?

- Ice charts at 100m resolution!
- Trajectories (icebergs, oil spills, man-over-board...)
- Single access to different ranges of forecasts from planning to operations
- Model outputs for forecasts, not climate: ice strength, ridging, pressure...
- Presentation of trustworthiness of forecasts
- Reliability of forecasts...



What can we do to increase user uptake?

- Pulling together different forecasts in the Arctic, but no coordination in products and services
- Potential for developing a multimodel **ensemble.**
  - Could highlight uncertainties in water mass properties and circulation.
  - Communicate strengths and weaknesses to users (via shared validation metrics or similar)
  - Draw attention to services in the Arctic
- **Arctic DCC task team trying to work on these!**

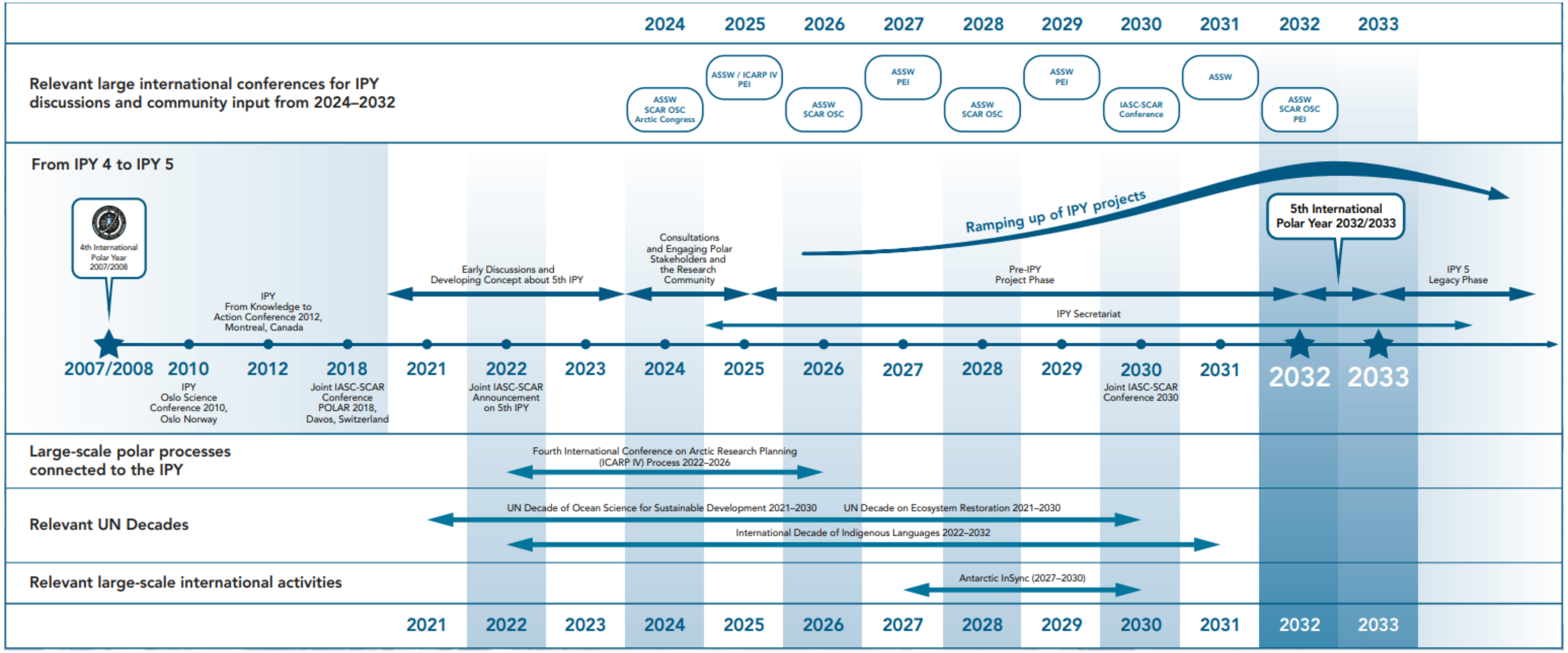
Key challenges in polar environmental prediction

- **Increased understanding of polar processes to allow improved formulation of ocean prediction models and parameterization schemes in the polar regions.**
  - Atm-ice-ocean heat, freshwater and momentum fluxes
  - Role of submesoscale and chaotic intrinsic variability
  - Strong sensitivity to ocean model numerics and mixing
- **Recommendations for an optimized Arctic and Antarctic observing system to benefit predictions in polar regions and beyond.**
  - ArcticArgo: Technical challenges significantly reduced, problem is lack of sustained funding, limited deployment opportunities
  - Better use could be made of satellite altimetry in polar regions to constrain smaller scales. However, ensembles will likely remain essential to adequately sample uncertainty.
  - International coordination efforts essential to implement OceanObs'19 recommendations

IPY 2032-33: A role for OceanPredict?

International Polar Year (2032-33) provides opportunity to demonstrate importance of polar observations for Environmental Prediction and inform observing system design.

UN Decade



Ocean Predict

In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

SYMPOSIUM OP'24

ADVANCING OCEAN PREDICTION SCIENCE FOR SOCIETAL BENEFITS

Thank you!

European Commission

Copernicus Marine Service

EU4Oceanobs INTERNATIONAL OCEAN GOVERNANCE EU COMPONENT TO GLOBAL OCEAN OBSERVATIONS

MERCATOR OCEAN INTERNATIONAL

esa

cnes CENTRE NATIONAL D'ÉTUDES SPATIALES

Australian Government Bureau of Meteorology

Met Office

NERSC

Canada

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Recommendations from OO19

- Deploy and support operationally an Arctic network of ice-borne measurement systems
    - Adapt technologies developed in Arctic for use in Antarctic as well
- Re-evaluate observing system design to account for changing patterns of ice-cover
    - Use of open-water observing systems (e.g. Argo and gliders) in seasonally ice-free areas
- Make better use of ships of opportunity, especially given increase in marine traffic in the Arctic
- Improve availability of near-real time in situ observations for calibration of remote sensing products.
    - Efforts involving multi-platform calibration are needed to improve remote sensing products
- Expand efforts for sea ice thickness use in environmental prediction
    - In particular, require products for southern ocean

Recommendations from OO19

- Call for coordinated efforts (including QND, OSEs and OSSEs) to enhance the Arctic and Southern Ocean observing networks
  - In particular, require OSEs using real-time prediction systems and multi-system exercises
- Require collocated information about the state of the atmosphere, sea ice and ocean, to be used for improving interfacial fluxes (esp. covariance measurements)
- Open access to real-time data is a critical capability for improved sea-ice and weather forecasting and other environmental prediction needs
  - Prioritize real-time dissemination of in-situ observations in polar regions to global data assembly centers
- International collaboration will continue to be key for facilitating deployment of polar ocean instrument systems, including the fielding of drifting and anchored buoys, floats and gliders and free, rapid dissemination of the resulting data

Recommendations (2 / 2)

Outlook

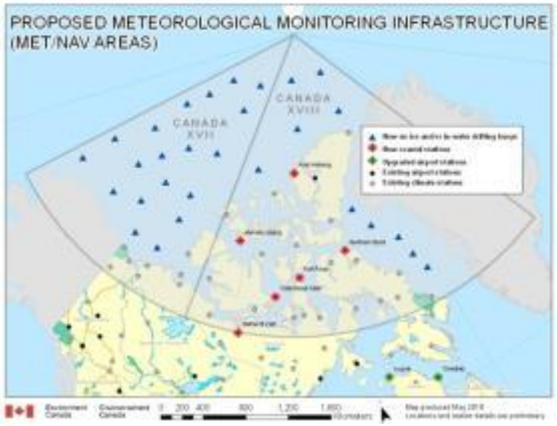
, are they worth the cost?

Important role for OceanPredict to play in answering this question

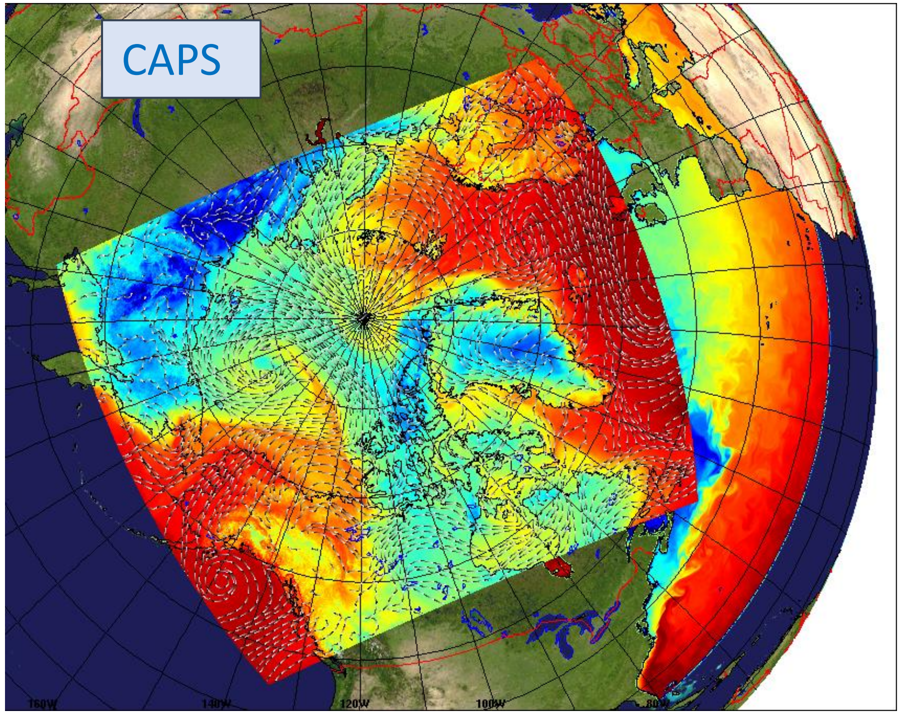
YOPP Final Summit 2022 provides opportunity to demonstrate importance of polar observations for Environmental Prediction and inform observing system design.

Canadian Arctic Prediction System (CAPS)

High-resolution coupled atmosphere-ice-ocean prediction system



- In support of :
  - Weather prediction for northern Canada
  - EC METAREAs Services
  - Marine emergency response
  - Study impact of fine-scale interactions
  - YOPP Community support
- Coupled atmosphere-ice-ocean model
  - Ice-ocean: NEMO-CICE (3-8 km)
    - Tides, landfast ice
  - Atmosphere: GEM (3 km)
    - Predicted particle properties microphysics
  - 48 h forecasts (2/day)
  - Uncoupled since Jan. 24, 2018
  - Coupled since Jun. 28, 2018
  - Decommissioned in Feb. 2022
  - To be re-instated in 2024!

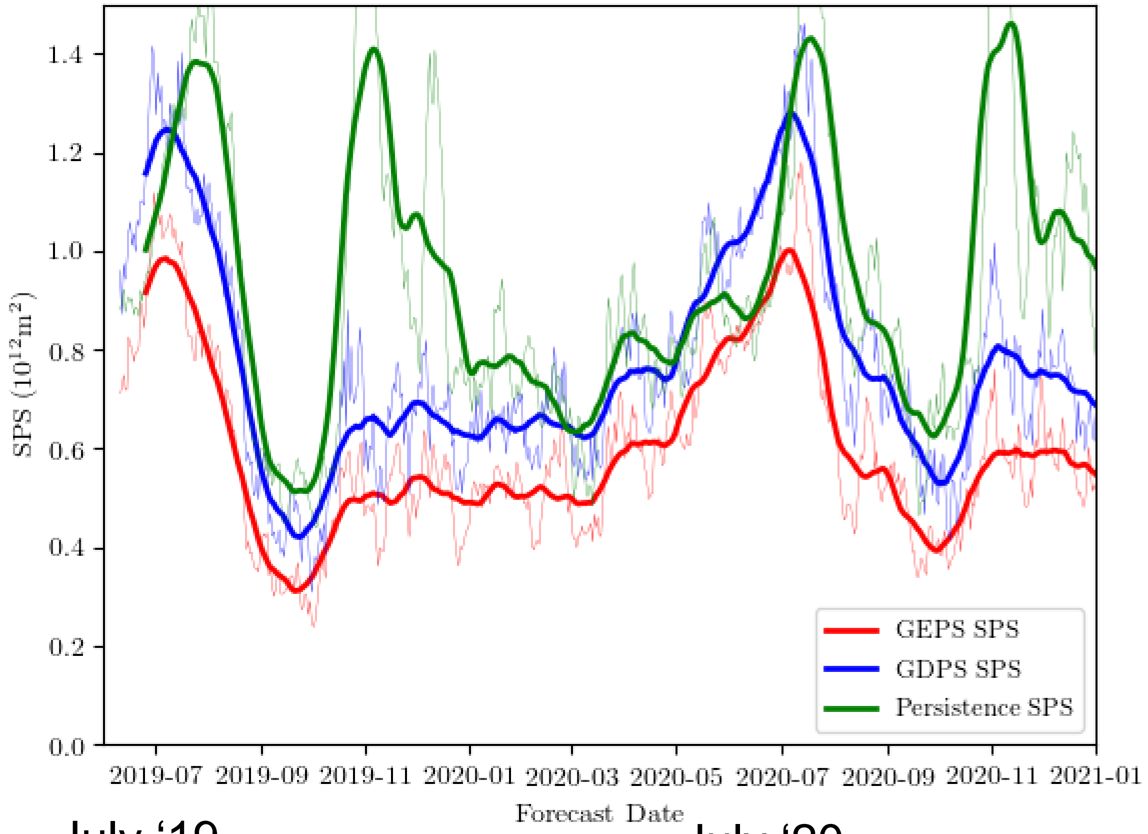


Casati et al. (Atm-Ocean, 2023)

Global ensemble cou

- Developed in response to need by Ice services for long-range forecast guidance
- 32d coupled forecasts now produced operationally with 21 members weekly
- Required new verification metrics
  - Integrated Ice Extent Error (Goessling et al., 2016)
  - Stochastic probability score(SPS; Goessling and Jung 2018)
- System is underdispersive due to use of a single ice-ocean initial condition
- Nonetheless, it shows valuable skill w.r.t deterministic system and persistence throughout the year.
  - Largest errors during melt season

Forecast errors over the Northern Hemisphere



July '19 July '20

Peterson et al. (QJRMS, 2022)

Ensemble uncertainties (Laurent)