Ivan Kuznetsov

Alfred Wegener Institute for Polar and Marine Research

(Институт полярных и морских исследований имени Альфреда Вегенера)

B. Rabe , Y.-C. Fang, A. Androsov, V. Fofonova, M. Hoppmann, MOSAiC OCEAN team, MOSAiC Distributed Network team

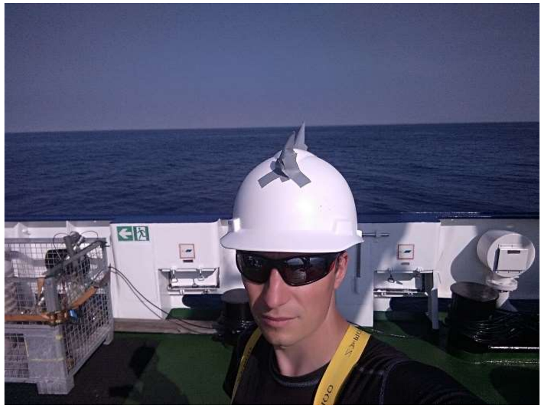
Photo by: Steffen Graupner

- Иван
- Вихри в Океане
- Арктический океан
- Исследования Арактики
- Проэкт MOSAiC
- Буи MOSAiC “eddy”

Photo by: Steffen Graupner

- Результаты измерений, примеры вихрей в наблюдениях
- Моделирование вихрей

Ivan Kuznetsov



1998

Moscow State University: Physics of Sea

2004

P.P. Shirshov Institute of Oceanology

2005

Baltic Sea Research Institute Warnemunde (IOW)

2011

Swedish Meteorological and Hydrological Institute (SMHI)

2015

Institute of Coastal Research, HZG New Technologies

2018

Alfred Wegener Institute for Polar and Marine Research

density flow in lakes

Black Sea: oxic/anoxic interface

Baltic Sea: oxygen dynamics; Carbon cycle; climate study

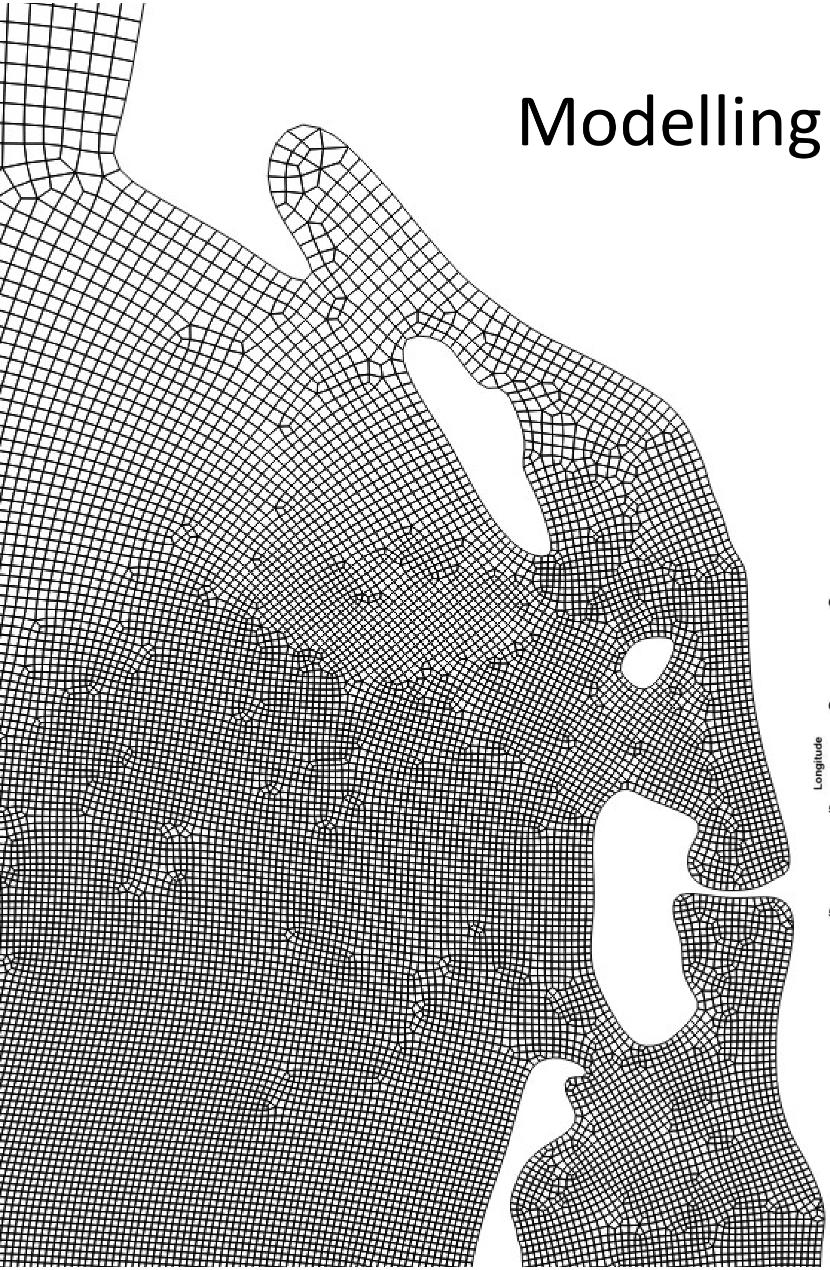
North and Baltic Seas: ecosystem dynamics; climate study

Research Interests:

main field:
Numerical Modelling , Marine Physics, Hydrodynamics, Biogeochemical Cycles, Anoxia in Aquatic Environment

other fields:
Carbonate System, Marine field studies

current research interest :
finite-volume discretization and mixed unstructured meshes

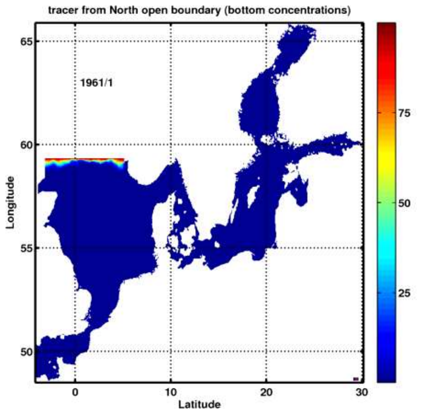


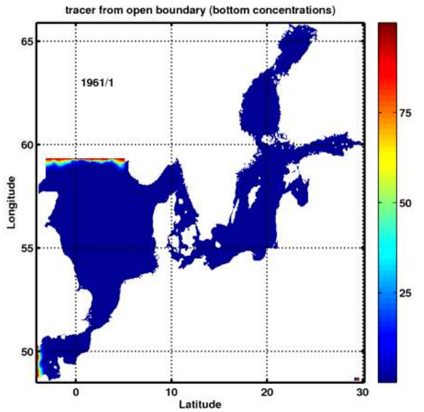
Modelling of hydrodynamic and biological processes

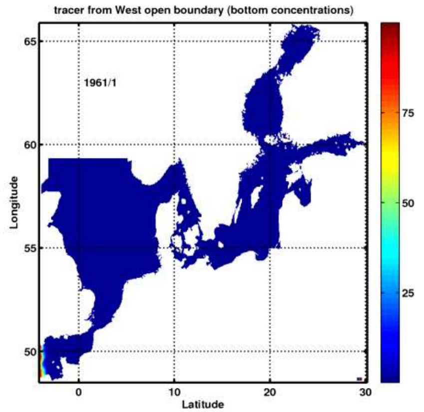
Model application and development:

Black Sea, Baltic Sea, North Sea, Antarctic region, Arctic region,

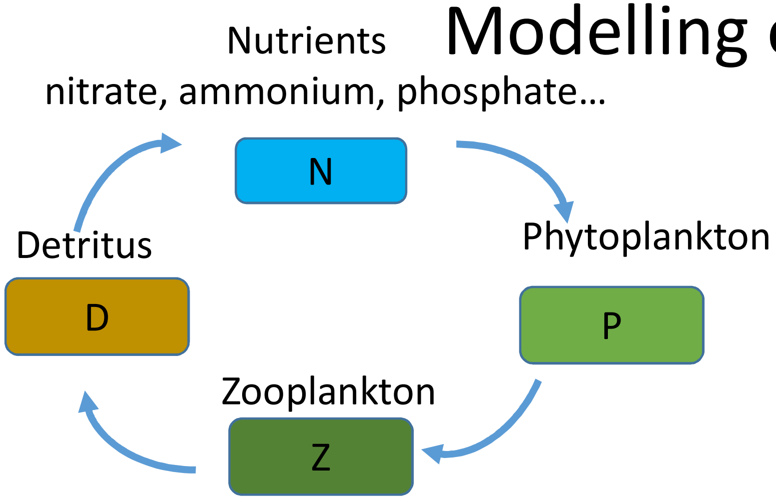
Sea of Okhotsk, Mediterranean, …



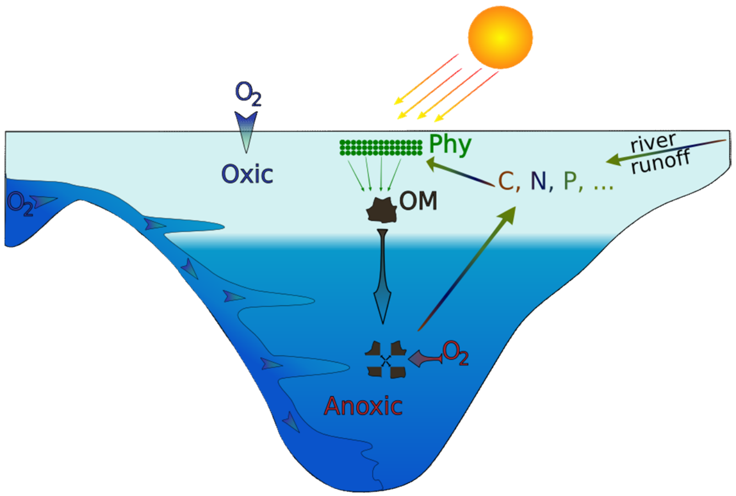




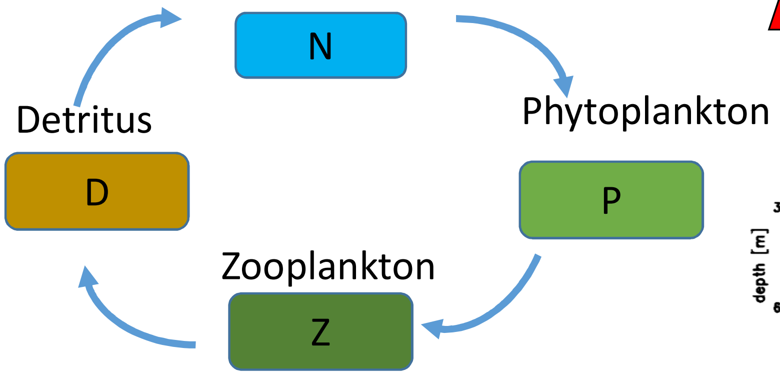
Modelling of hydrodynamic and biological processes



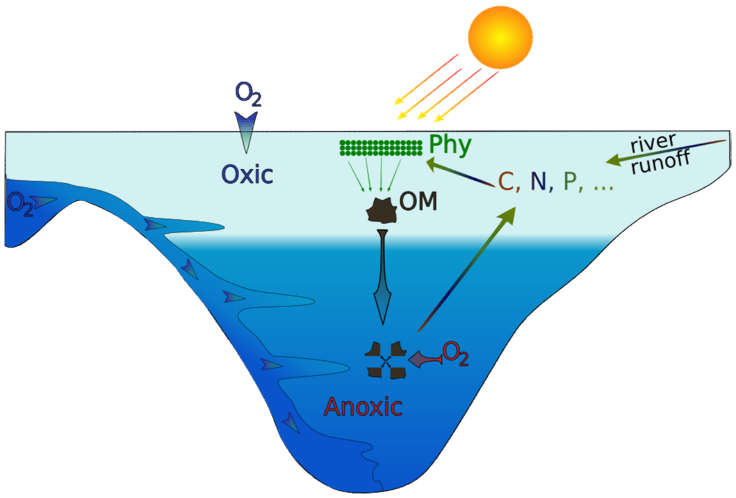
Fasham et al, 1990.

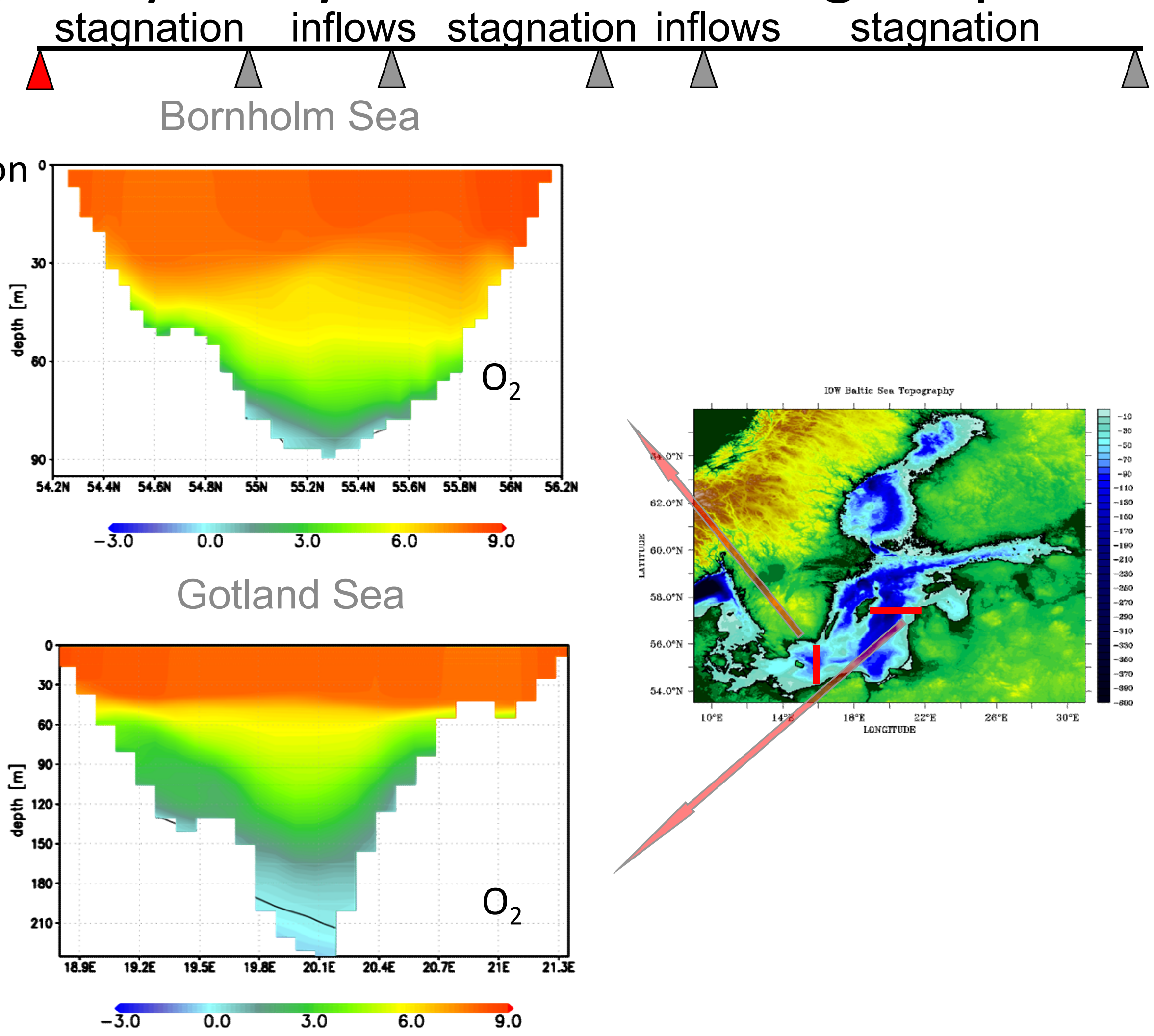


Modelling of hydrodynamic and biological processes

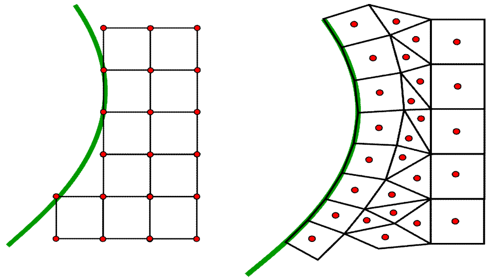


Fasham et al, 1990.



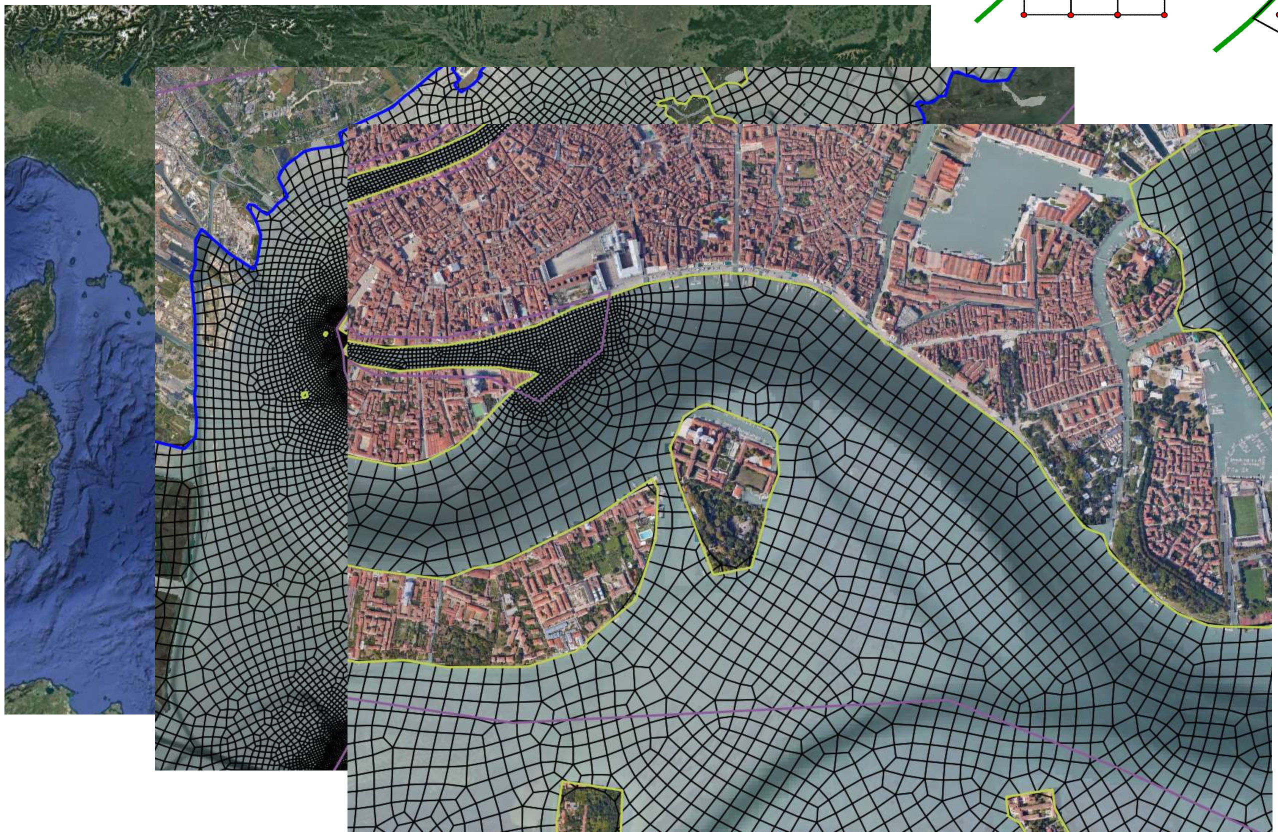


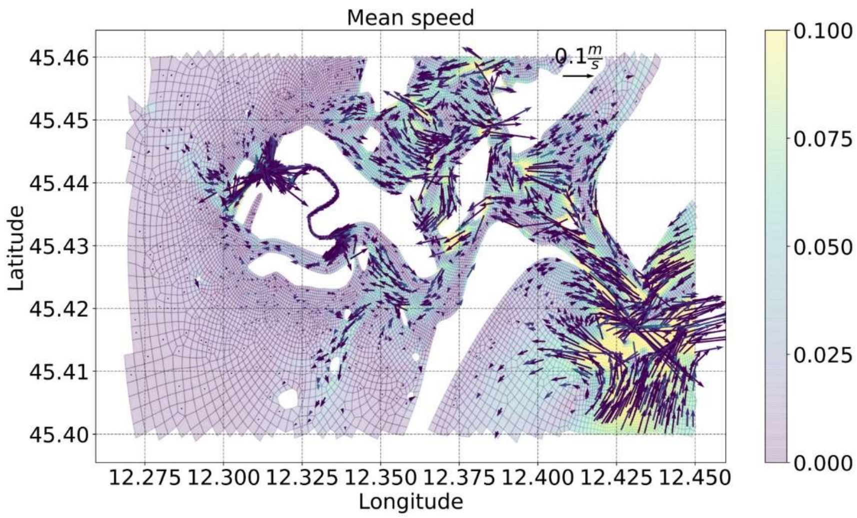
FESOM-C: coastal dynamics on mixed unstructured meshes



FESOM-C: examples

Venetian Lagoon



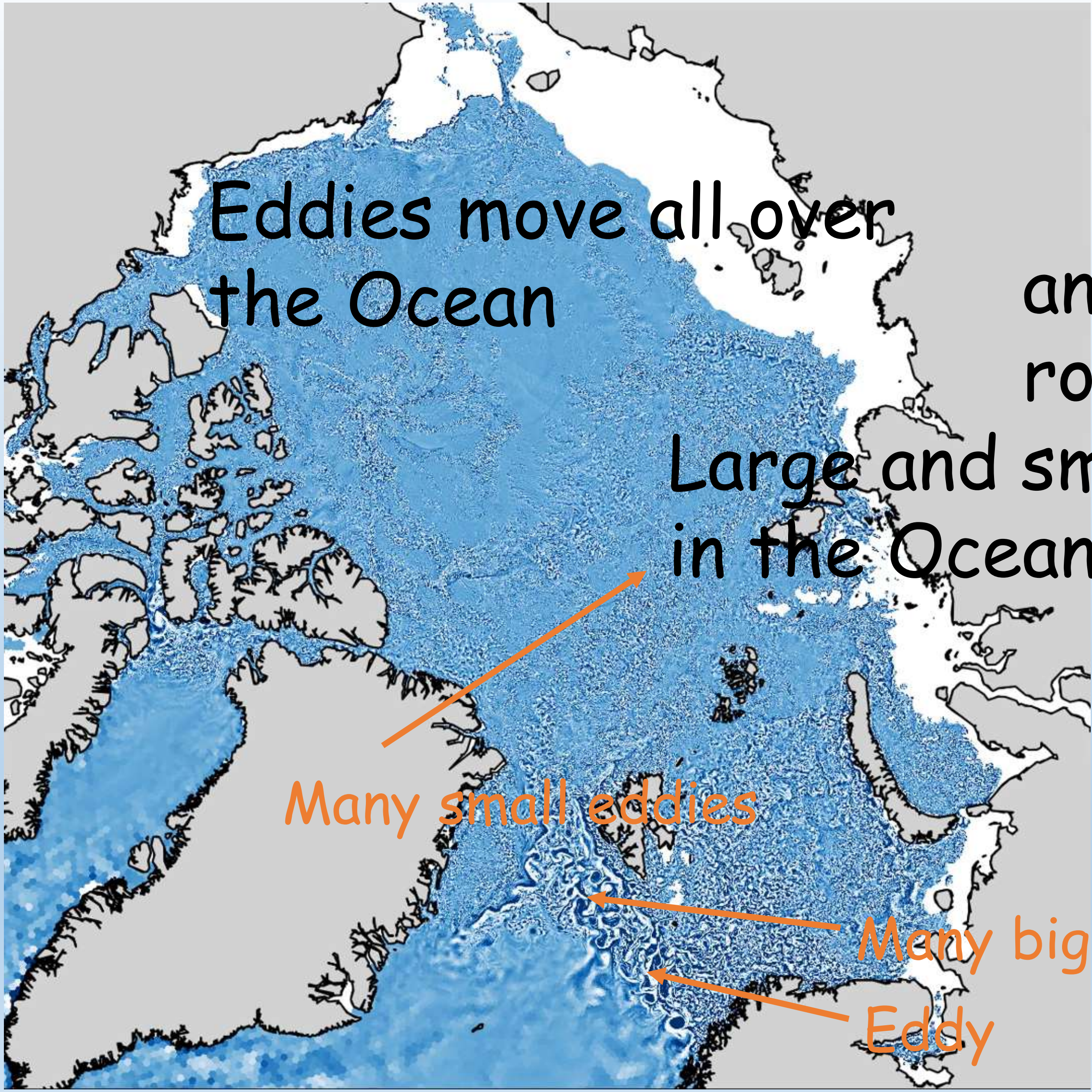


Video provided by:
Nikolay Koldunov (AWI)
FESOM2 model simulations

Eddies move all over the Ocean

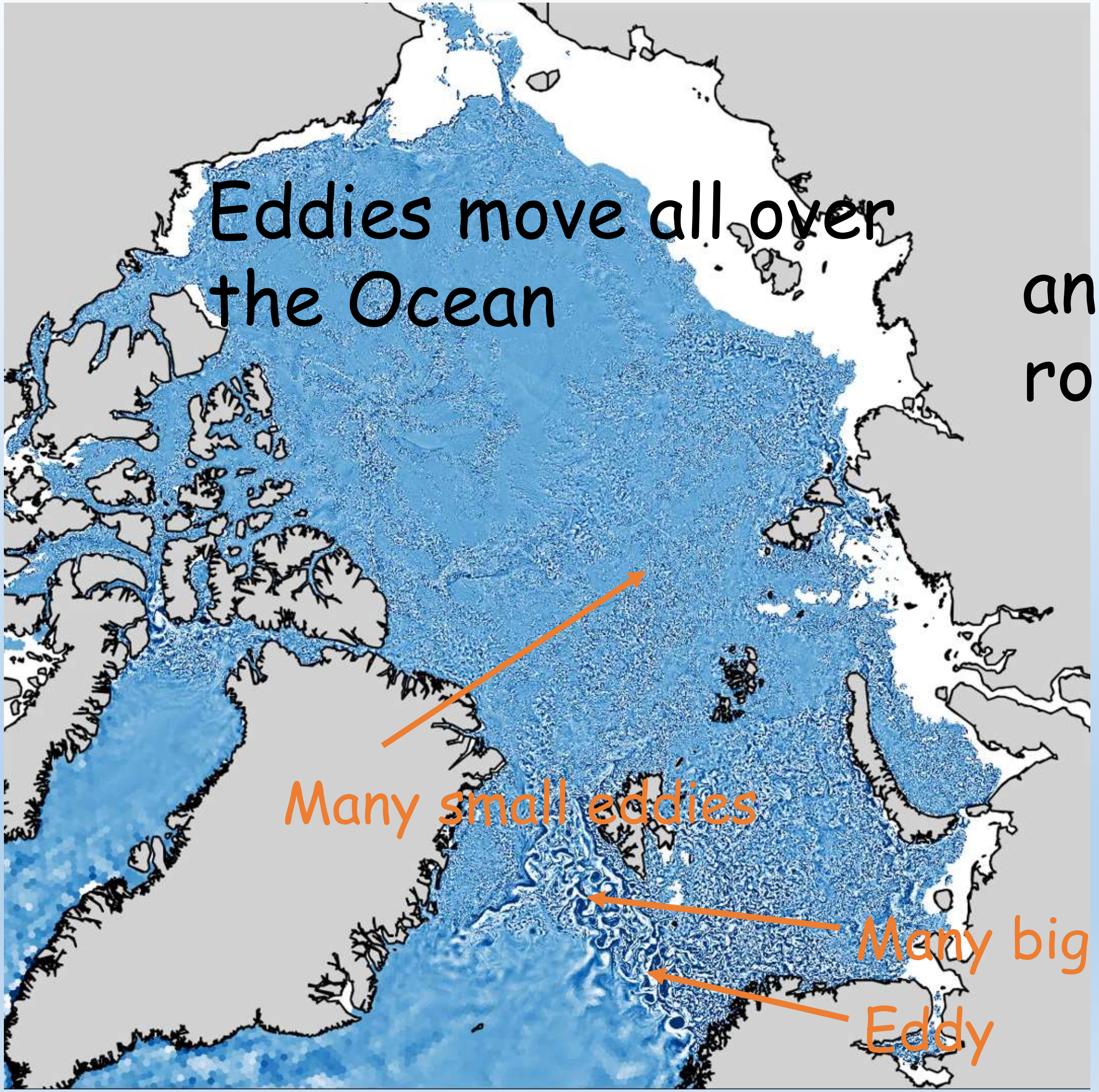
and play a significant role:

Large and small eddies form in the Ocean



I. Kuznetsov, Y.C. Fang, B. Rabe, A. Androsov, M. Hoppmann, V. Mohrholz, S. Tippenhauer, K. Schulz, V. Fofonova, M.A. Janout, I. Fer, T. Baumann, T.P. Stanton, H. Liu, M. Mallet, Ocean Team MOSAiC

* ...



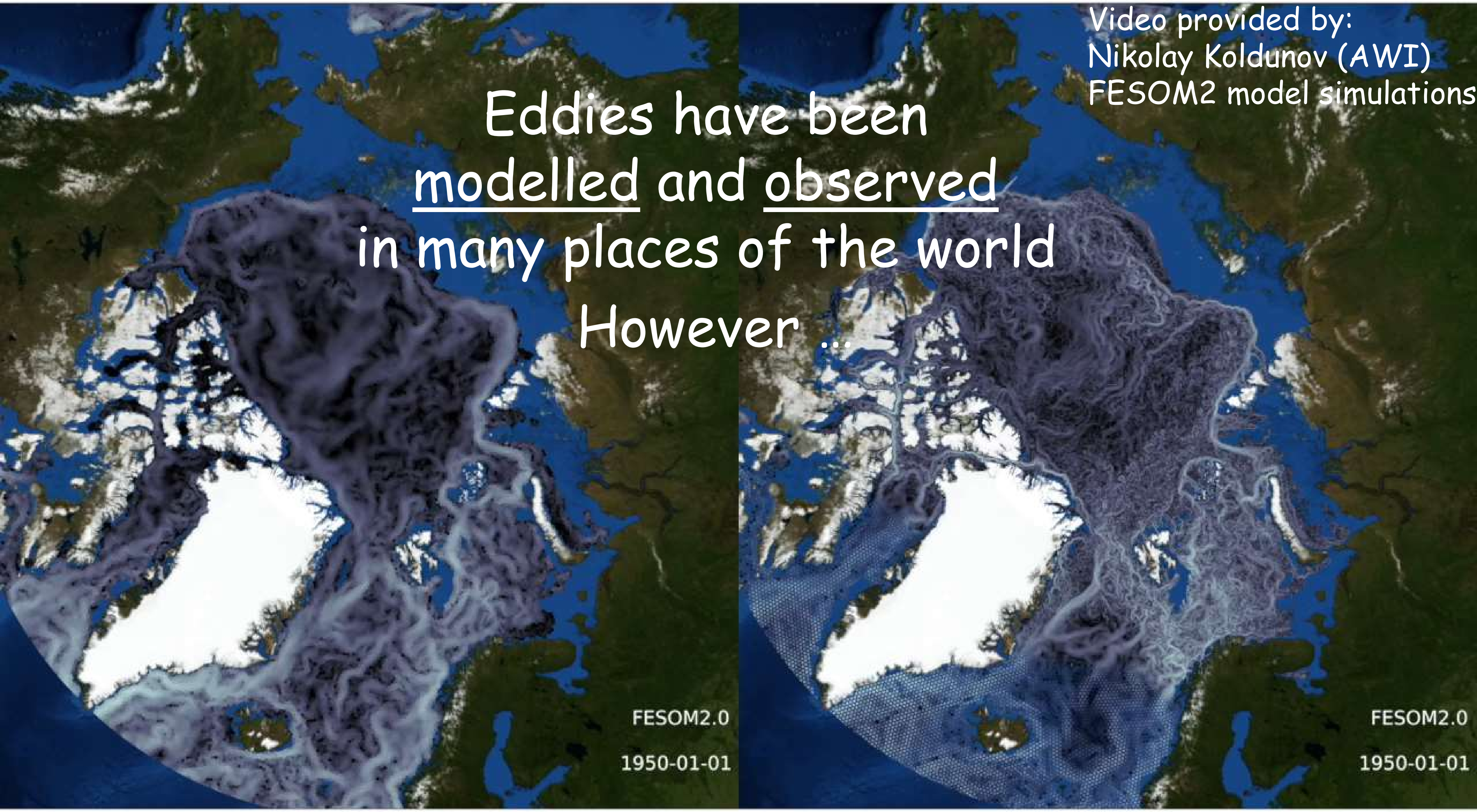
Video provided by:
Nikolay Koldunov (AWI)
FESOM2 model simulations

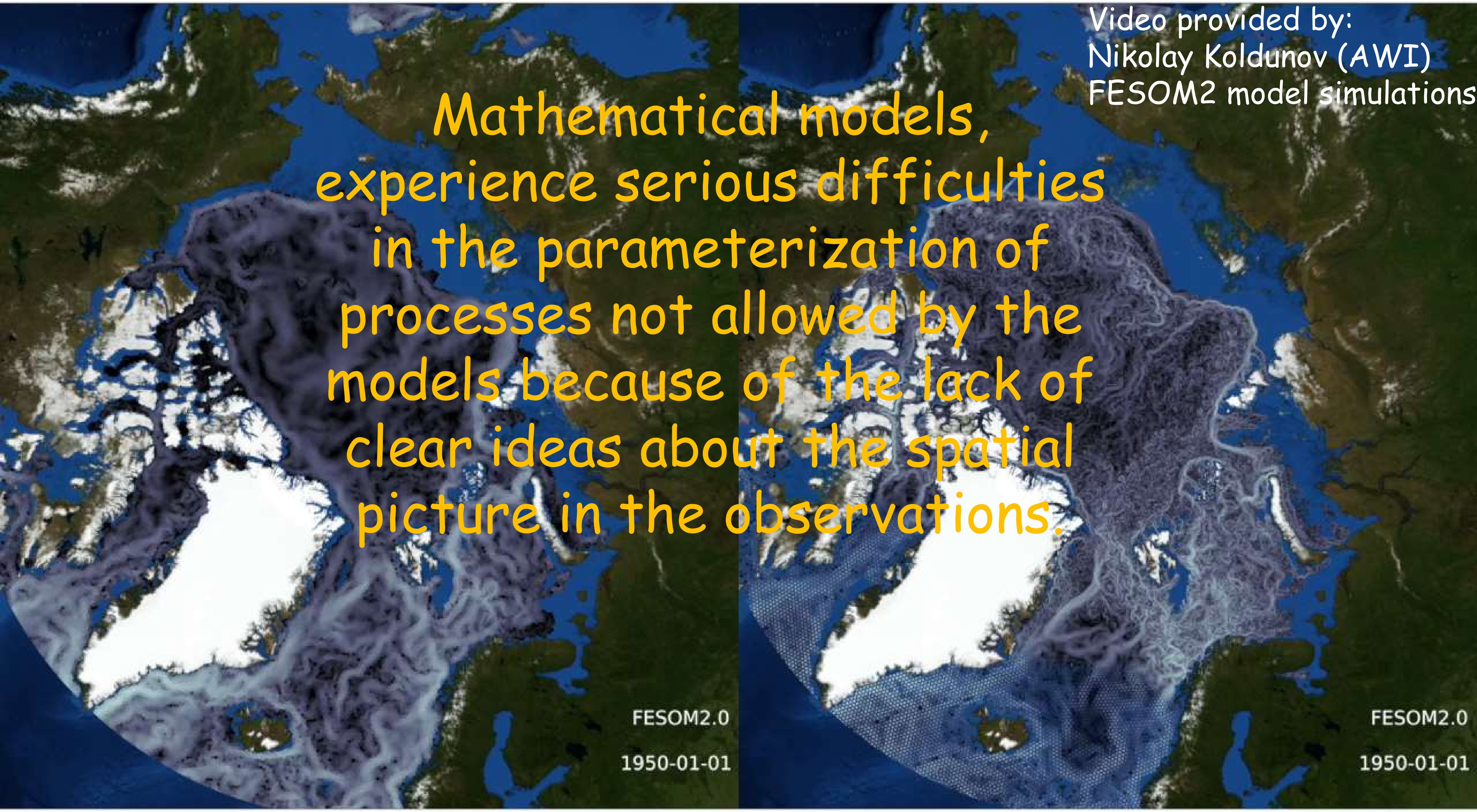
and play a significant role:

* ventilation of halocline
* heat fluxes
* fluxes of organic and inorganic matter (nutrients or carbon…)
* …

Eddies have been modelled and observed in many places of the world

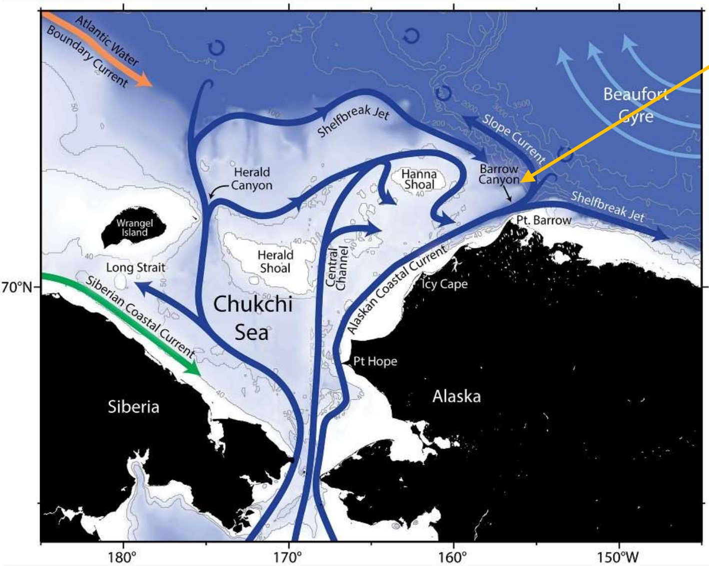
However …

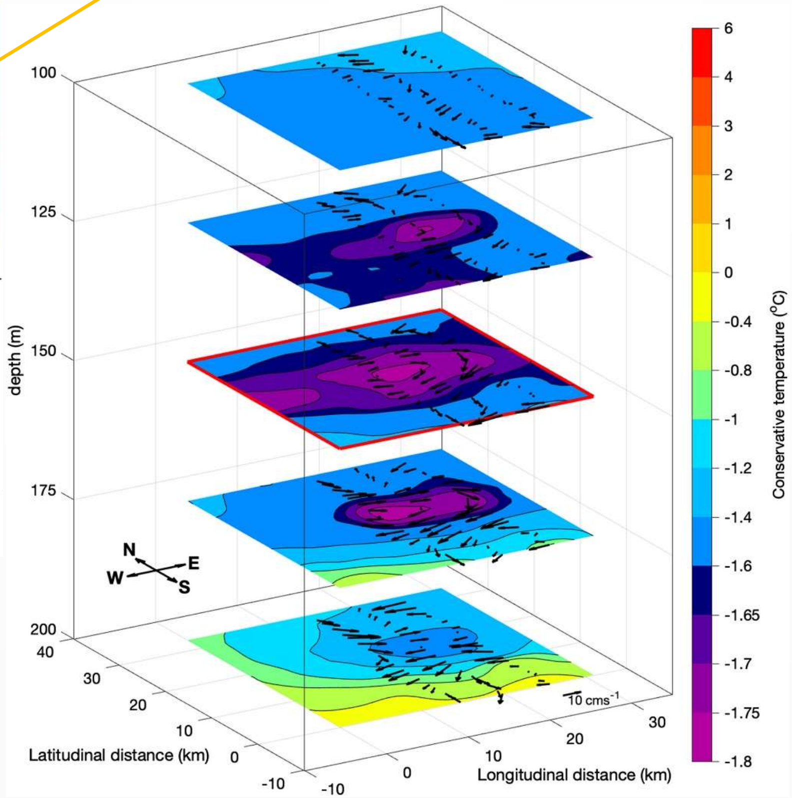


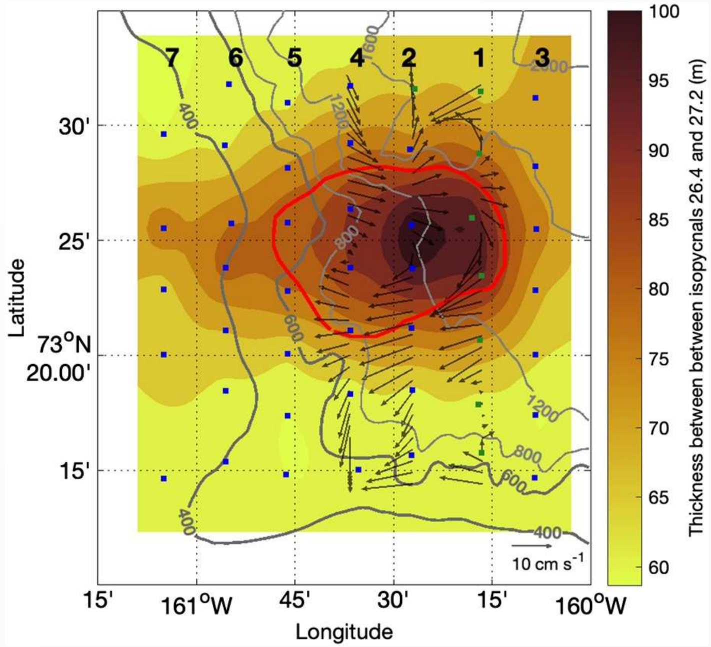


Mathematical models, experience serious difficulties in the parameterization of processes not allowed by the models because of the lack of clear ideas about the spatial picture in the observations.

Example of eddy (ship measurement)



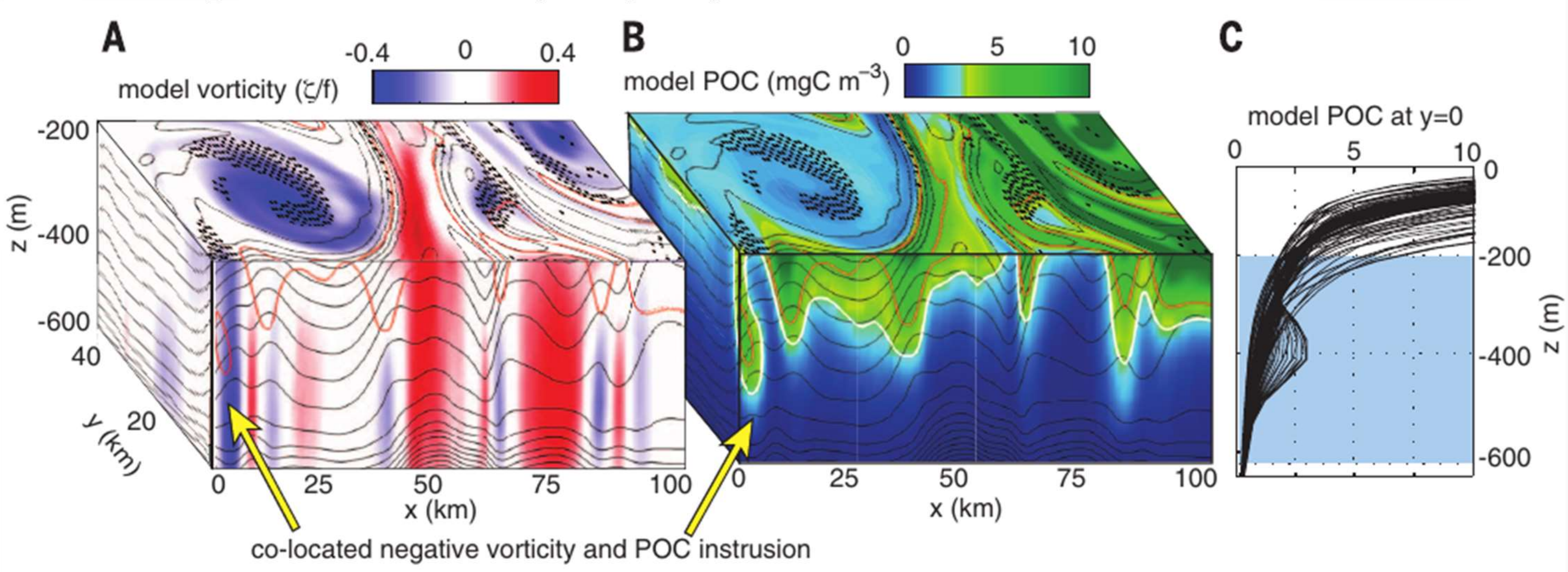




Taken from:
Three-Dimensional Structure of a Cold-Core Arctic Eddy Interacting with the Chukchi Slope Current
Ryan M. Scott, Robert S. Pickart, Peigen Lin, Andreas Münchow, Min Li, Dean A. Stockwell, J. Alexander Brearley
https://doi.org/10.1029/2019JC015523

Example of eddies role

Particulate organic carbon (POC) export by Eddy-driven subduction



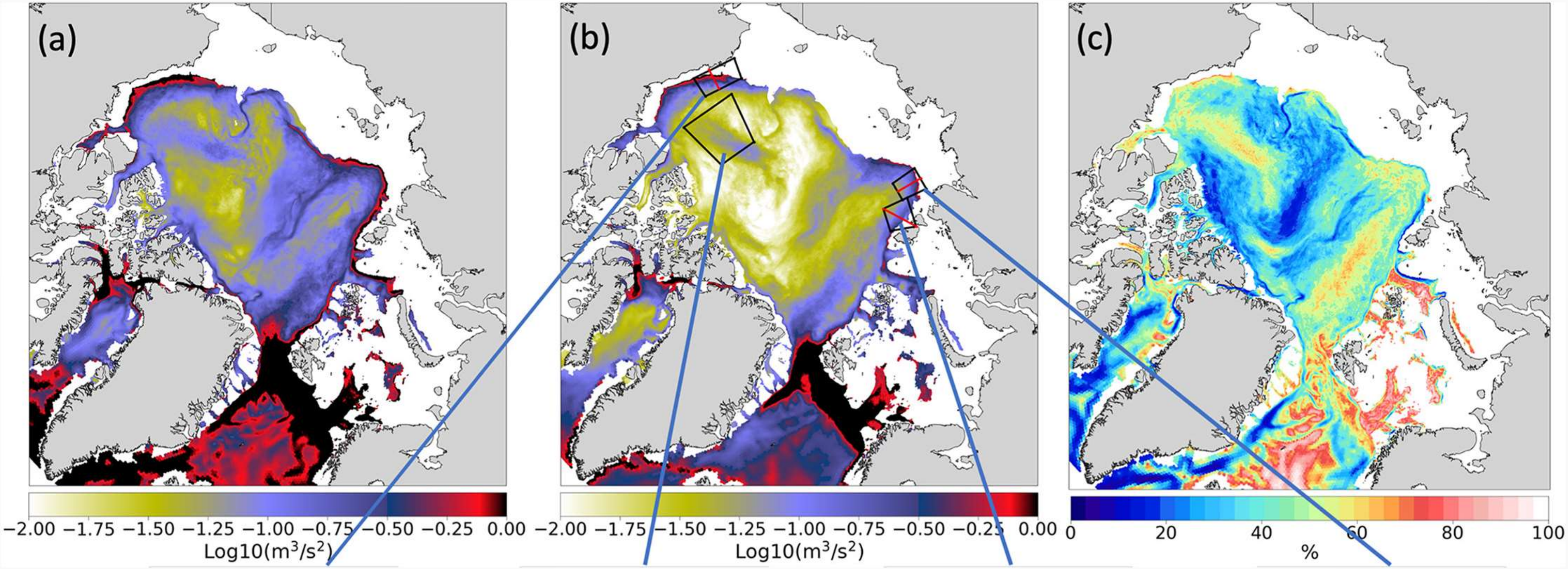
Taken from:

Eddy-driven subduction exports particulate organic carbon from the spring bloom.

Melissa M. Omand, Eric A. D'Asaro, Craig M. Lee, Mary Jane Perry, Nathan Briggs, Ivona Cetinic and Amala Mahadevan. Science 348 (6231), 222-225.

DOI: 10.1126/science.1260062 originally published online March 26, 2015

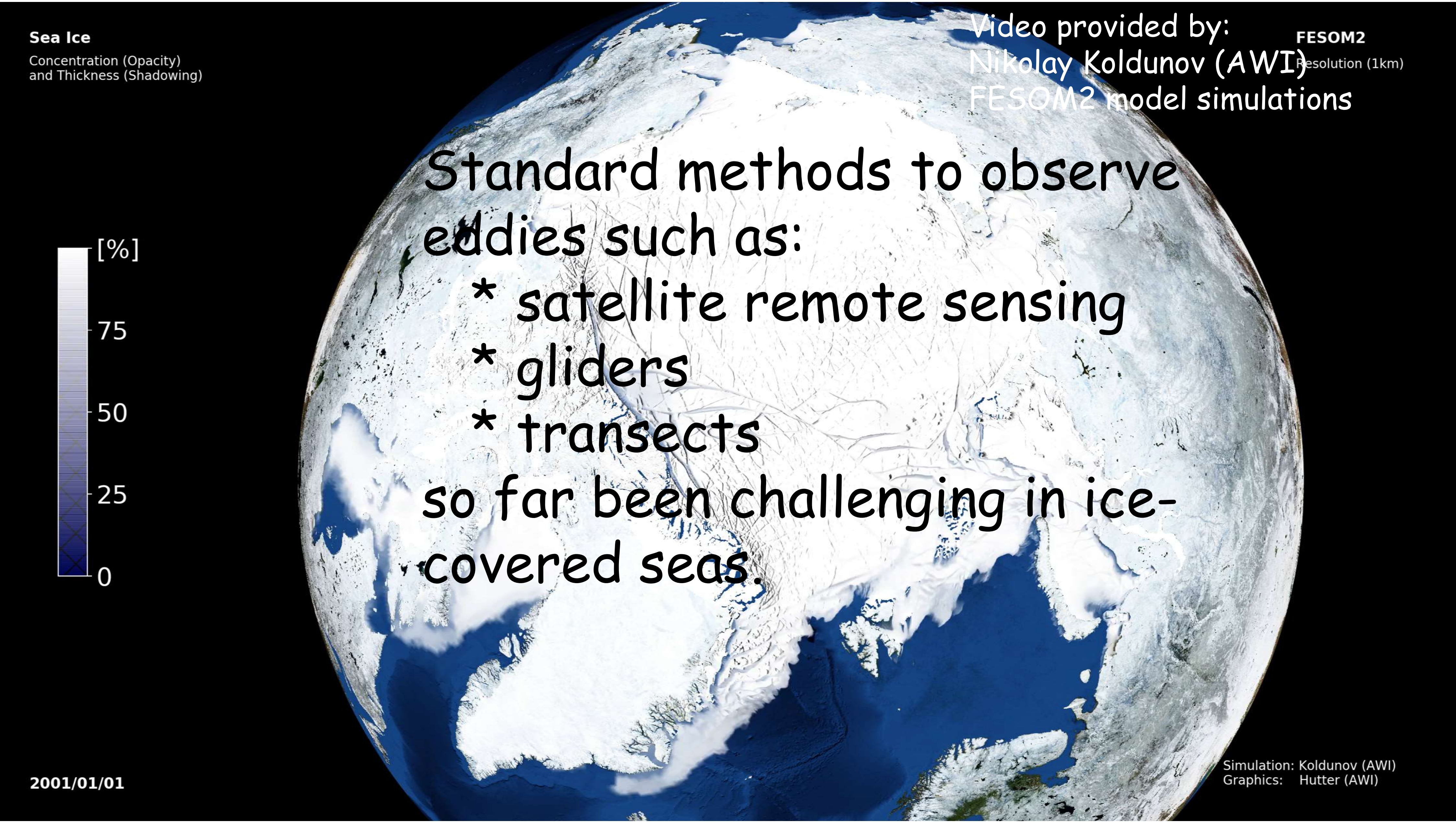
Eddy Kinetic Energy in the Arctic Ocean From a Global Simulation With a 1-km Arctic



(a) Total kinetic energy (TKE) … (b) Eddy kinetic energy (EKE)… (c) EKE/ TKE ….

Taken from:

Wang, Q., Koldunov, N. V., Danilov, S., Sidorenko, D., Wekerle, C., Scholz, P., Bashmachnikov, I. L., and Jung, T.: Eddy Kinetic Energy in the Arctic Ocean from a Global Simulation with a 1-km Arctic, Geophys. Res. Lett., 47, e2020GL088550, https://doi.org/10.1029/2020GL088550, 2020.


Sea Ice
Concentration (Opacity)
and Thickness (Shadowing)
Video provided by:
Nikolay Koldunov (AWI)
FESOM2 model simulations
FESOM2
Resolution (1km)
Standard methods to observe eddies such as:
* satellite remote sensing
* gliders
* transects
so far been challenging in ice-covered seas.
[%]
75
50
25
0
2001/01/01
Simulation: Koldunov (AWI)
Graphics: Hutter (AWI)

Introduction

- Mesoscale and (sub)mesosclae eddies have been observed in many basins of the Arctic
- Eddies could play a significant role in the various aspects of upper ocean dynamics (e.g. ventilation of the halocline, vertical and horizontal fluxes of matter, ...)
  - In the Canada Basin: eddy kinetic energy = 1/3 total kinetic energy (0-200 meters depth) (Manley, T. O., & Hunkins, K. (1985). Mesoscale eddies of the Arctic Ocean. Journal of Geophysical Research, 90, 4911–4930. (ice drift camp)
  - typical radius of observed halocline eddies in the probability distribution shows two peaks centered around 4 and 7 km for Canadian Basin (Zhao, M., Timmermans, M. L., Cole, S., Krishfield, R., Proshutinsky, A., & Toole, J. (2014). Characterizing the eddy field in the Arctic Ocean halocline. Journal of Geophysical Research: Oceans, 119, 8800–8817.)
- standard methods to observe eddies in open water, such as satellite remote sensing, have so far been challenging in ice-covered seas

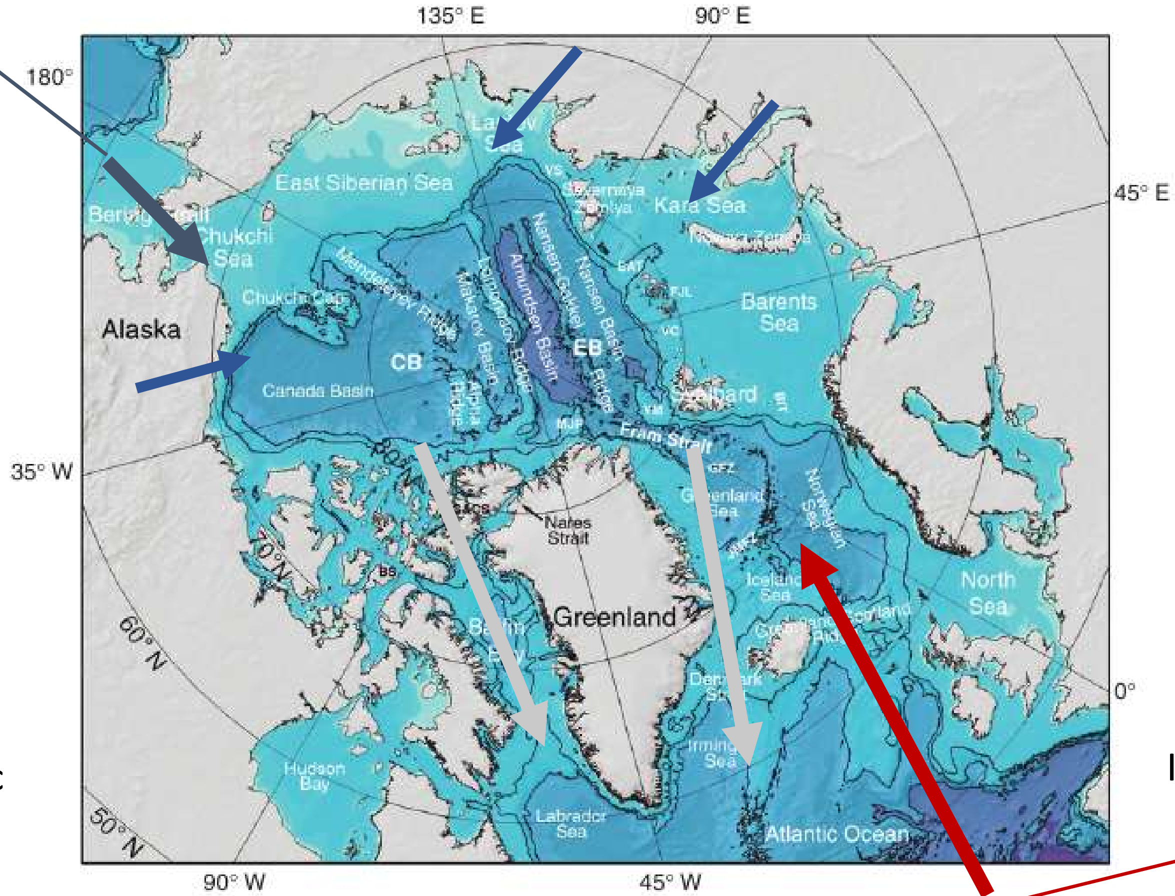
Autonomous distributed buoy systems were deployed to better understand (sub)mesoscale dynamics in the central Arctic Ocean

Arctic Ocean Circulation

From: B. Rudels, Finnish Institute of Marine Research, Helsinki, Finland. 2009 Elsevier Ltd.

Inflow from Pacific

Rivers runoff (11% of world)



Outflow to Atlantic

Inflow from Atlantic

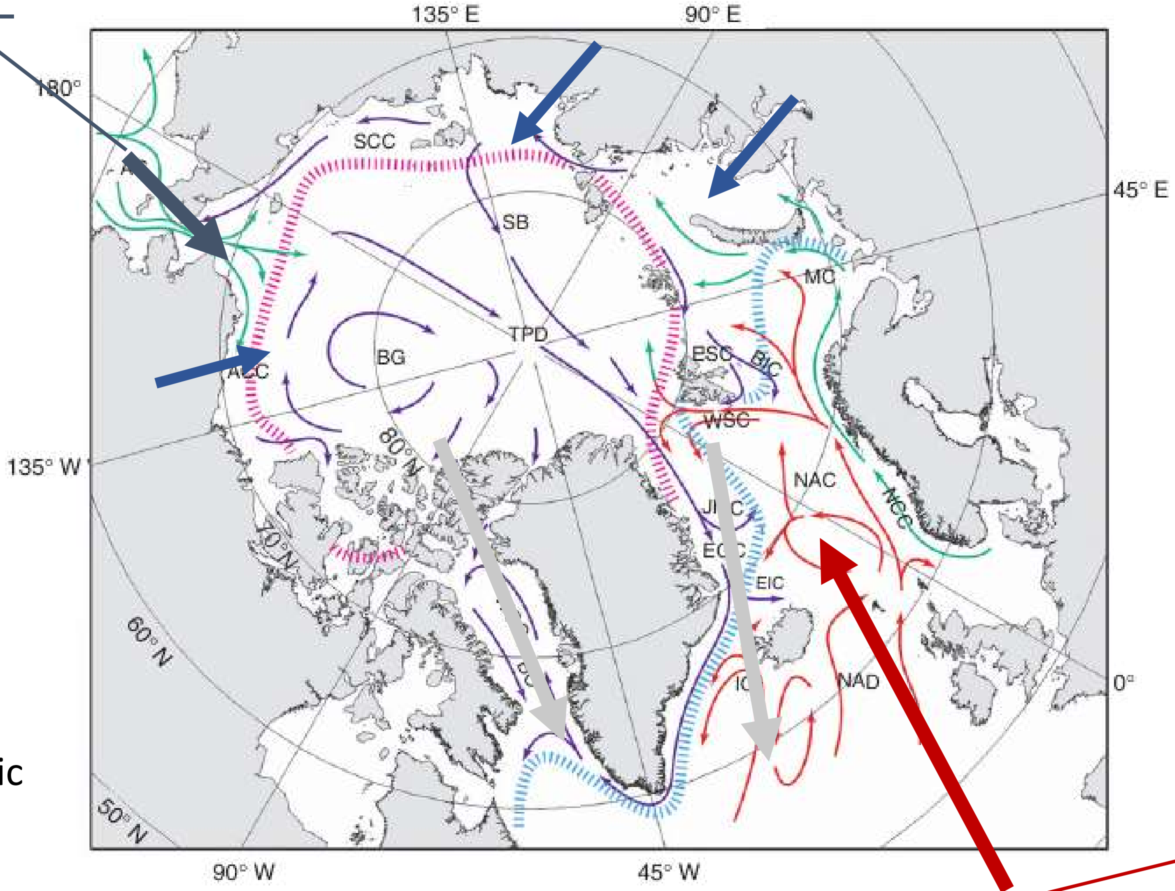
Map of the Arctic Mediterranean Sea showing geographical and bathymetric features.

Arctic Ocean Circulation

From: B. Rudels, Finnish Institute of Marine Research, Helsinki, Finland. 2009 Elsevier Ltd.

Inflow from Pacific

Rivers runoff (11% of world)



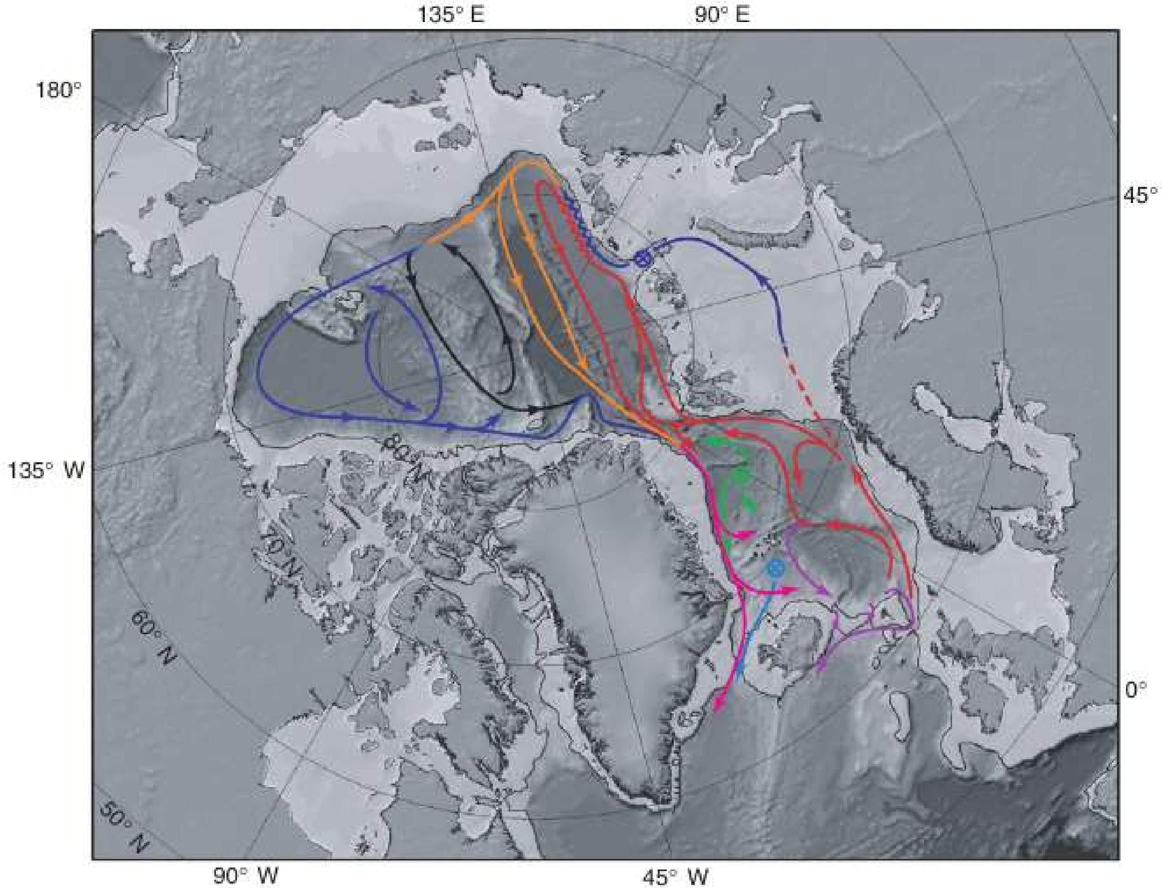
Outflow to Atlantic

Inflow from Atlantic

The circulation of the upper layers of the Arctic Mediterranean Sea.

Arctic Ocean Circulation

From: B. Rudels, Finnish Institute of Marine Research, Helsinki, Finland. 2009 Elsevier Ltd.



Schematics showing the circulation in the subsurface Atlantic and intermediate layers in the Arctic Mediterranean Sea.

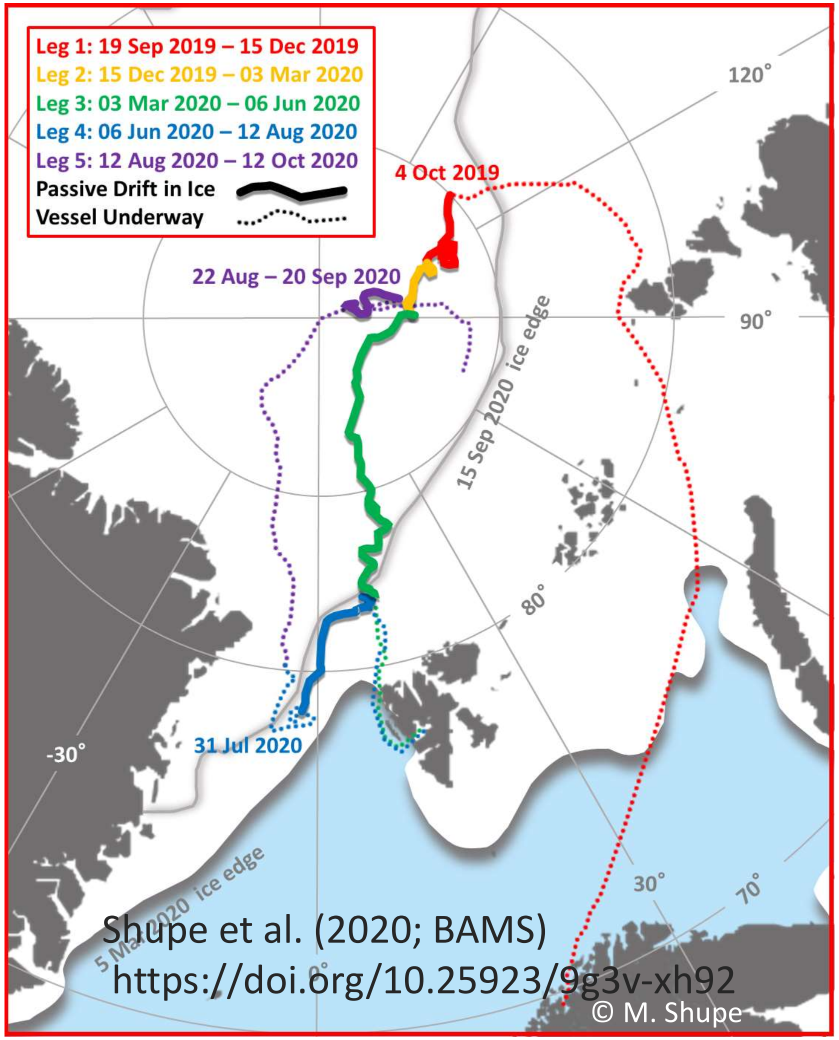
International Arctic Drift Expedition

A year-long drift across the Eurasian Arctic

Centralized and distributed observations

Slide by Benjamin Rabe (AWI)

Drift

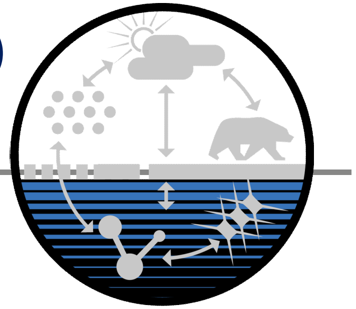


MOSAiC
International Arctic Drift Expedition

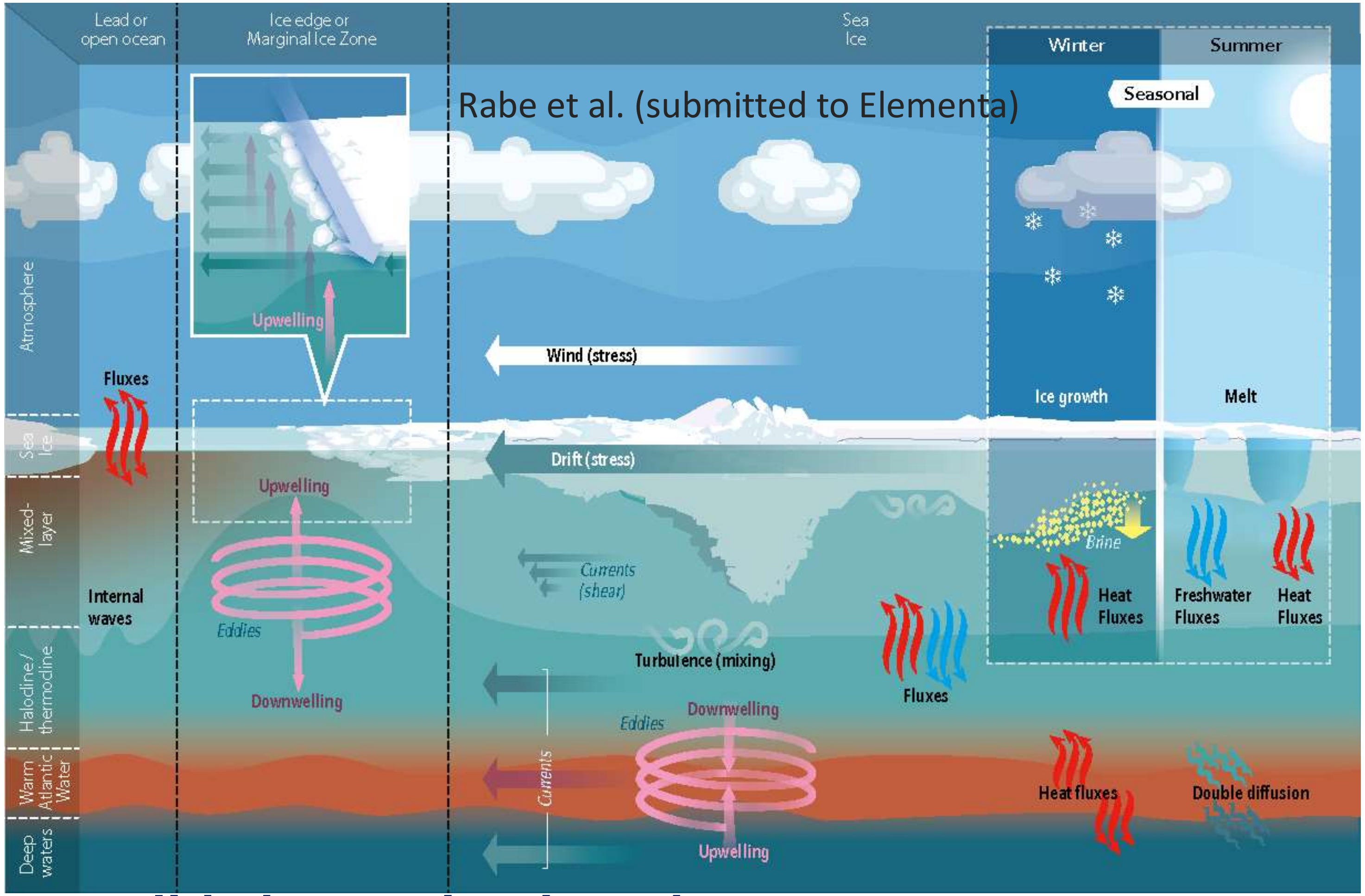
MOSAiC leg1 Photos by: Stefan Hendricks

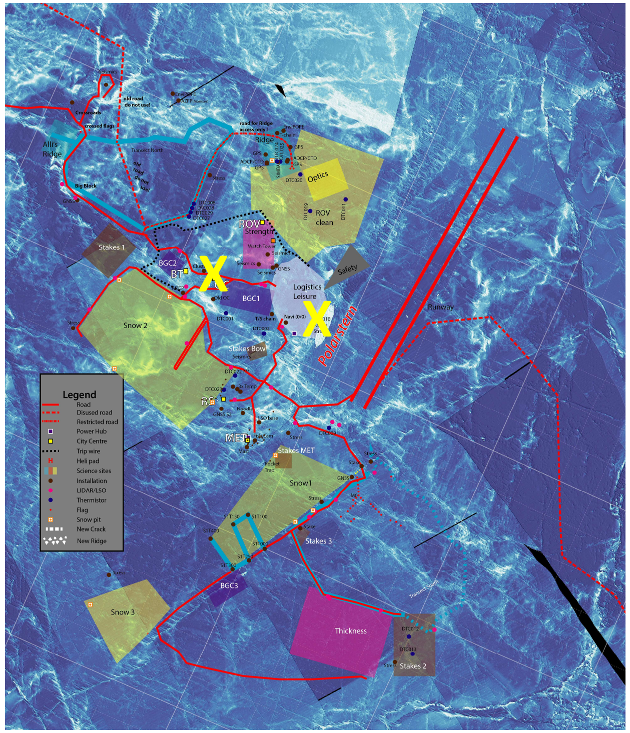
MOSAiC International Arctic Drift Expedition

MOSAiC: Coupled system OCEAN (physics)



What's our focus?

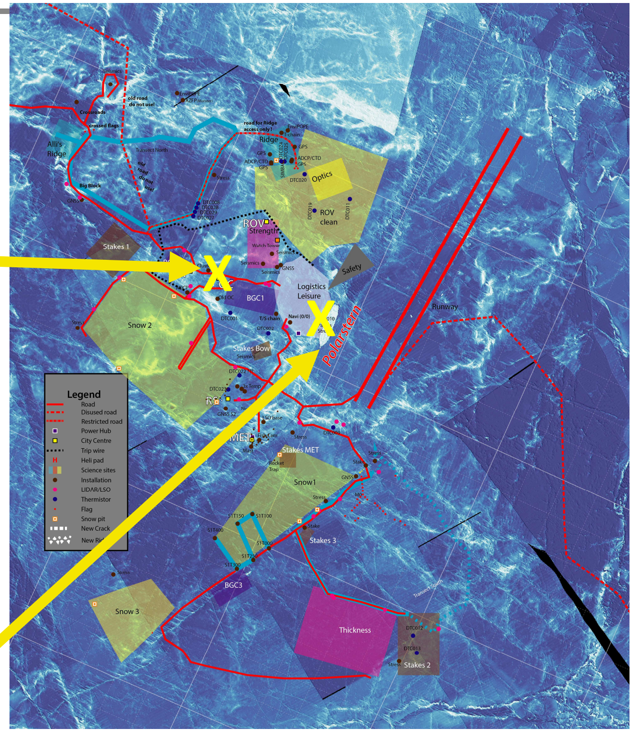




Slide by Benjamin Rabe (AWI)

MOSAiC
International
Arctic Drift
Expedition

Ingenious solutions: CTD/rosette hole and Ocean City



Daylight pictures: Janin Schaffer

Broken power line → sledge with fuel barrel / generator.

Slide and photos by Benjamin Rabe (AWI)

From: MOSAiC report leg 1 and 2

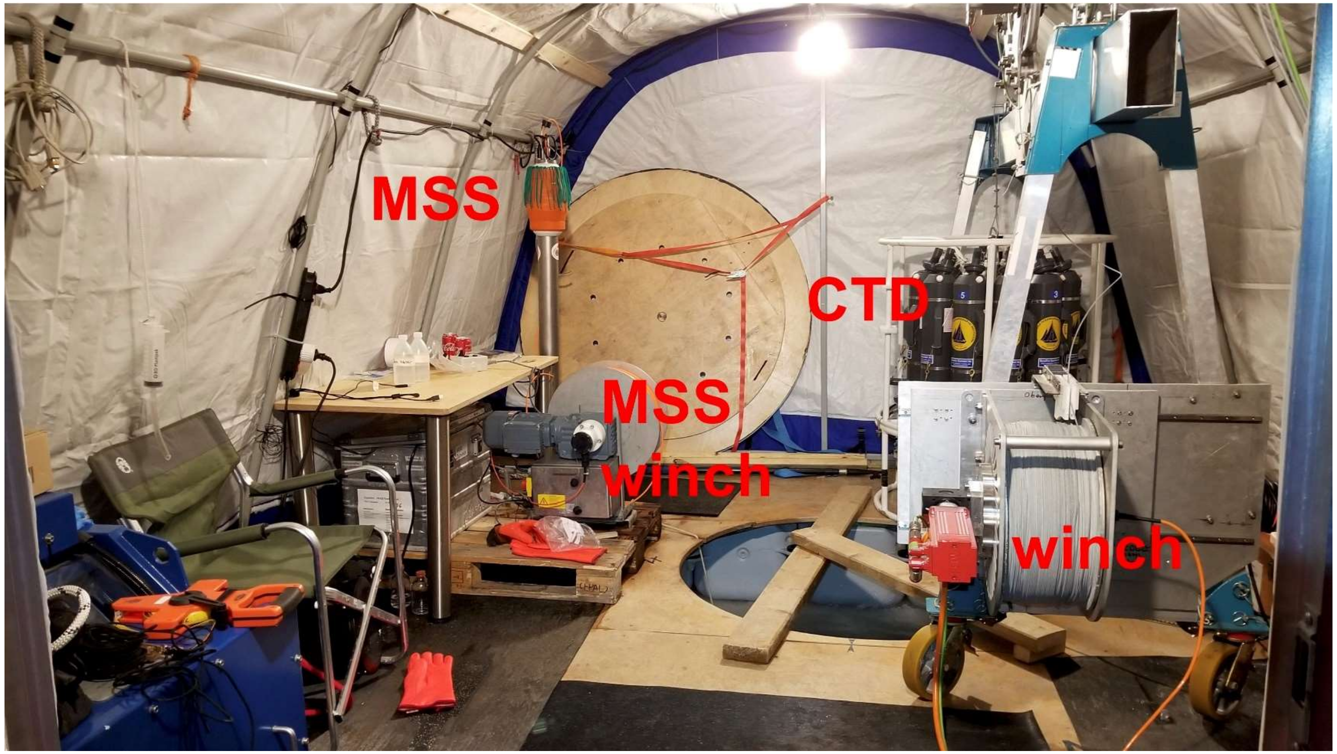
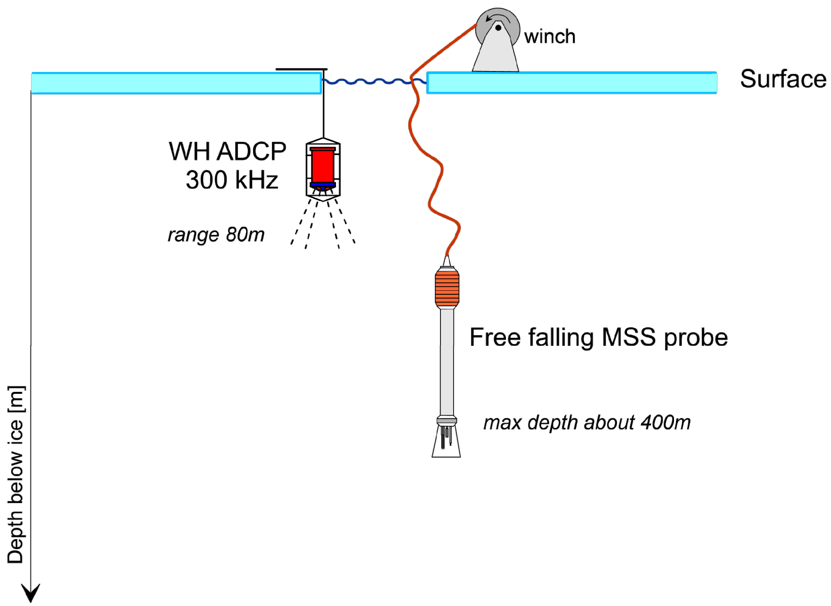


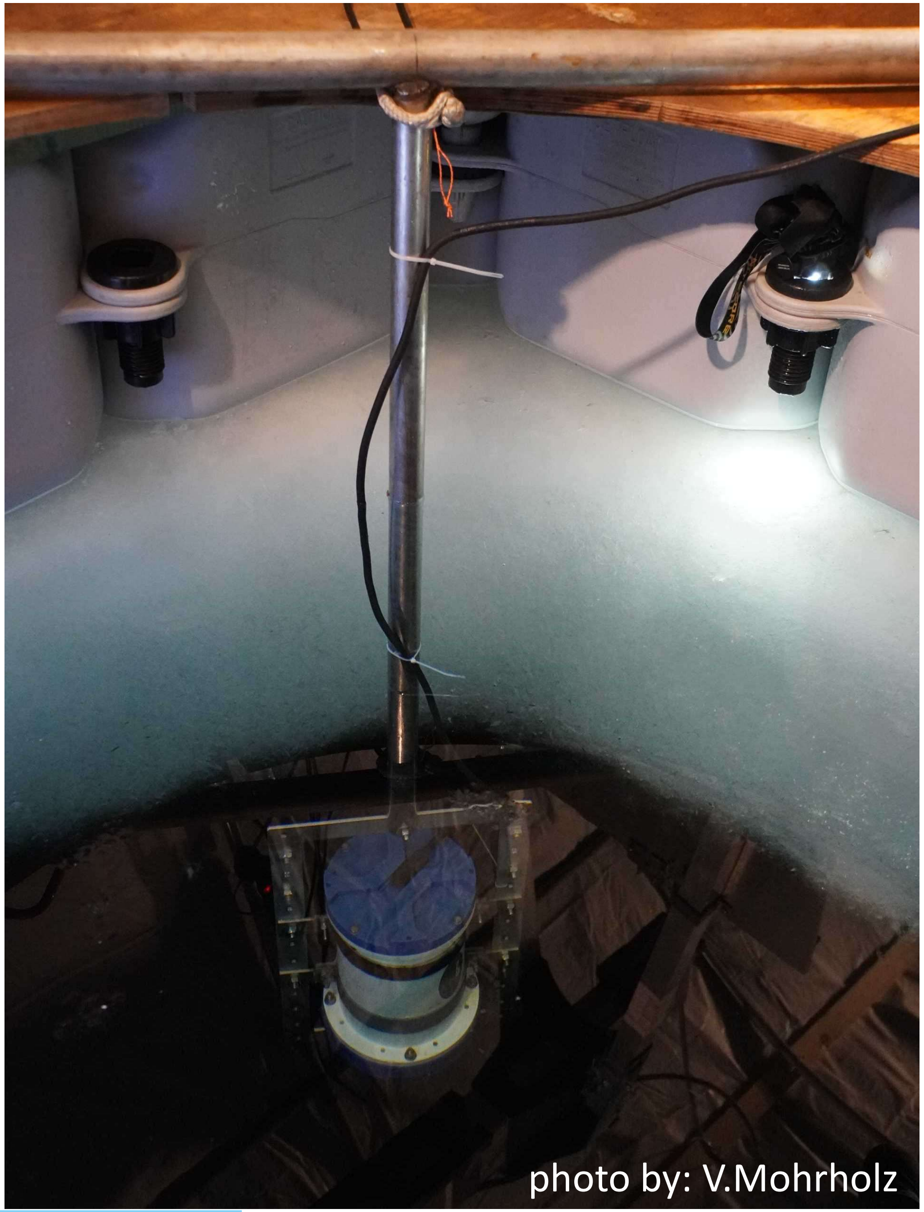
photo by: M. Hoppmann

From: MOSAiC report leg 1 and 2

photo by: V.Mohrholz



From: MOSAiC report leg 2



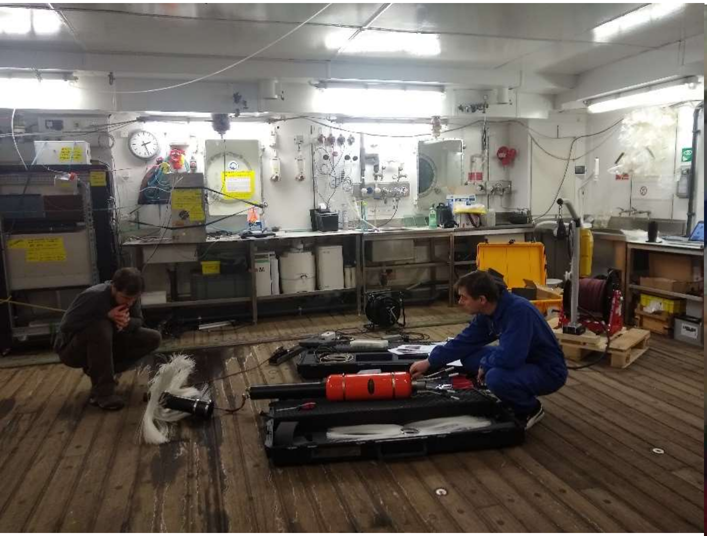
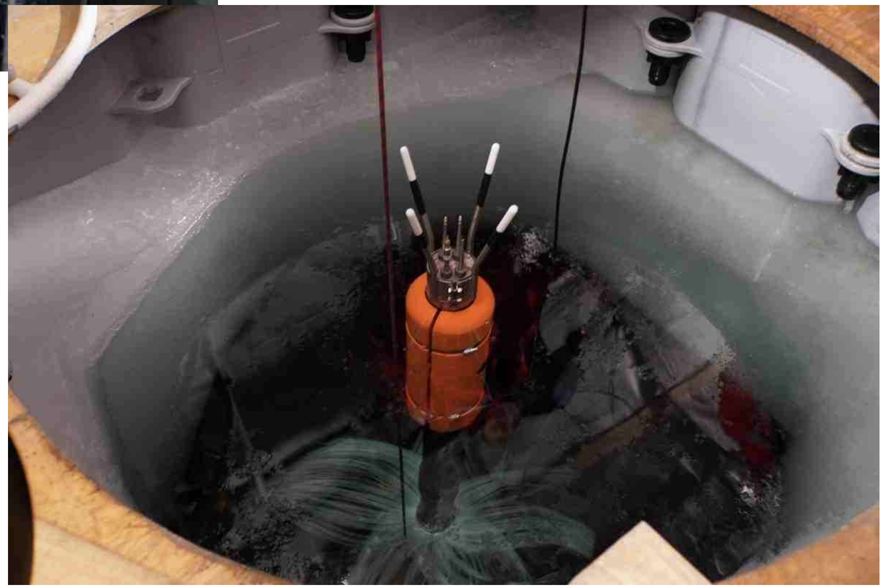


Photo by: V.Mohrholz,
I.Kuznetsov, M. Mallet, B. Rabe,
E. Brossier



From: MOSAiC report leg 2

V.Mohrholz, B. Rabe, photo by: : Steffen Graupner

16 November 2019

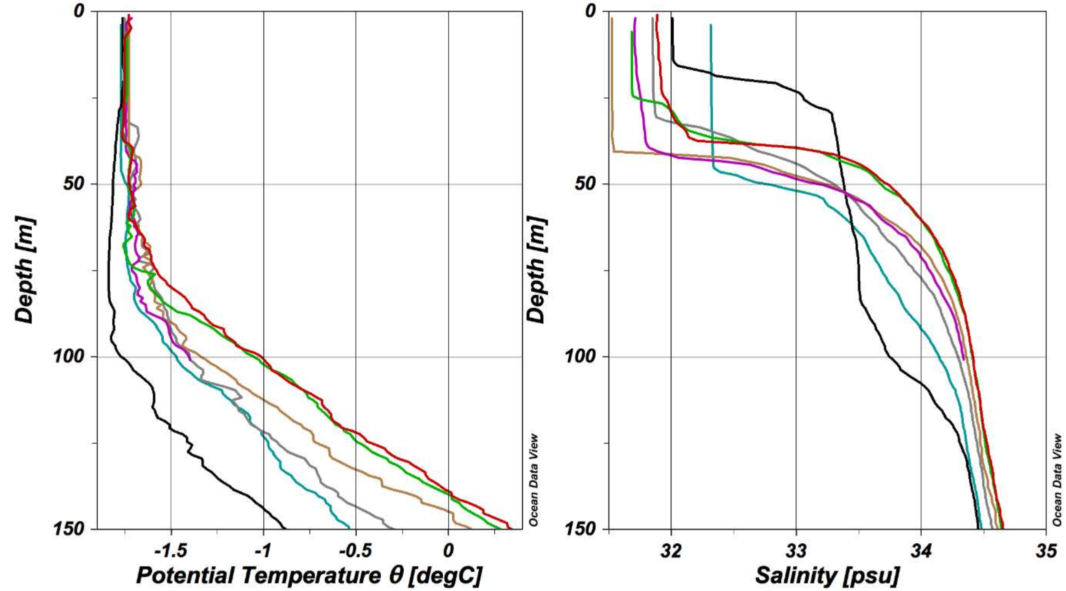
Photo: Y.C. Fang / M. Hoppmann

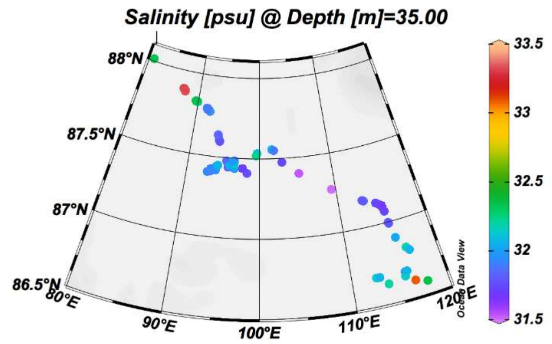
17 November 2019

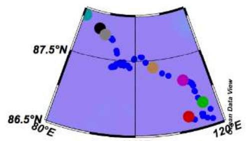
Photo: Y.C. Fang / M. Hoppmann

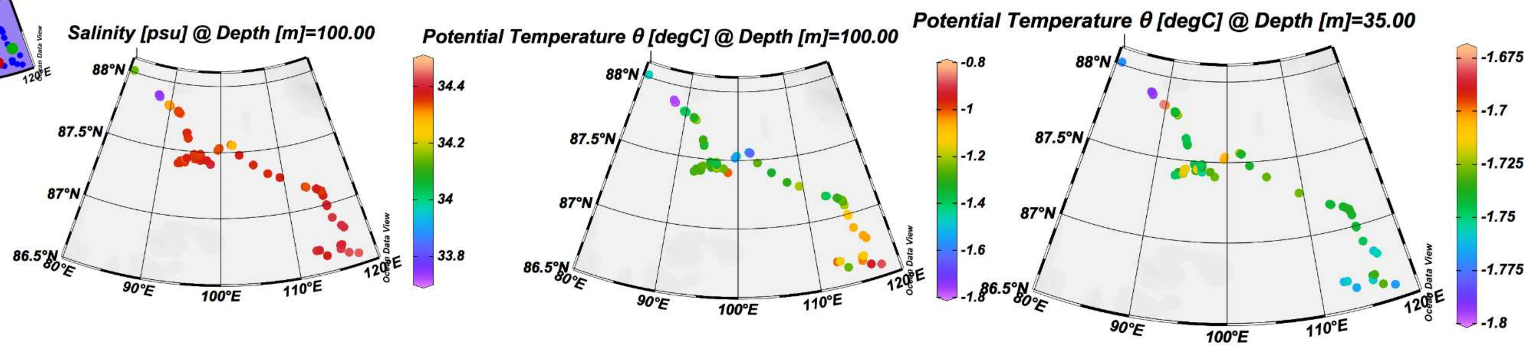
Video (CTD/MSS)

Vertical structure: 0 to 150 meters



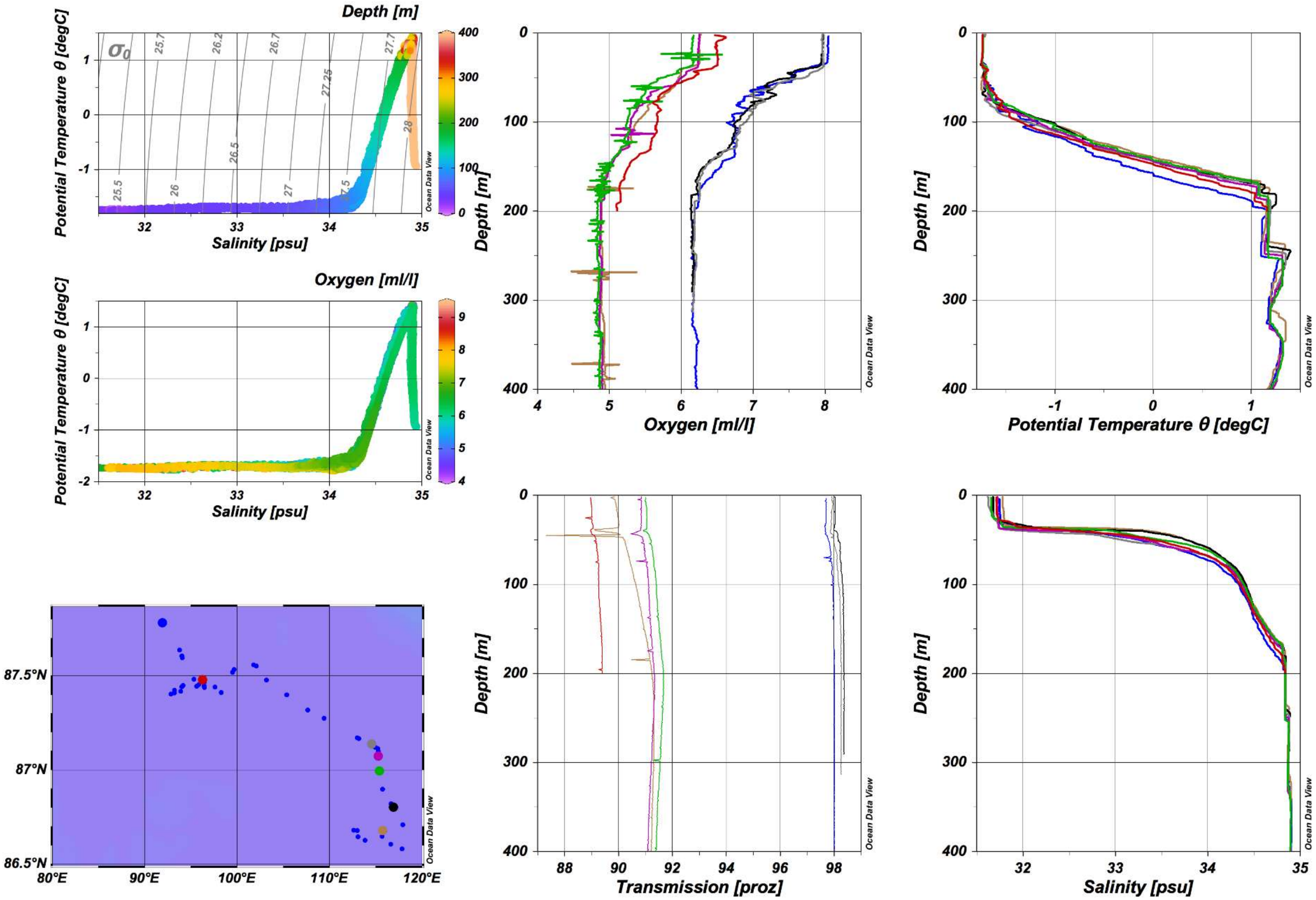






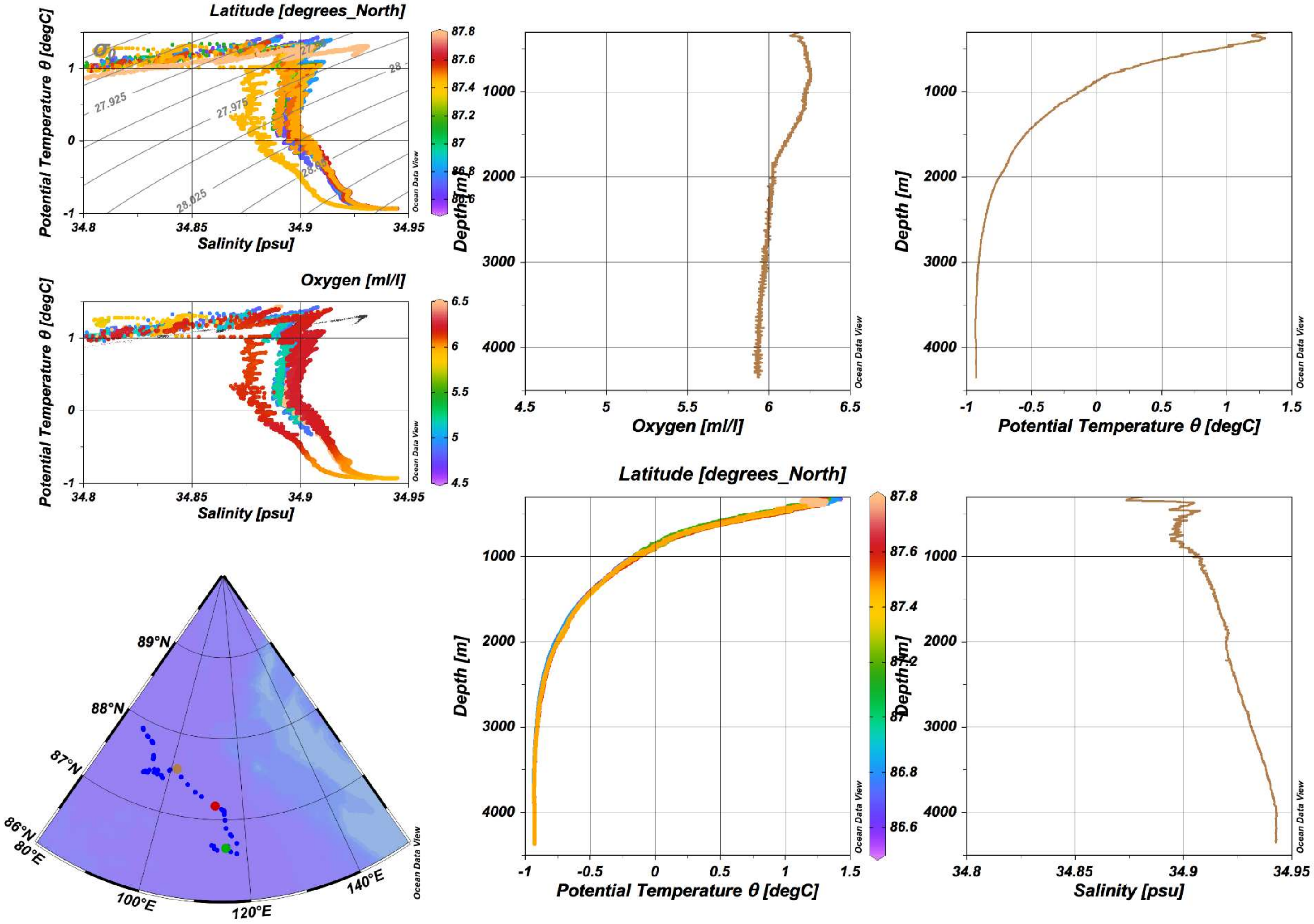
Tippenhauer et al. (in prep); Figure: B. Rabe, V.Mohrholz, M. Mallet

Vertical structure: 0 to 400 meters



Tippenhauer et al. (in prep); Figure: B. Rabe, V.Mohrholz, M. Mallet

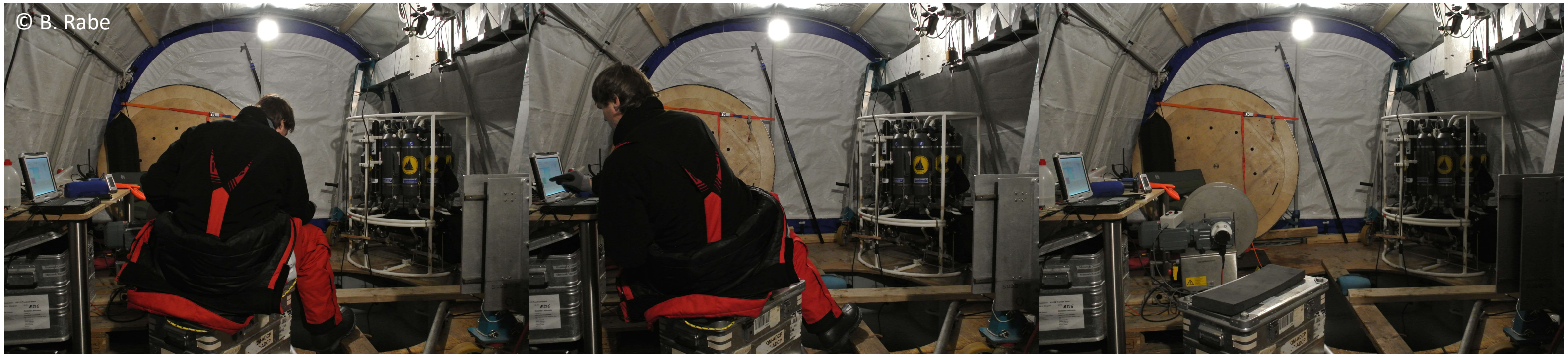
Vertical structure: 300 to 4500 meters



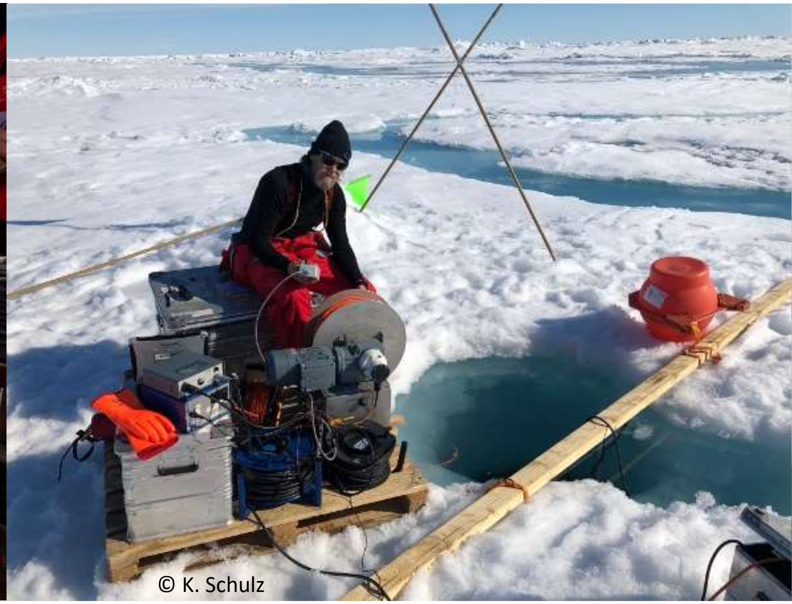
Tippenhauer et al. (in prep); Figure: B. Rabe, V.Mohrholz, M. Mallet

Slide by Benjamin Rabe (AWI)

How to run the same device from the ice in different seasons: turbulence in the ocean



Leg 5 PI Zoé Koenig during the 36h obs.



Leg 4’s Ingo Schuffenhauer measuring in a lead

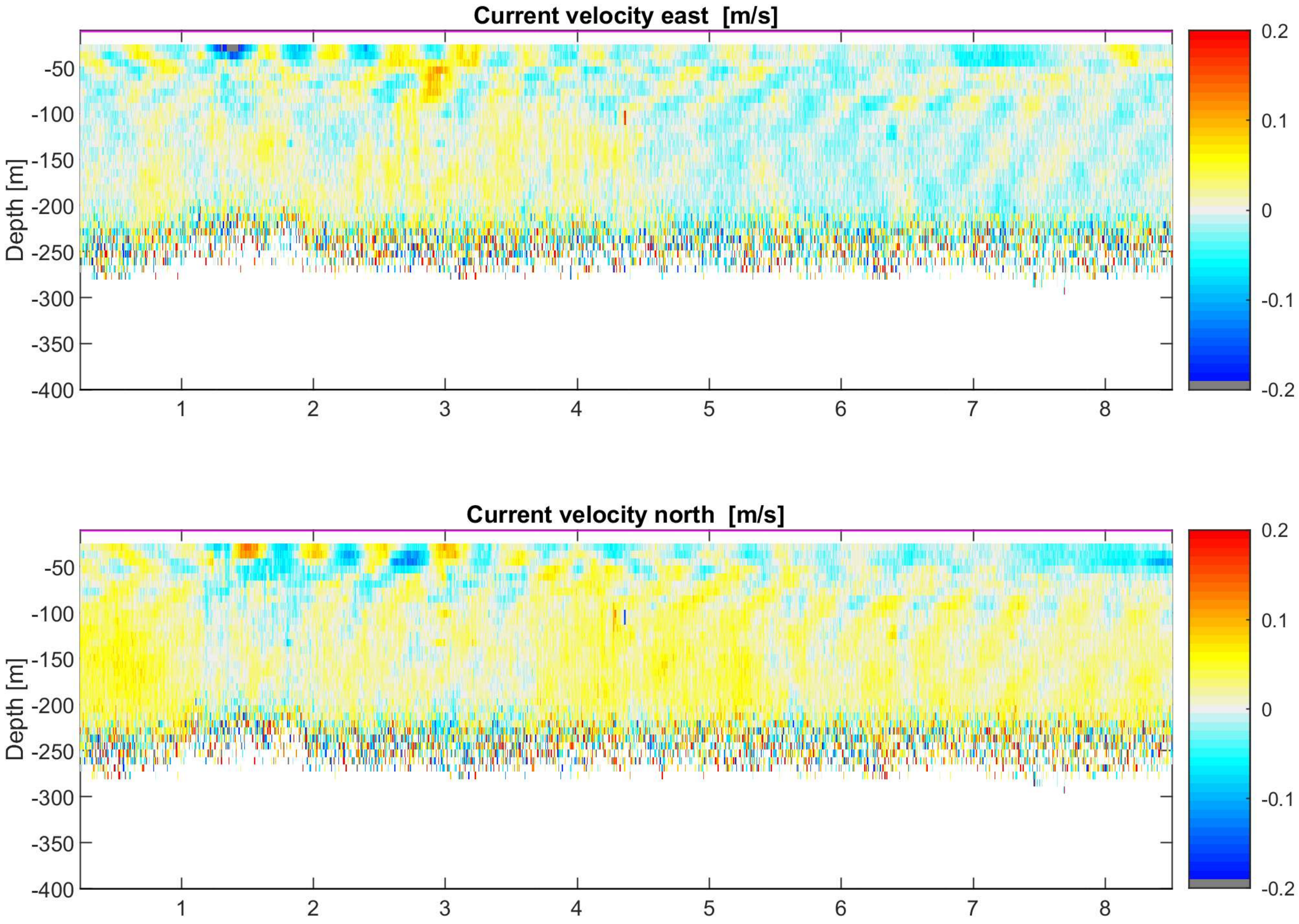
Leg 4 full-day in the fog

Bear guarding

Egor Shimanchuk Photo by: Polona Itkin (NERSC)

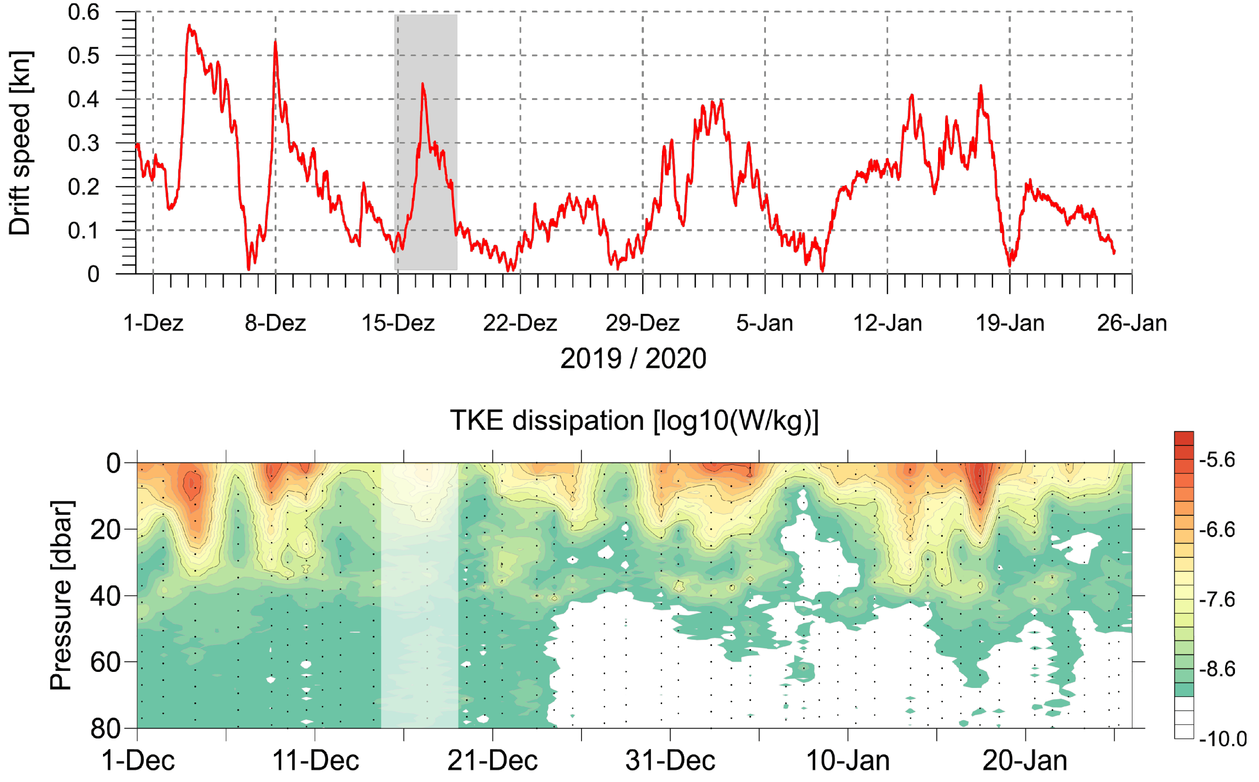
Photo by: Ivan Kuznetsov (AWI)

Currents, ship ADCP



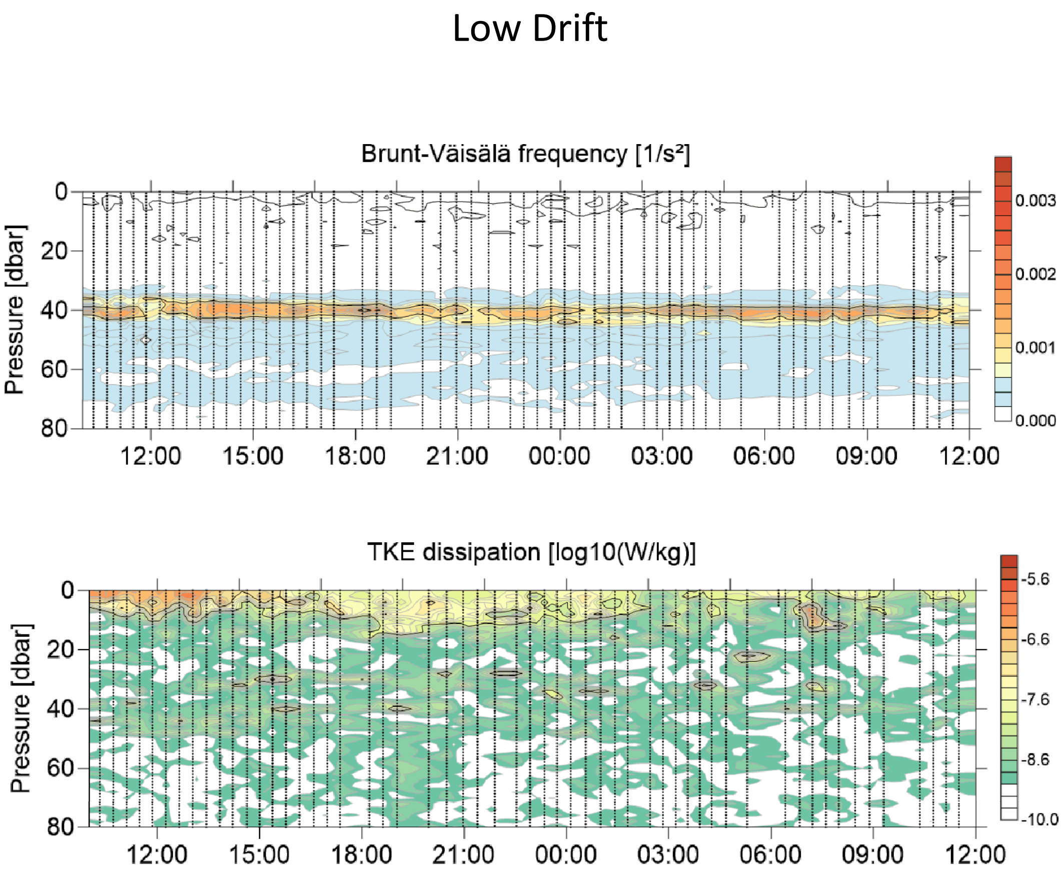
Schulz et al. (in preparation); Figure: V. Mohrholz

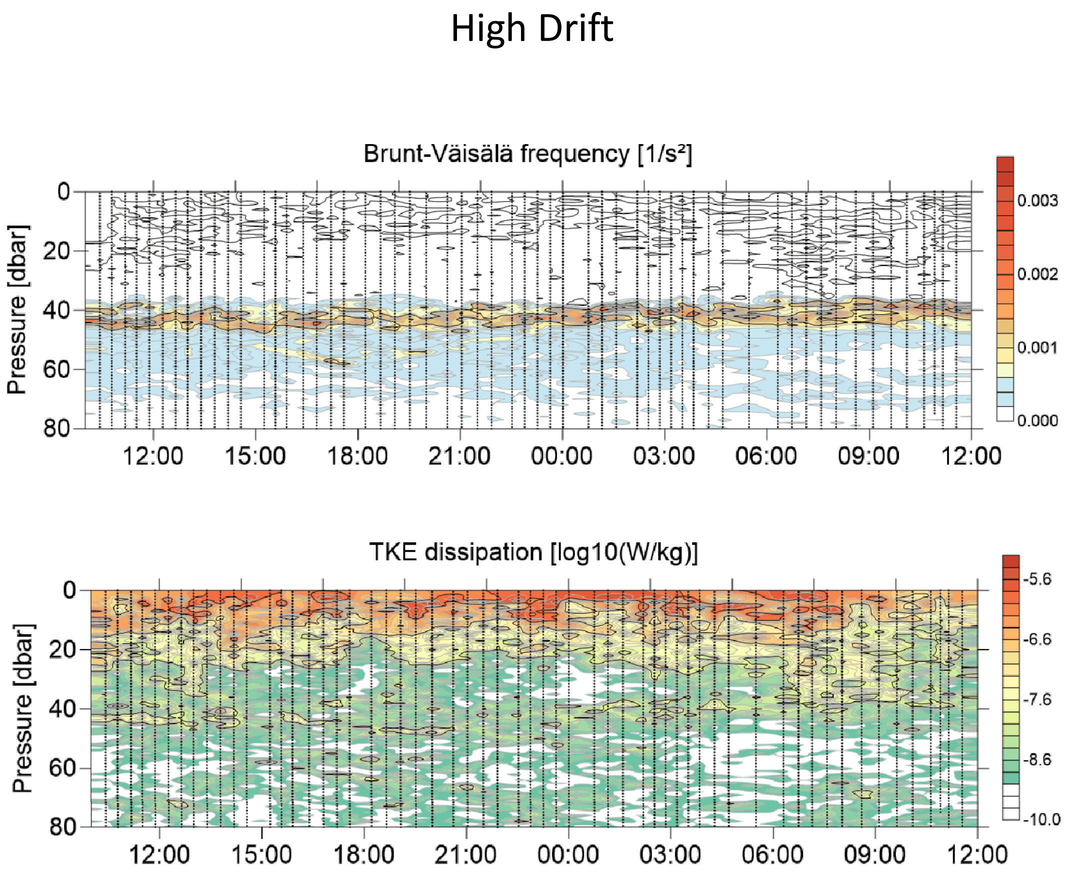
Drift and surface mixing



Schulz et al. (in preparation); Figure: V. Mohrholz

Drift and surface mixing, 24h





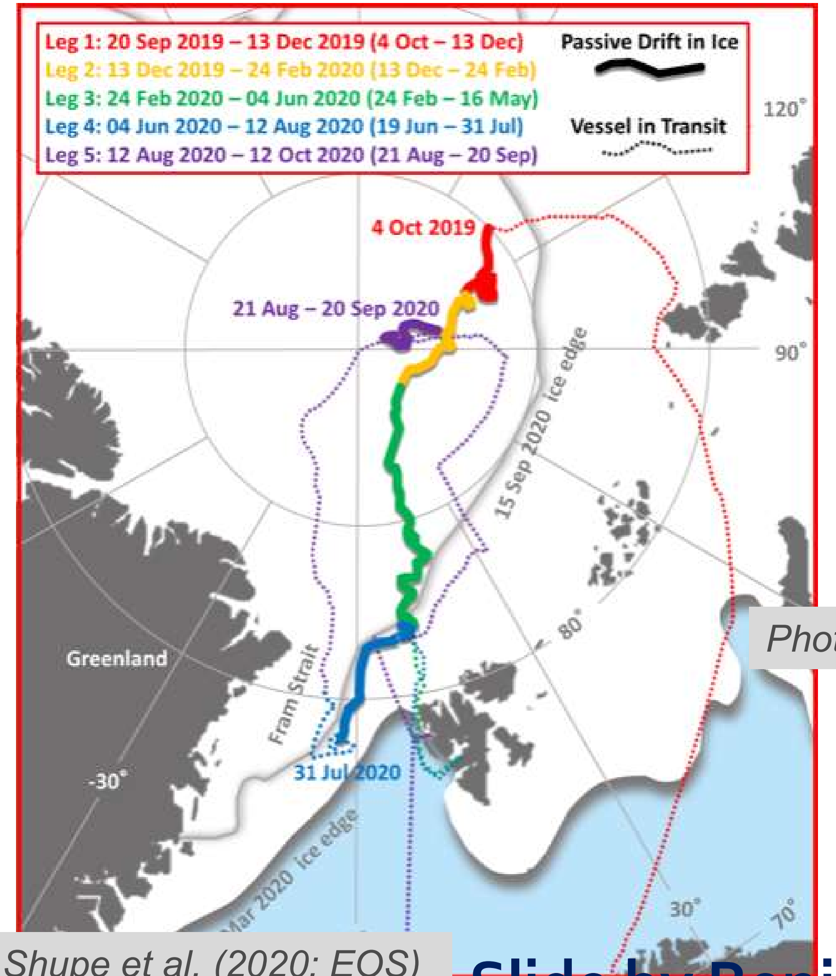
Schulz et al. (in preparation); Figure: V. Mohrholz

Videao by Polona Itkin (Ice breaking)

MOSAiC
International Arctic Drift Expedition

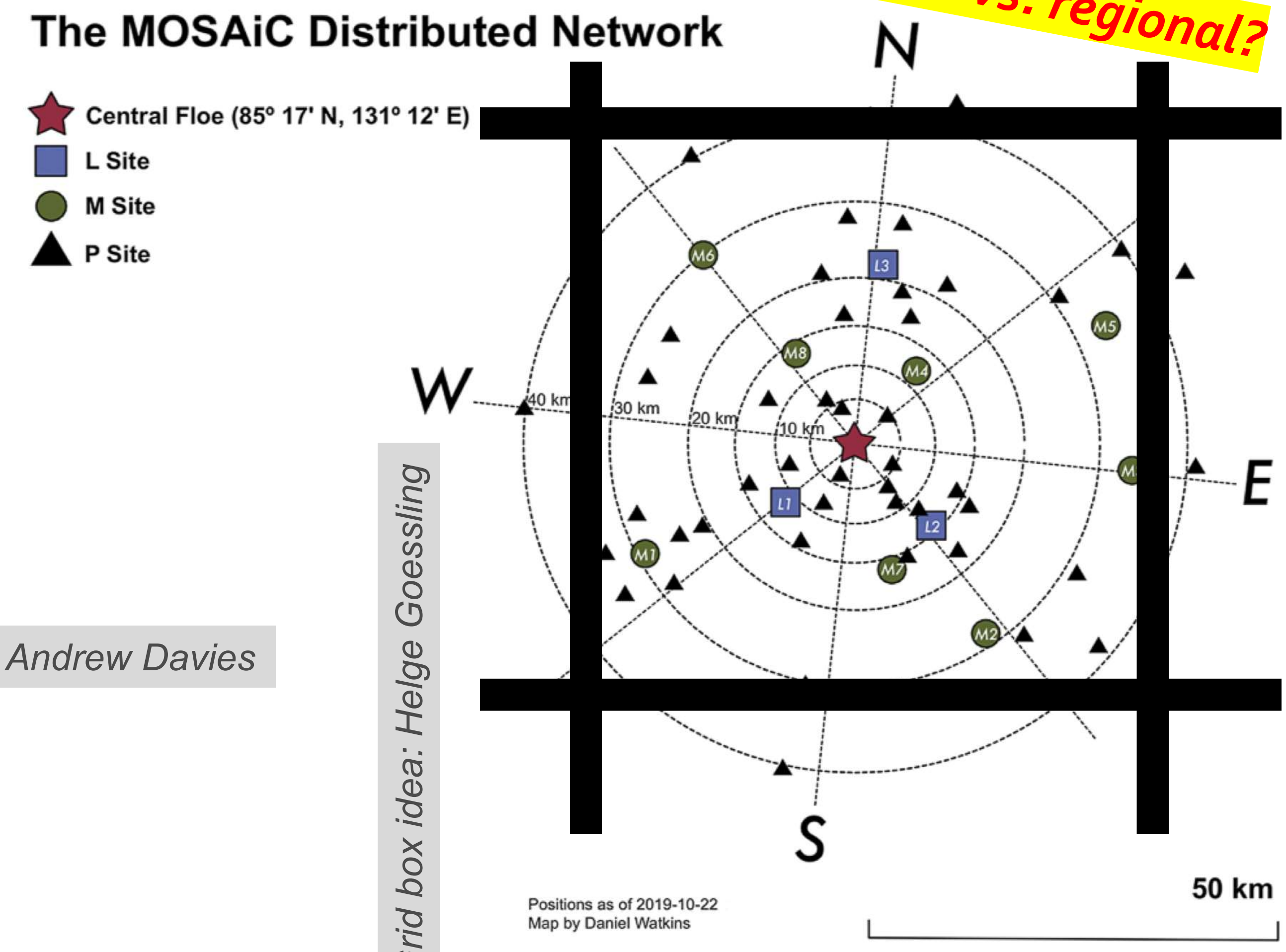
MOSAiC: a drifting observatory network

How to get local vs. regional?



Shupe et al. (2020; EOS)

Photo: Andrew Davies



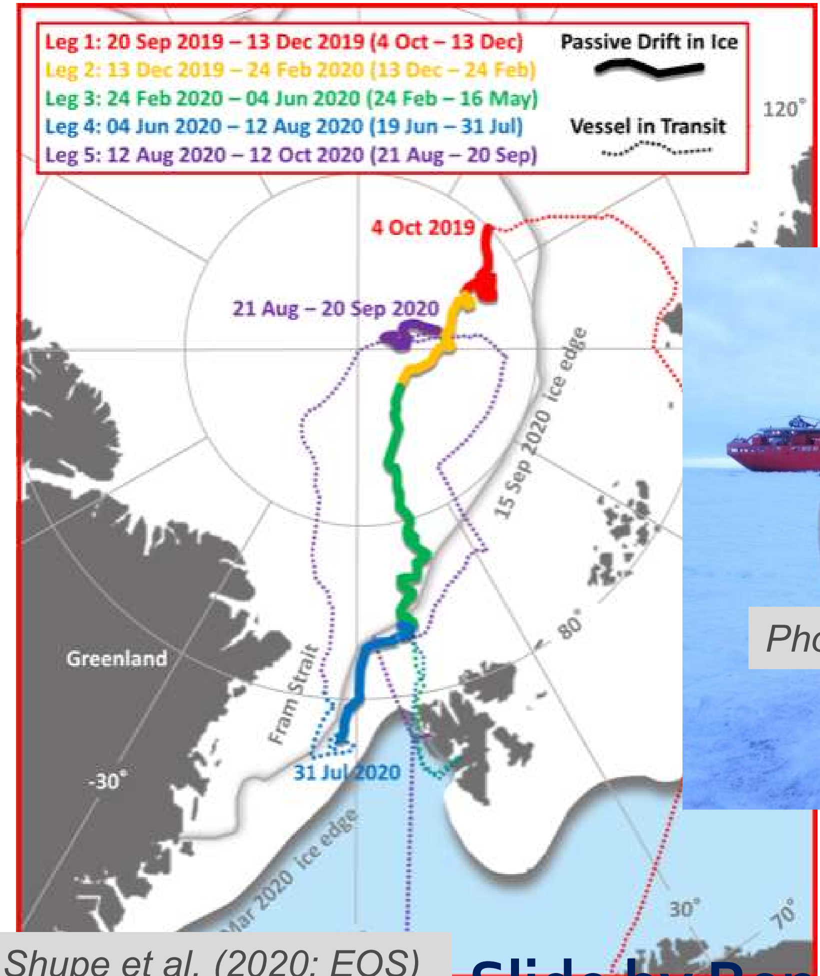
Grid box idea: Helge Goessling

Map: Krumpen and Sokolov (2020)

Slide by Benjamin Rabe (AWI)

MOSAiC: a drifting observatory network

How to get local vs. regional?

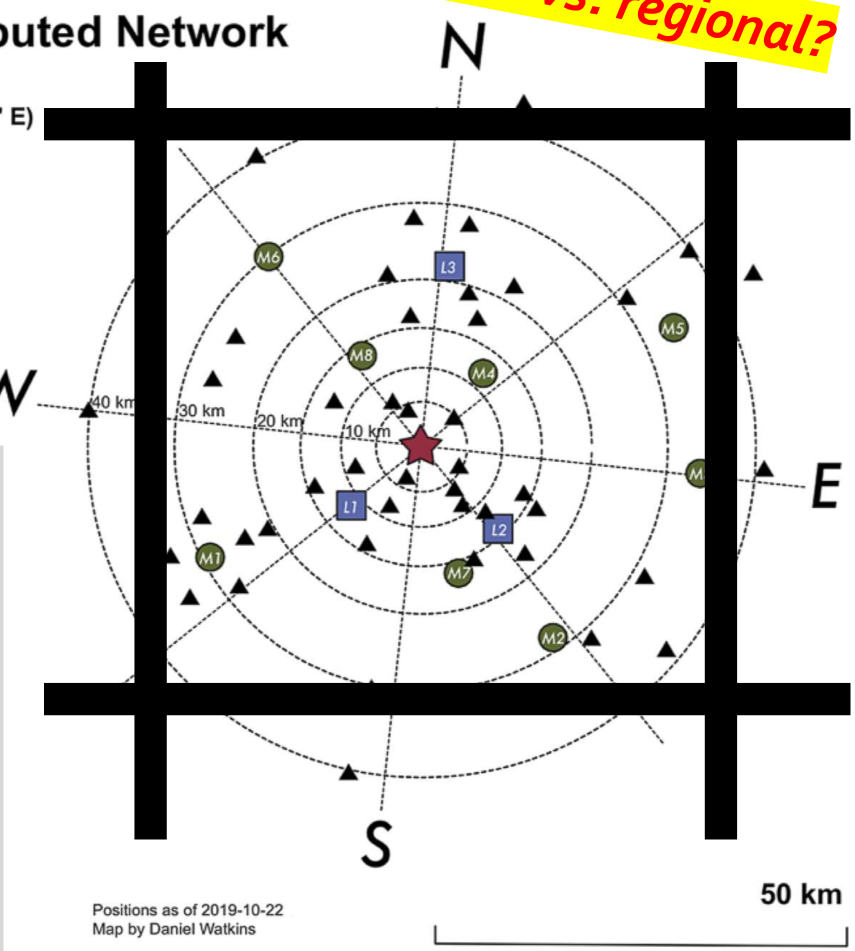


Shupe et al. (2020; EOS)

What's a buoy?

Photo: Andrew Davies

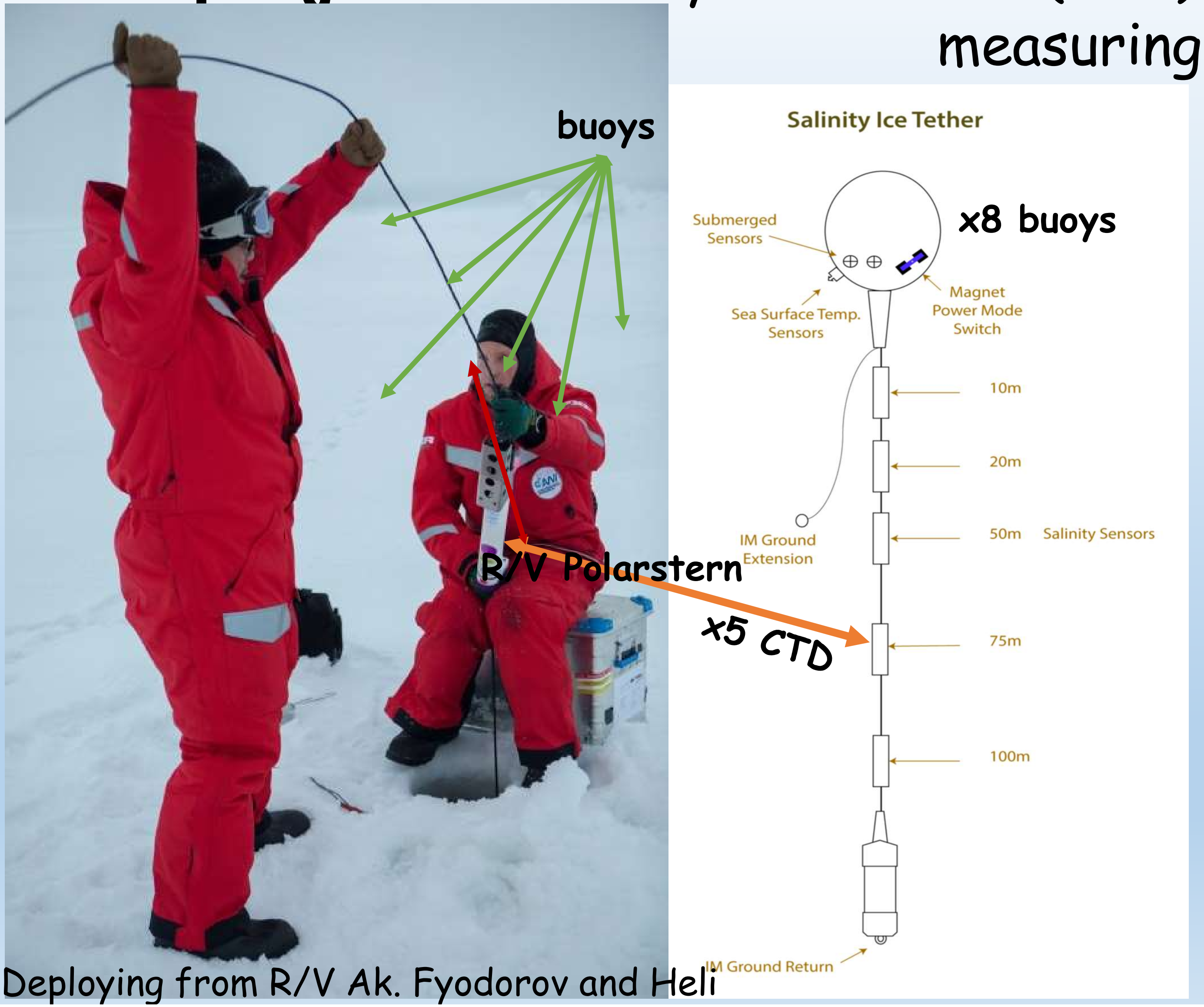
Grid box idea: Helge Goessling



Map: Krumpen and Sokolov (2020)

Slide by Benjamin Rabe (AWI)

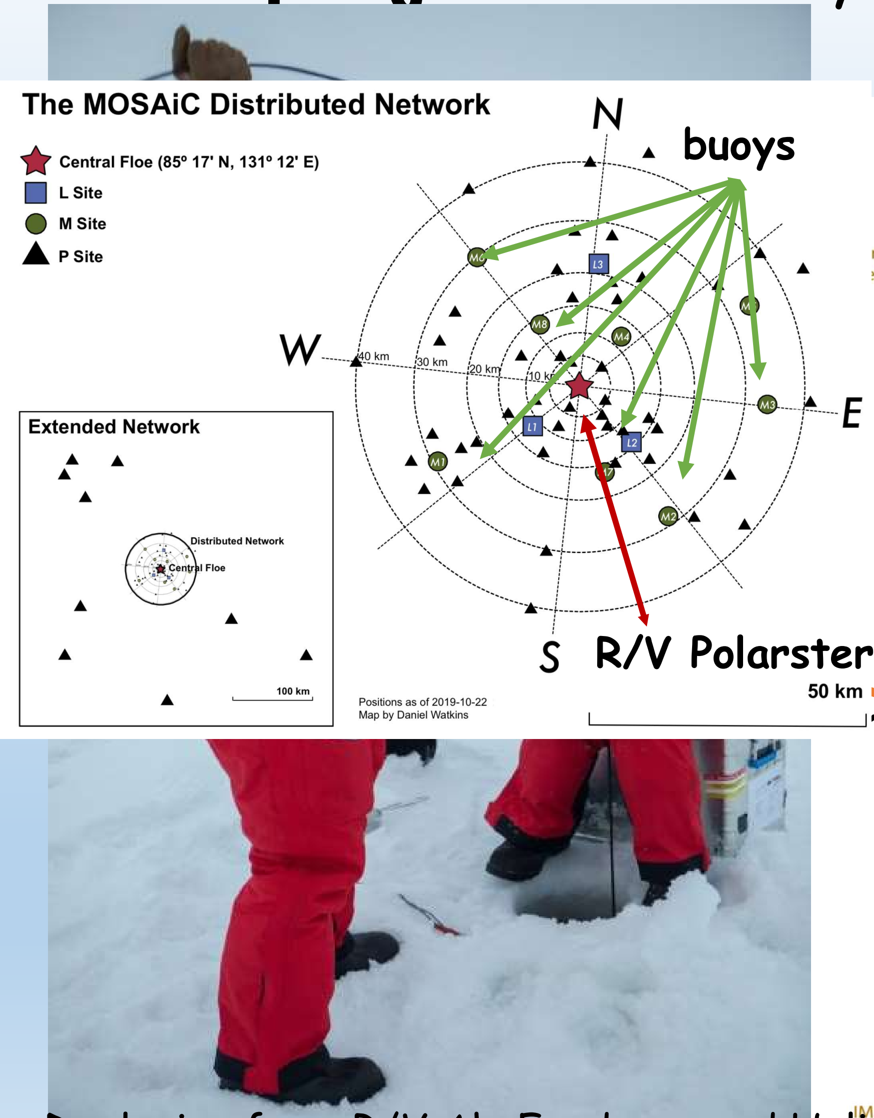
AWI project: Salinity Ice Tether (SIT) aka CTD buoy in DN measuring sub-mesoscale eddies and upper-ocean hydrography



Deploying from R/V Ak. Fyodorov and Heli

On photo: Y.C. Fang and M. Hoppmann

AWI project: Salinity Ice Tether (SIT) aka CTD buoy in DN measuring sub-mesoscale eddies and upper-ocean hydrography



Deploying from R/V Ak. Fyodorov and Heli

2 min internal logging and 10 min via irdium

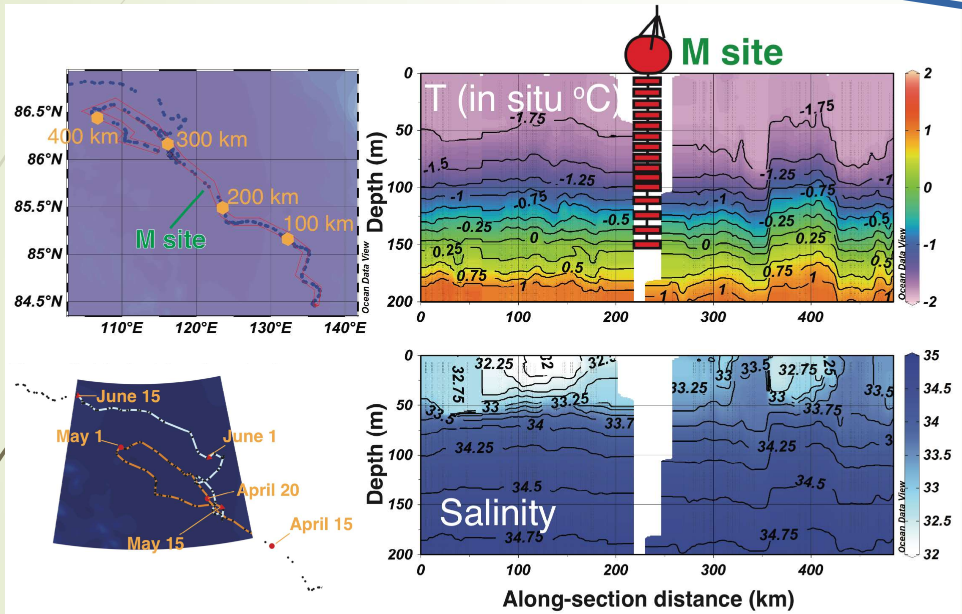
On photo: Y.C. Fang and M. Hoppmann

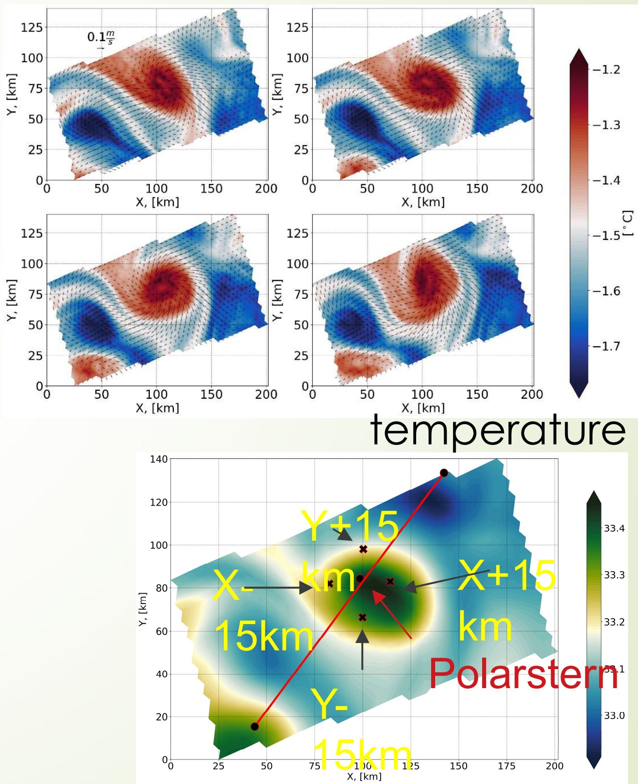
Regional scale and process study

Model + Observations

Observation

Model





temperature

salinity

From: ?

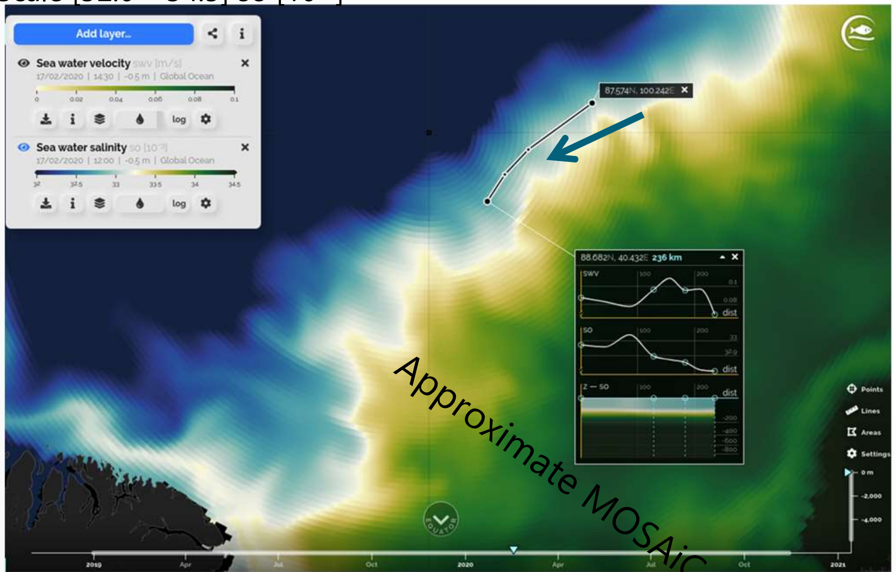
From: I.Kuznetsov, C. Fang, B. Rabe, ...

Winter data and “eddies” examples

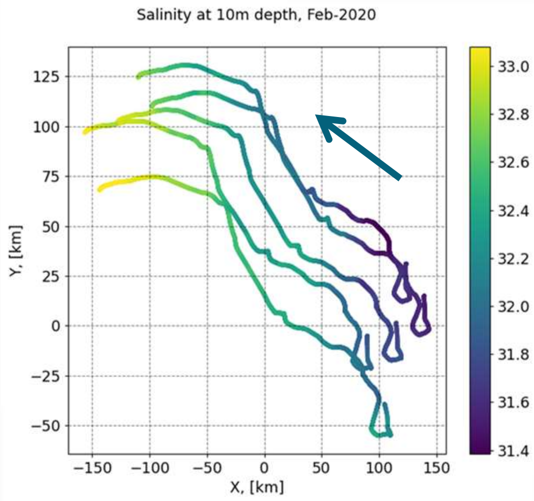
Sea surface salinity, February 2020

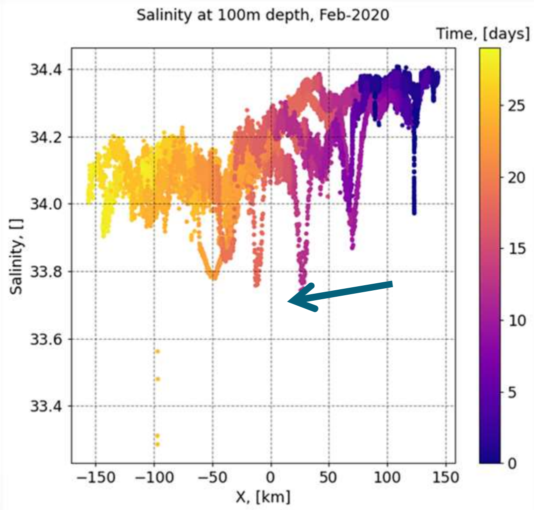
Global Ocean 1/12° Physics Analysis and Forecast, CMEMS

Scale [32.0 – 34.5] so [10^{-3}]



Data from 5 buoys at 10 and 100 m.



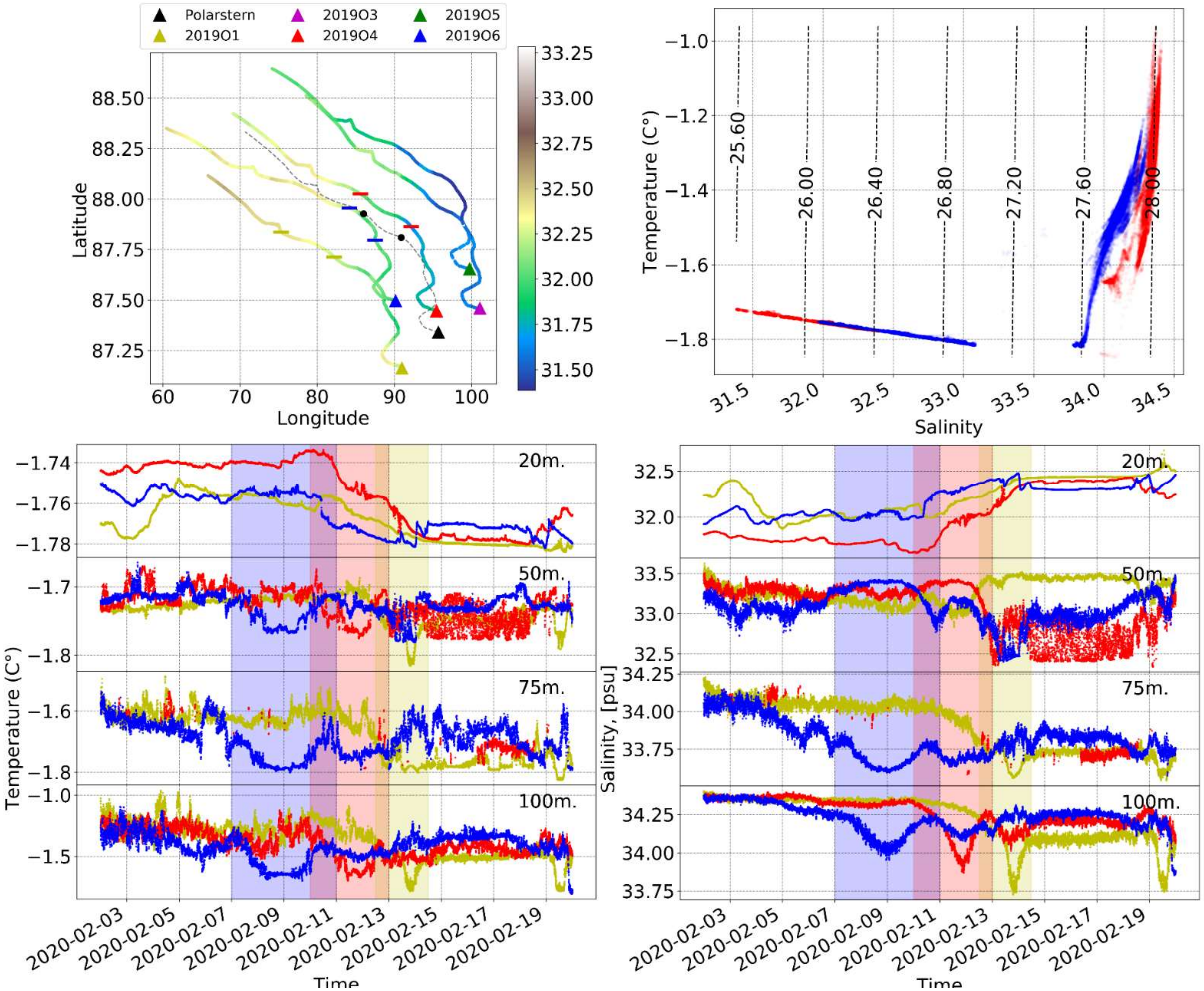


Mean ice drift speed ~11 cm/s

Mean ocean speed ~1-4 cm/s

Winter data and “eddies” examples

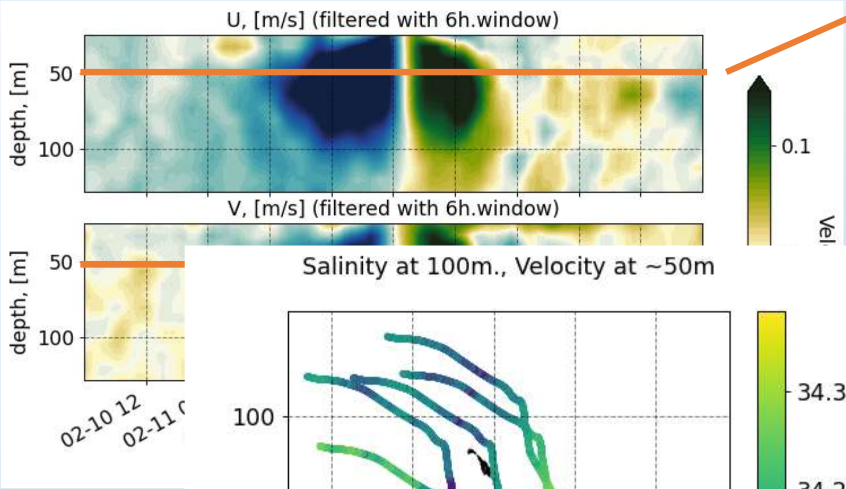
Taken from:
Mesoscale observations of temperature and salinity in the Arctic Transpolar Drift: a high-resolution dataset from the MOSAiC Distributed Network.
M.Hoppmann, I. Kuznetsov, Y.-C. Fang and Benjamin Rabe (submitted)

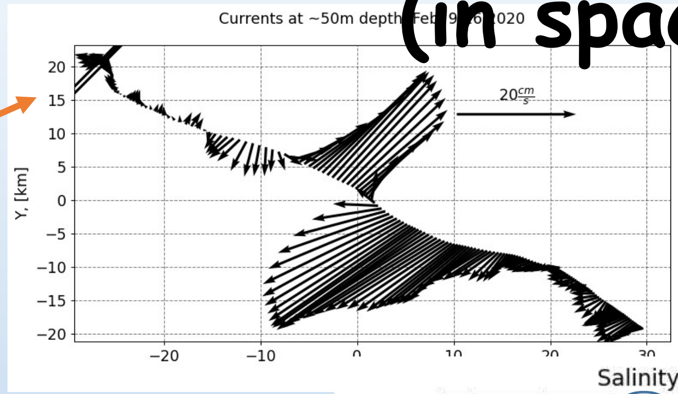


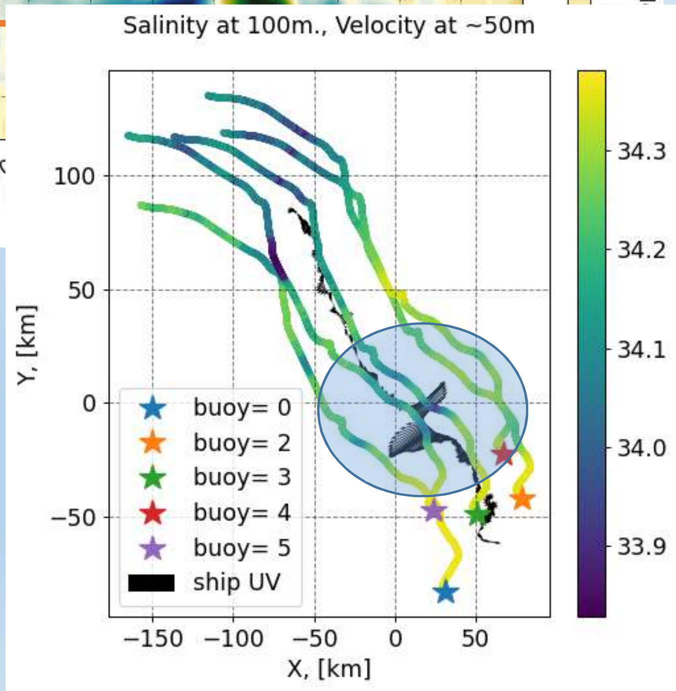
How it works ?

3D eddie measuring (in space and time)

Currents from Polarstern ADCP



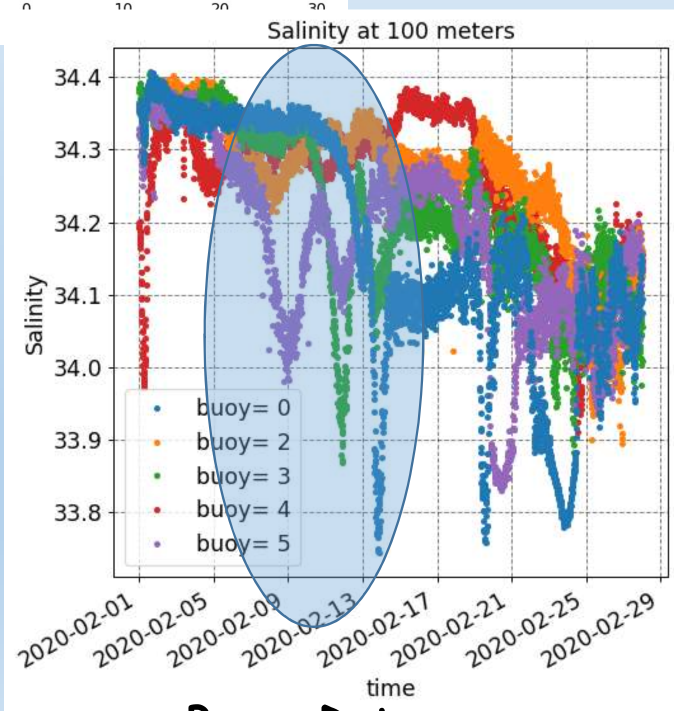




Buoys positions drifting with Polarstern

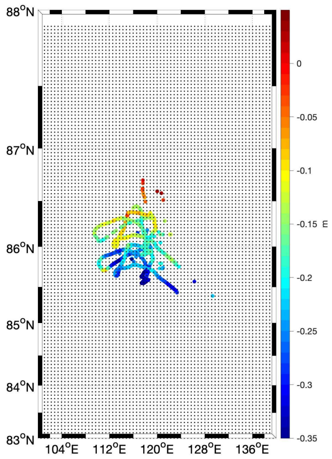
Big Eddie

Data

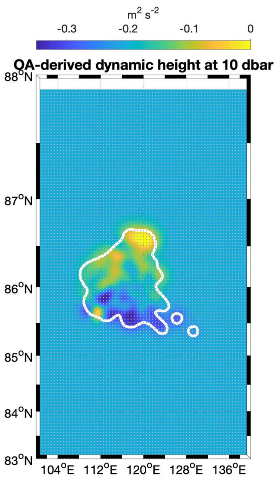


Buoys Data

Distributed obvservations and model simulations: from meso scale to sub-meso scale



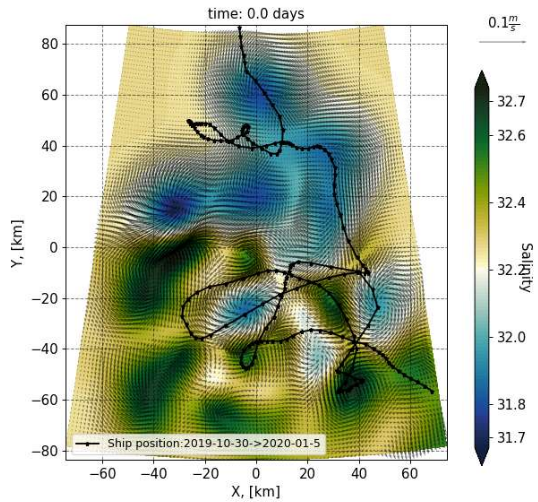
Dynamic height (m^2s^{-2}) from buoys

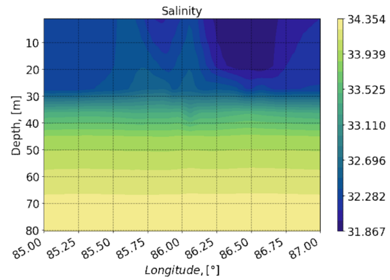


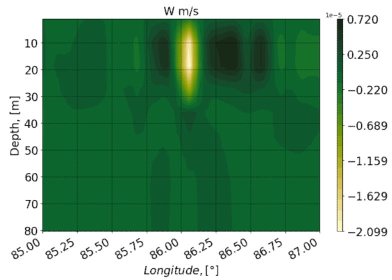
Gridded / mapped observations

Images: Ivan Kuznetsov and Ying-Chih Fang

High-resolution model simulation using mapped obs. as initial conditions (FESOM-C)

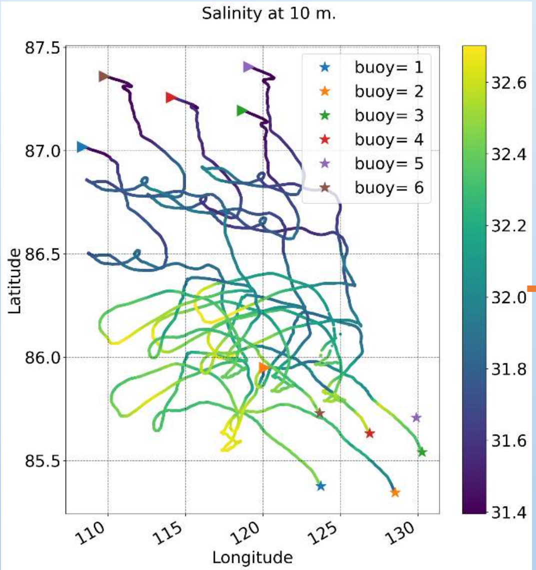






How to analyze scattered in time and space data ?

To understanding of (sub)mesoscale dynamics and its role in vertical transport of energy and mass we apply a 3D regional **model FESOM-C**



Buoys data
November - December

Data nudging →

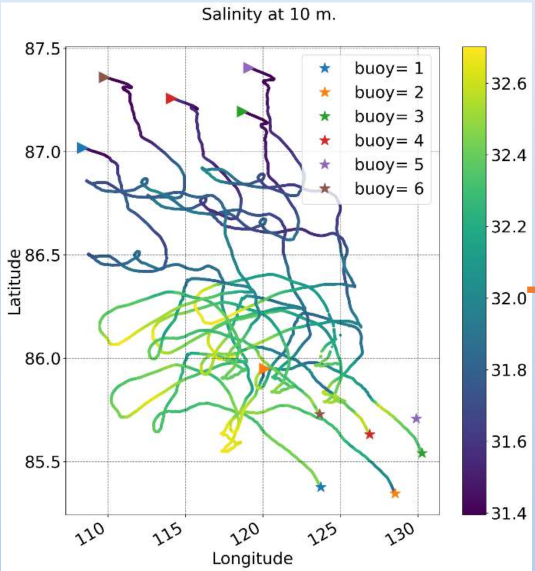
FESOM-C model

* finite volume discretization
* mixed meshes
* Vertical sigma coordinates
* High vertical and horizontal resolutions
* Various turbulence closers
* MPI / OpenMP parallelization
* …

(A. Androsov, et al. 2019, 2021, V. Fofonova, et al. 2019, 2021, I. Kuznetsov, et al. 2020, …)

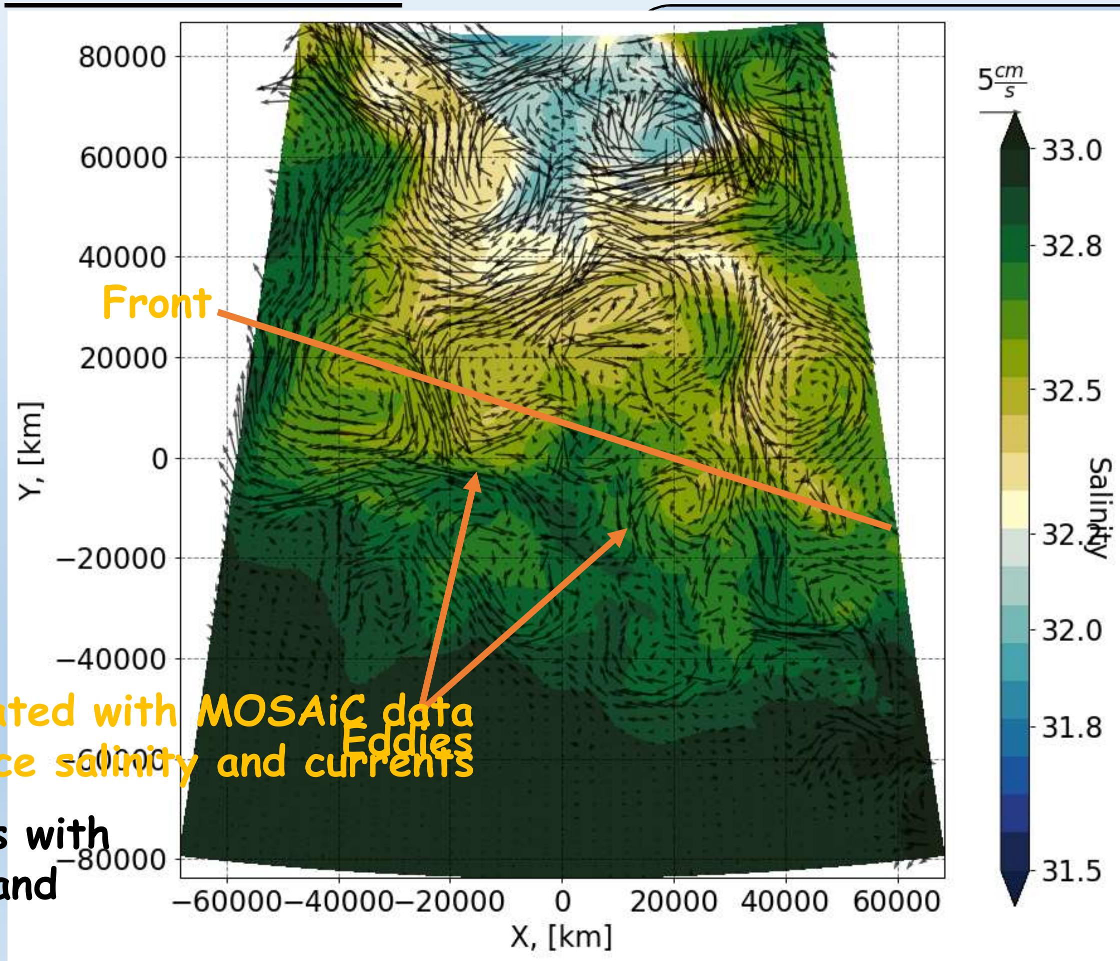
How to analyze scattered in time and space data ?

To understanding of (sub)mesoscale dynamics and its role in vertical transport of energy and mass we apply a 3D regional **model FESOM-C**



Buoys data
November - December

Data nudging



Series of simulations with various parameters and resolutions

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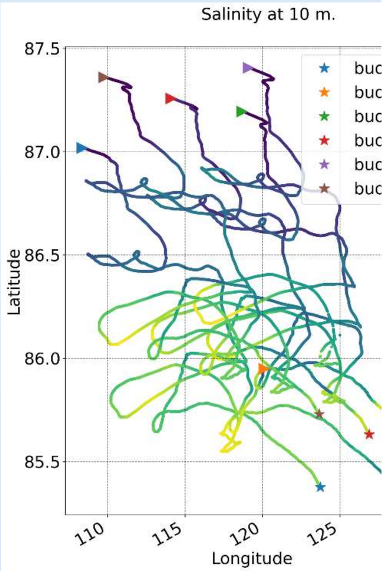
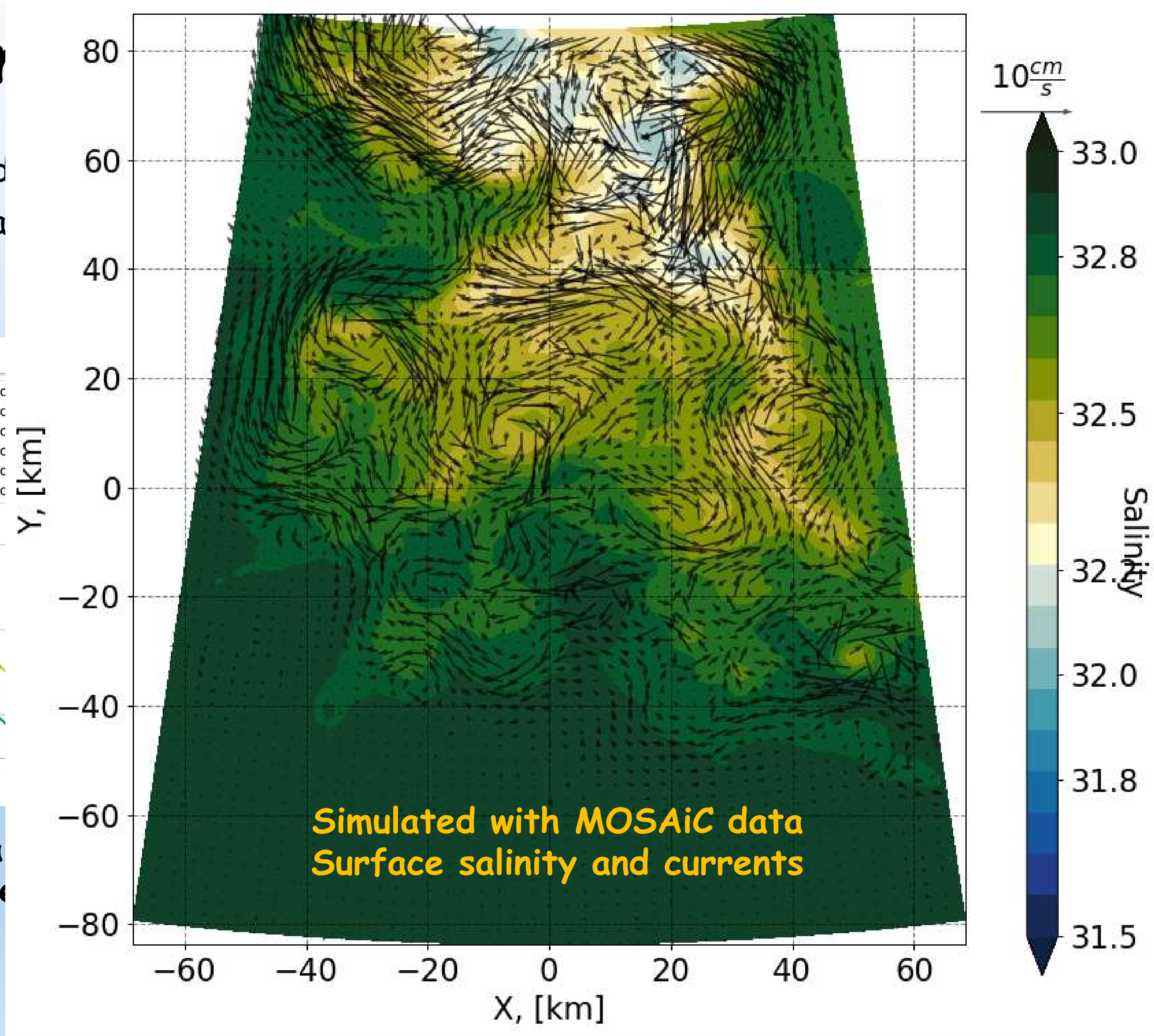
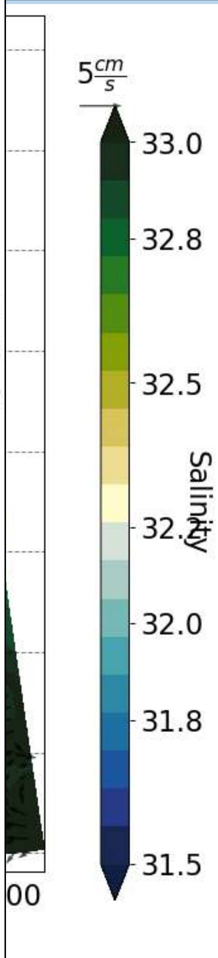
How to an… data ?

To understand…
energy and ma…



Buoys data…
November - Dec…





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Acknowledgments

* MOSAiC OCEAN team

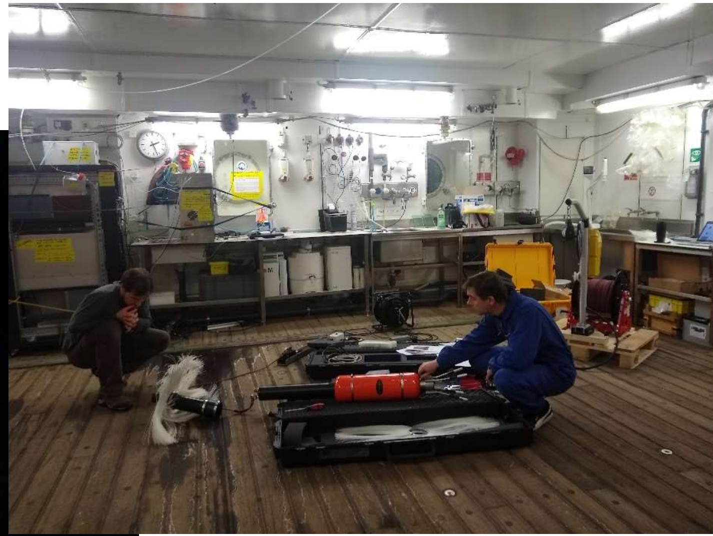
* MOSAiC Distributed Network team

* Crews of R/V Polarstern and R/V Akademik Fyodorov

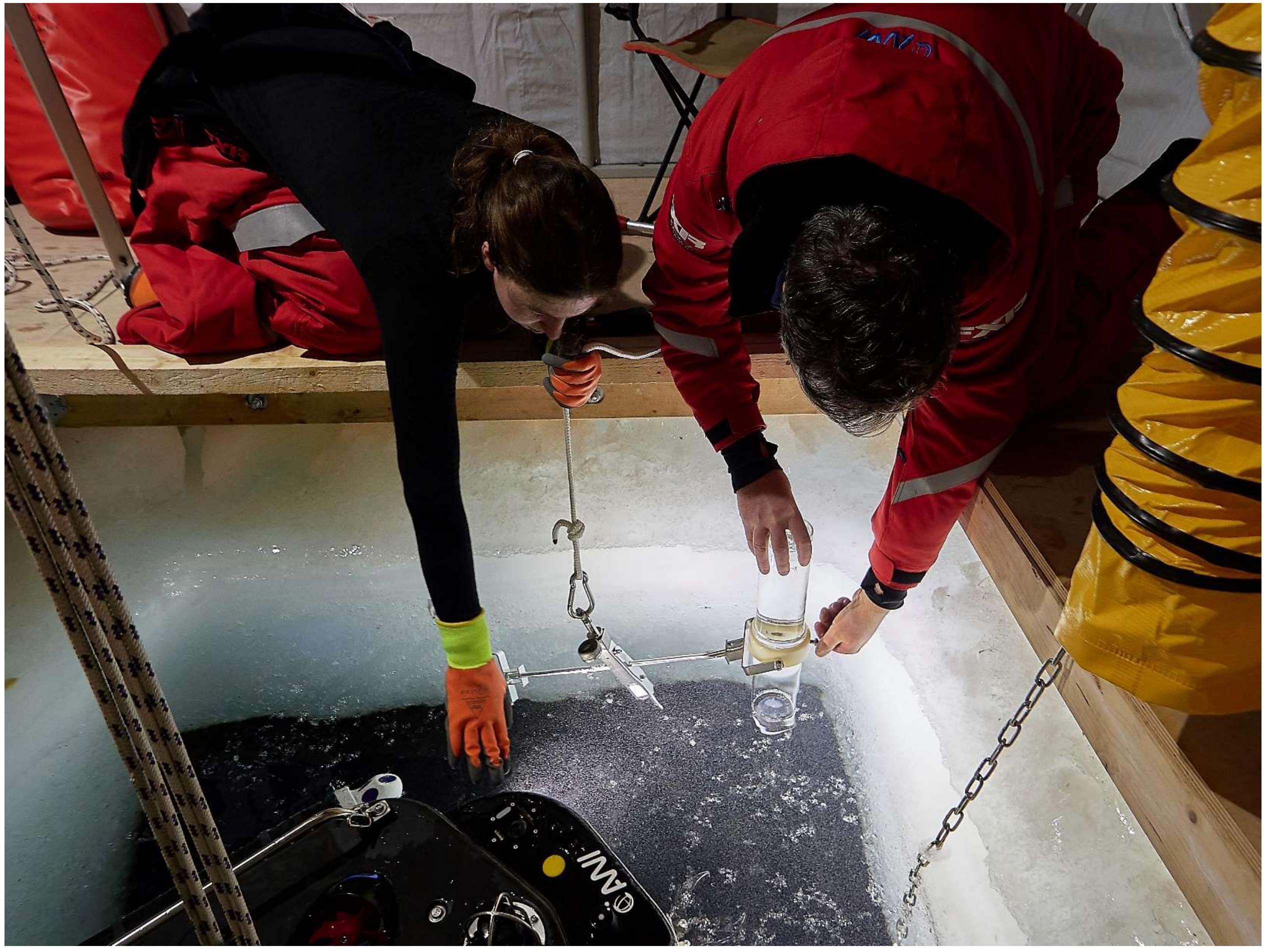
* AWI cluster Ollie

* Everyone that contributed over the last 10+ years to making MOSAiC a reality

photo: L. Piotrowski



Polarstern Tour – YouTube
https://www.youtube.com/watch?v=CKYJDQOZ5r0



Entnahme Wasserprobe photo by: Matthias Jaggi

MOSAiC leg2 photo by: Folke Mehrtens

Reopening CTD hole photo by: (c)Eric Brossier

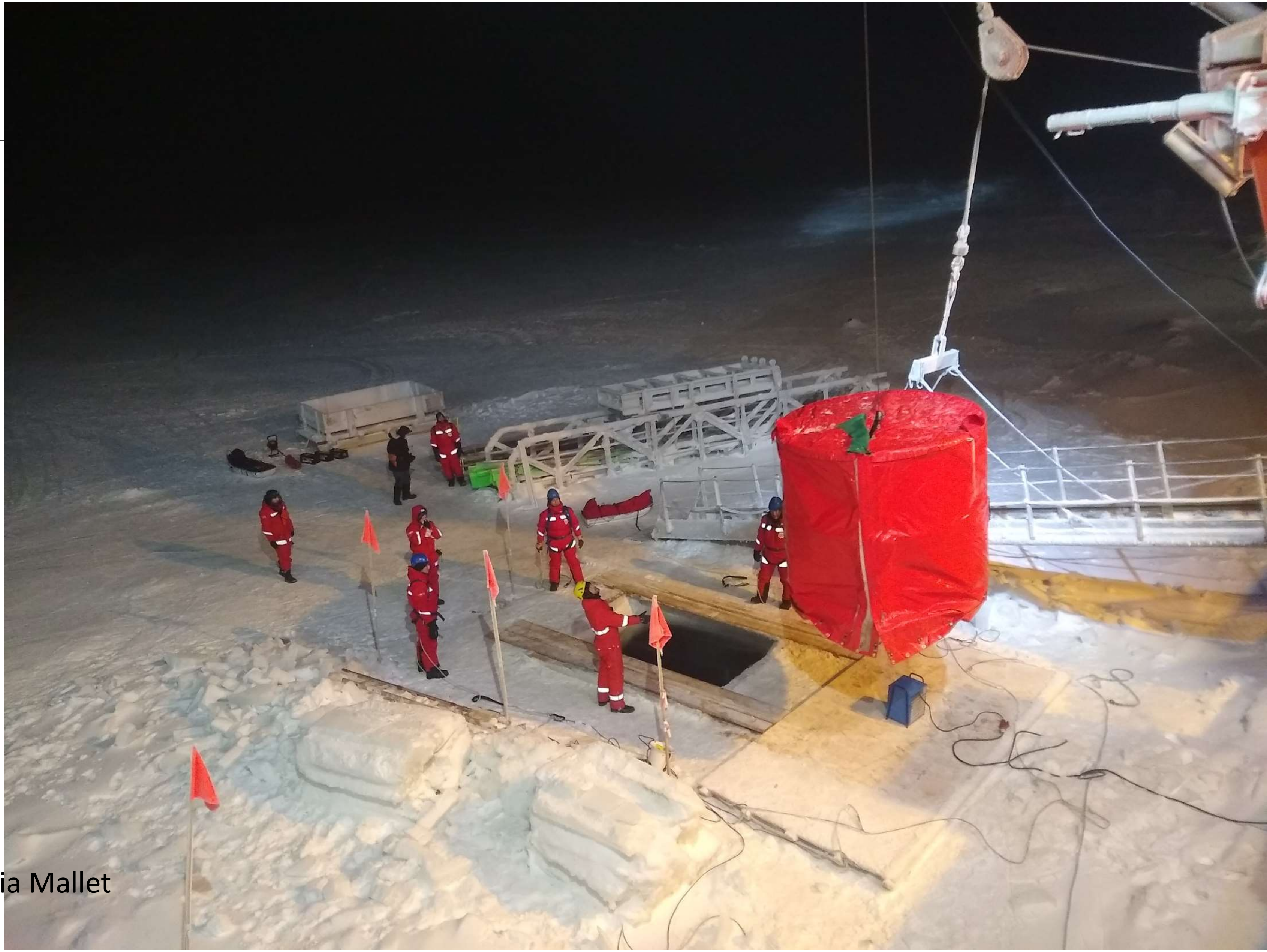


Photo by: Maria Mallet

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