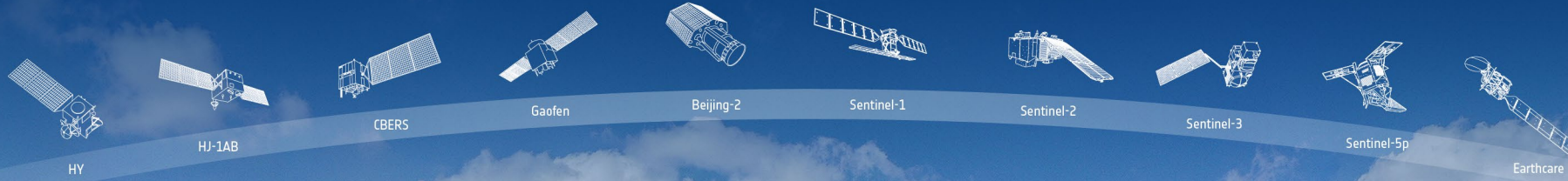




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# 2025 DRAGON 6 SYMPOSIUM

14-18 JULY 2025

[PROJECT ID. 95451]

[LOFOTEN BASIN EDDIES AND ITS INFLUENCE ON THE ATLANTIC WATER HEAT  
TRANSPORT TOWARDS THE ARCTIC (LOWA)]



# 2025 Dragon 6 Symposium



<16-JUL-2025>

ID. 95451

PROJECT TITLE: LOFOTEN BASIN EDDIES AND ITS INFLUENCE ON THE ATLANTIC WATER HEAT TRANSPORT TOWARDS THE ARCTIC (LOWA)

PRINCIPAL INVESTIGATORS: ROSHIN. P. RAJ (NANSEN ENVIRONMENTAL AND REMOTE SENSING CENTER, NORWAY),  
HUIZI DONG (SHANGHAI JIAO TONG UNIVERSITY, CHINA)]

CO-AUTHORS: NORWAY: J. A. JOHANNESSEN, A. BONADUCE, L. BERTINO, J. BRAJARD  
CHINA: MENG ZHOU, HUALING WANG, XINYI GU

PRESENTED BY: ROSHIN. P. RAJ



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The Geophysical Institute, University of Bergen.  
Founded in **1917** by **Bjørn Helland-Hansen**.



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## Ocean Eddies and Norway



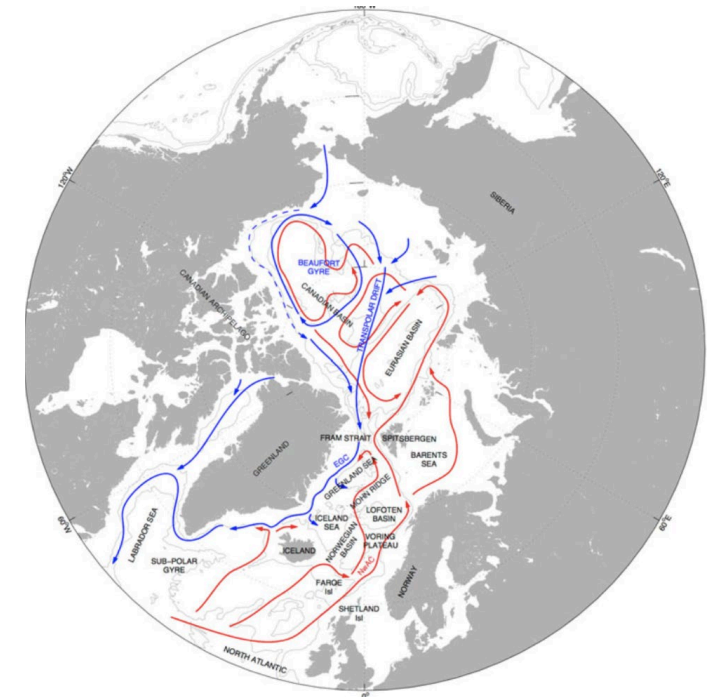
Bjørn Helland-Hansen and Fridtjof Nansen

Source: National Library of Norway

Ocean eddies were first reported as **puzzling waves** in the Norwegian Sea by Helland-Hansen and Nansen in 1909.



Helland-Hansen and Nansen, 1909





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SHANGHAI JIAO TONG  
UNIVERSITY



# Dragon 6 – LoWa Team



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Chinese PI: Huizi Dong

European PI: Roshin Raj



A. Bonaduce



J. Brajard



L. Bertino



J.A. Johannesen



M. Zhou



Hualing Wang



Xinyi Gu





Journal of Geophysical Research

RESEARCH ARTICLE Quantifying

10.1002/2016JC011637

R. P. Raj<sup>1</sup>, J. A. J.



OPEN ACCESS

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\*CORRESPONDENCE

Interaction Between

R. P. Raj<sup>1,2</sup>, I. Halo<sup>3,4</sup>,  
I. Bashmachnikov<sup>7,9</sup>

Dynamical Controls of the Eastward Transport of  
Overwintering *Calanus finmarchicus* From the Lofoten Basin  
to the Continental Slope

Huizi Dong<sup>1,2</sup>, Meng Zhou<sup>1</sup>, Walker O. Smith<sup>1,3</sup>, Baosheng Li<sup>4</sup>, Ziyuan Hu<sup>5</sup>,  
Sünnje L. Basedow<sup>6</sup>, Frank Gaardsted<sup>7</sup>, Zhaoru Zhang<sup>1</sup>, and Yisen Zhong<sup>1</sup>

JGR Oceans

RESEARCH ARTICLE  
10.1029/2020JC016102

Key Points:  
• Cyclonic drift of mesoscale eddies in  
the western Lofoten Basin resembles  
the pattern of the cyclonic gyre

JGR Oceans

RESEARCH ARTICLE  
10.1029/2022JC018909

Key Points:  
• Lagrangian Coherent Structures reveal  
persistent eastward transport between  
600 and 1,100 m depth in winter in  
the northern Norwegian Sea

Surface chlorophyll anomalies  
induced by mesoscale eddy-  
wind interactions in the  
northern Norwegian Sea

Huizi Dong<sup>1,2\*</sup>, Meng Zhou<sup>1\*</sup>, Roshin P. Raj<sup>3</sup>,  
Walker O. Smith Jr<sup>1,4</sup>, Sünnje L. Basedow<sup>5</sup>, Rubao Ji<sup>2</sup>,  
Carin Ashjian<sup>2</sup>, Zhaoru Zhang<sup>1</sup> and Ziyuan Hu<sup>6</sup>

JGR Oceans

RESEARCH ARTICLE  
10.1029/2021JC017408

Key Points:  
• We identified a transport barrier  
along the shelf break, trapping

Transport Barriers and the Retention of *Calanus  
finmarchicus* on the Lofoten Shelf in Early Spring

Huizi Dong<sup>1</sup>, Meng Zhou<sup>1</sup>, Ziyuan Hu<sup>2</sup>, Zhaoru Zhang<sup>1</sup>, Yisen Zhong<sup>1</sup>,  
Sünnje L. Basedow<sup>3</sup>, and Walker O. Smith Jr.<sup>1,4</sup>

International Journal of Remote Sensing

TYPE Original Research  
PUBLISHED 29 September 2022  
DOI 10.3389/fmars.2022.1002632

Homepage: <http://www.tandfonline.com/loi/tres20>

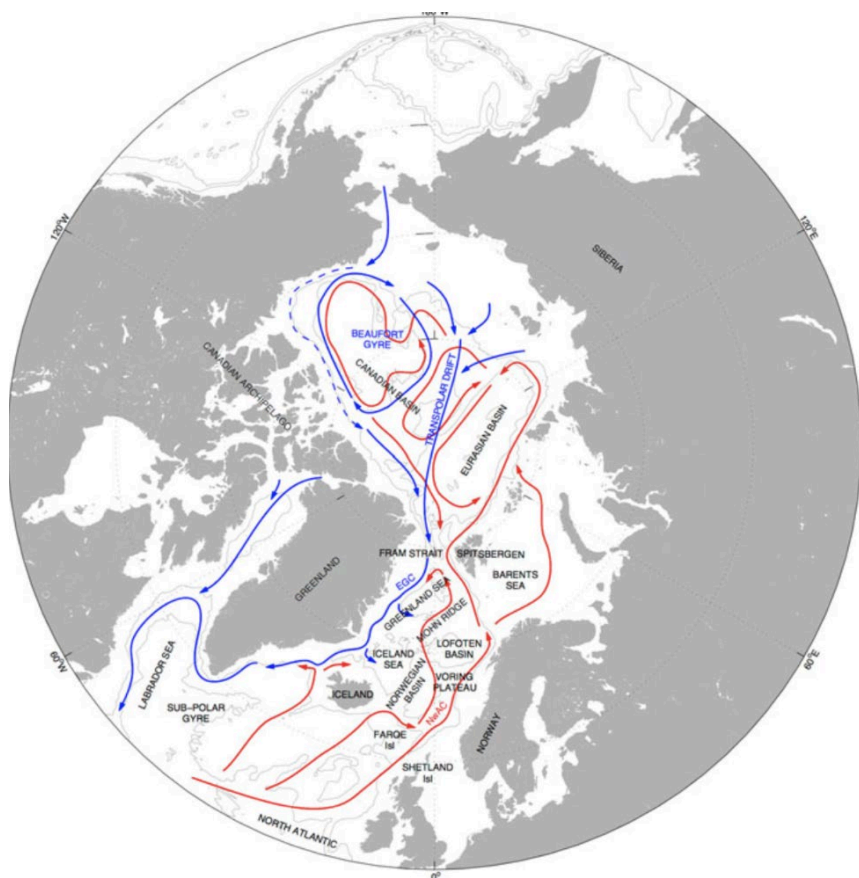
eddies of the Lofoten  
s, and challenges



ssufo Halo<sup>e,f</sup>



**The overall objective of LoWa** is to quantify the impact of ocean eddies on the heat transport across the Lofoten Basin affecting **Atlantification**.

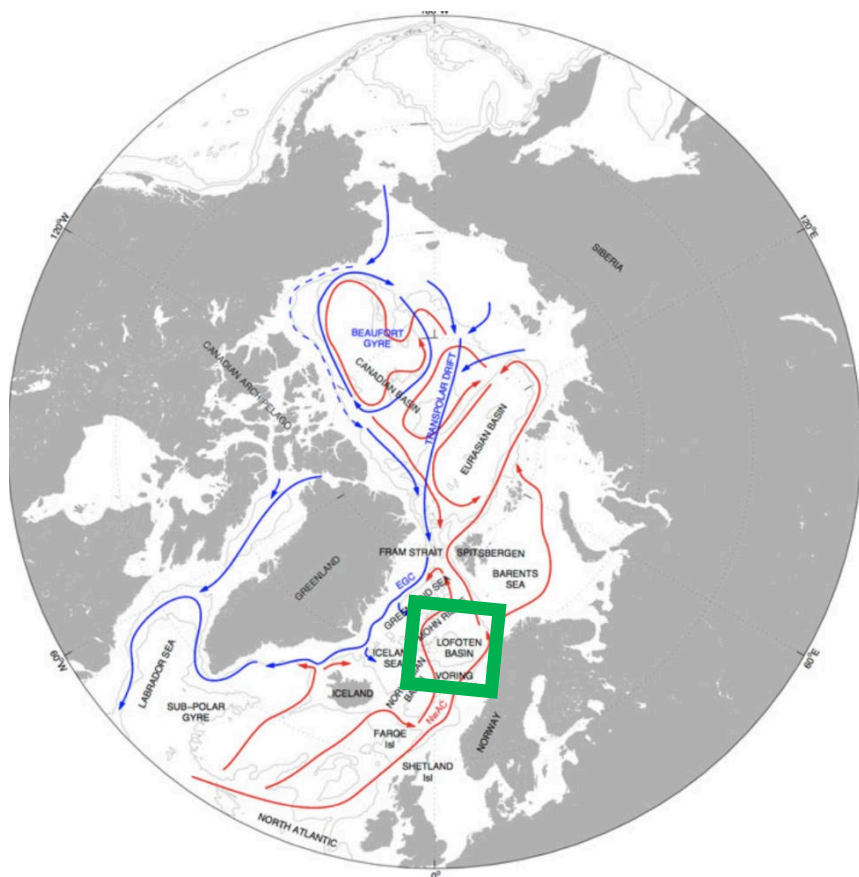


**Atlantification:** is a commonly used term for the increasing influence of Atlantic Water (AW) in the Arctic Ocean.

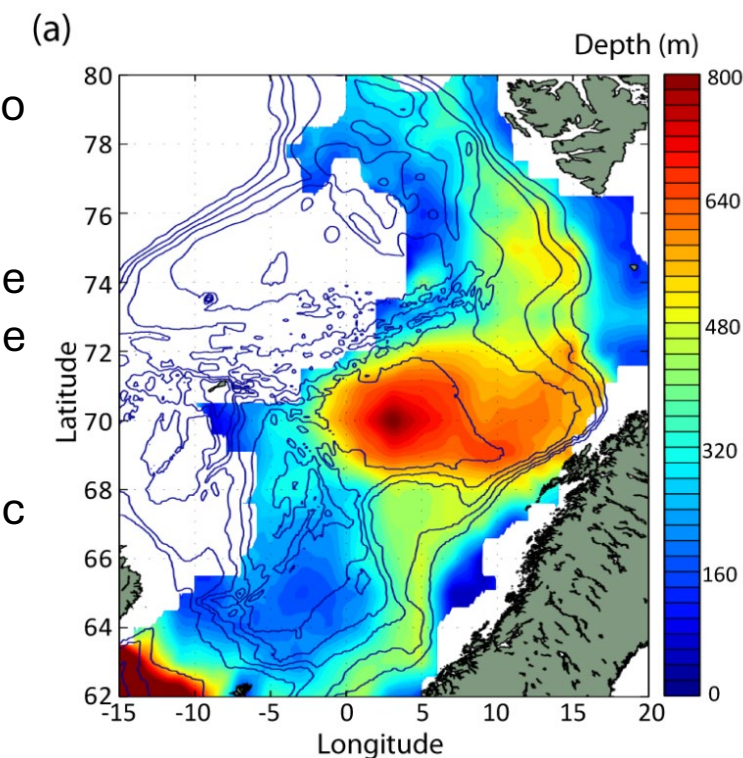
There is a wide range of ecosystem responses to Atlantification which includes increased production, borealization, changes in fish spawning, increased importance of the pelagic compartment populated by new species, and an increasingly connected food web



The overall objective of LoWa is to quantify the impact of ocean eddies on the heat transport across the **Lofoten Basin** affecting **Atlantification**.



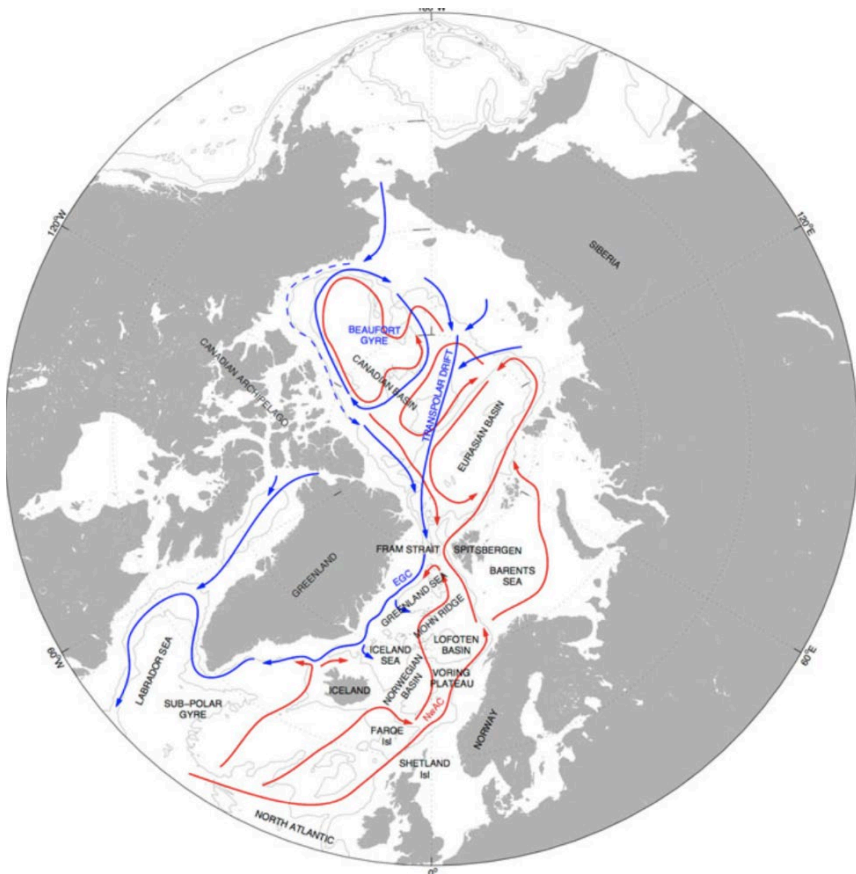
- Advective path of Atlantic Water into the Arctic
- Region where bulk of light to dense water formation takes place in the entire Nordic Seas
- Longer residence time of Atlantic Water
- Heat reservoir of the Nordic Seas
- Large winter heat loss



Depth of Atlantic Water in the Nordic Seas (Raj et al., 2015)



The overall objective of LoWa is to quantify the impact of **ocean eddies** on the heat transport across the **Lofoten Basin** affecting **Atlantification**.



- No mean flow into the Lofoten Basin
- Mesoscale eddies transport heat, salt and ocean biology
- Highest eddy active region in the entire Nordic Seas
- Eddies via transporting heat results in the cooling of the northward flowing Norwegian Atlantic Current.

# Ocean Eddies



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Ocean eddies. Image: NASA/GSFC Scientific Visualization Studio

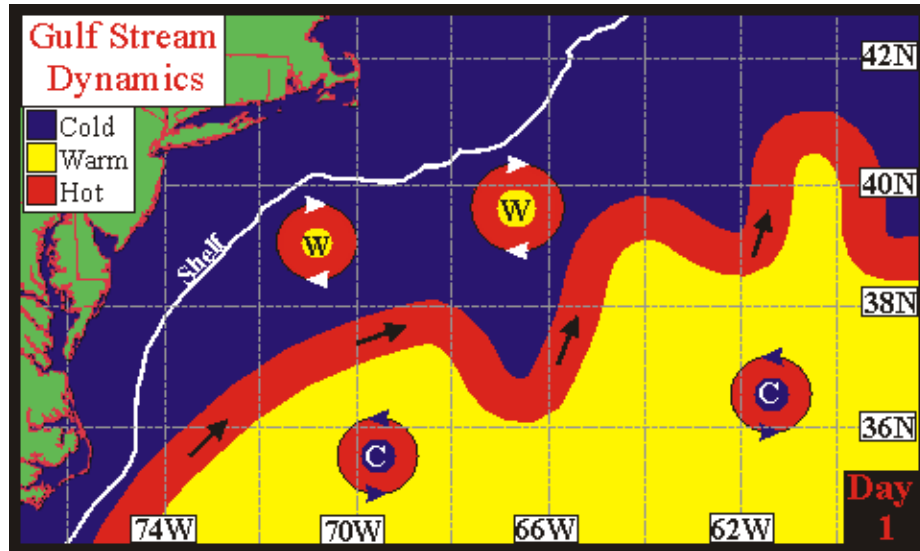
- Ubiquitous features of the ocean
- Vortices or flows :  $L_R$  – 100's km

In physical Oceanography,  $L_R$ , the Rossby radius of deformation, is the length scale at which rotational effects becomes important in the evolution of a flow.



## Instabilities of the mean flow

[Stammer and Wunsch, 1999]



## Fluctuating winds

[Frankignoul and Muller, 1979]



- Feed **momentum and energy back** into the mean flow [Morrow et al., 1994; Lozier, 1997].
- Total oceanic heat and salt transport by **advective trapping** [Dong et al., 2014]

## Specific objectives:



- Objective 1:** Strengthen co-variability analyses of the 2D surface expression of the meso- and sub-mesoscale eddies from satellite sensor synergy including novel satellite missions and remote-sensing retrievals;
- Objective 2:** Apply a Data-driven approach to advance the 2D to 3D characterisation of meso- and sub-mesoscale eddies from colocation of satellite observations and Argo profiling floats also sampled at high frequency.
- Objective (3):** Conduct 4D reconstructions based on machine learning experiments combining observations and model fields
- Objective (4):** Study the patterns and dynamical processes in the enhancement of submesoscale pumping and vertical heat transport at the edge of eddies induced by geostrophic deformation field
- Objective (5):** Study the energy source that sustain the occurrence of submesoscale dynamical processes at the edge of ACEs and CEs, as well as their seasonal characteristics
- Objective (6):** Quantify the AW heat transport in and out of the Lofoten Basin.

## Specific objective 1:



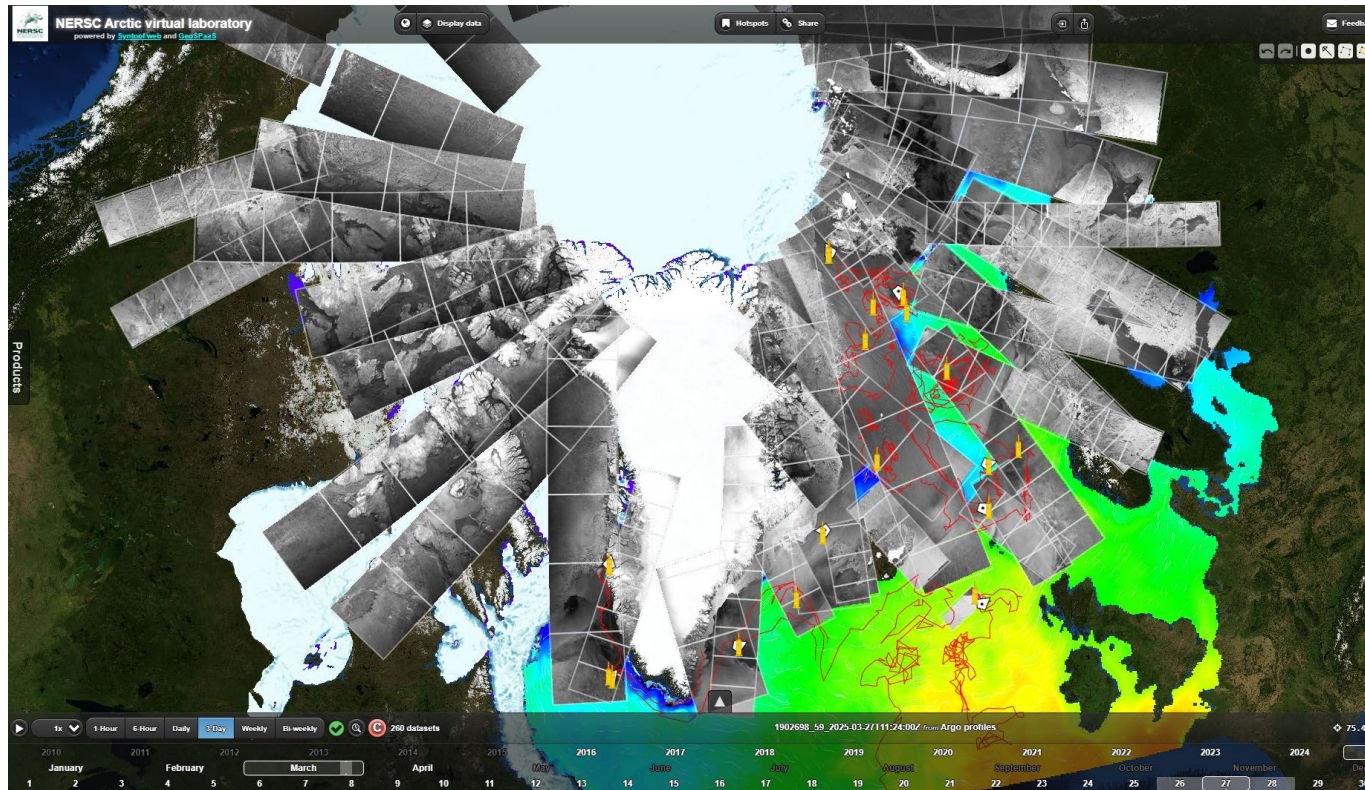
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**Specific Objective 1:** Strengthen co-variability analyses of the 2D surface expression of the meso- and sub-mesoscale eddies from satellite sensor synergy including novel satellite missions and remote-sensing retrievals;

### NERSC Arctic Virtual Laboratory (NARVAL)

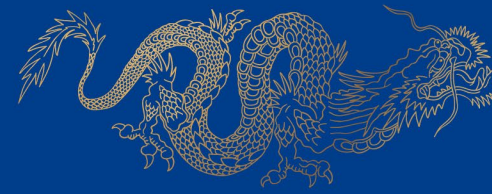


- Visualisation portal for Earth data
- Based on:
  - o NERSC's GeoSPaaS cataloguing system
  - o Oceandatalab's Syntool interface
- Automatic daily updates
- 1 month retention + 10 days forecast
- Publicly available since winter 2023
- <https://narval.nerisc.no/>
- Uses:
  - o Data discovery
  - o Dissemination
  - o education

<https://narval.nerisc.no/>



# Specific objective 1: Results:



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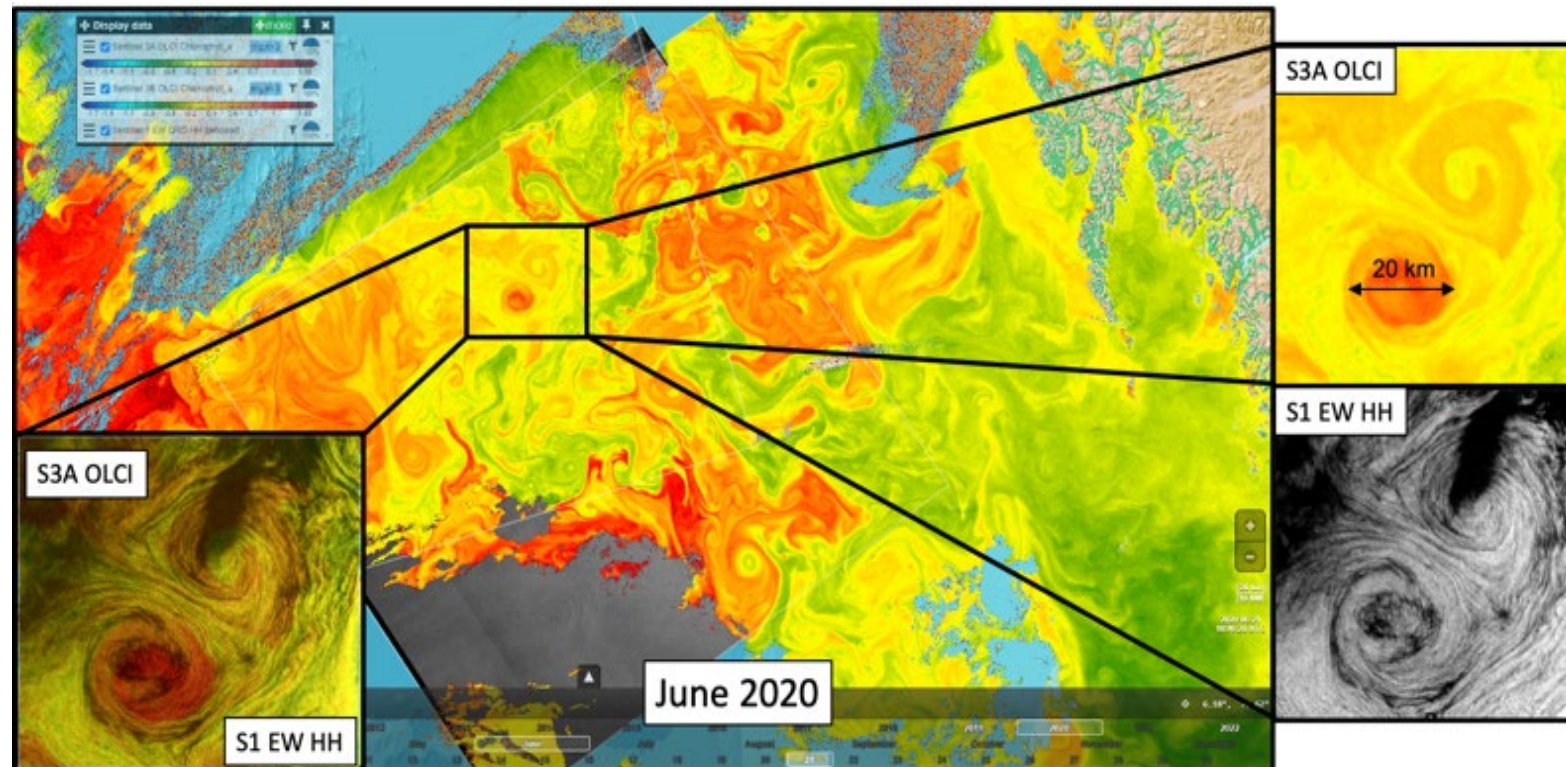


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## Paper 1 (in prep) : Advancing Mesoscale Eddy Characterization in the Lofoten Basin Using Satellite Sensor Synergy and Machine Learning Approaches

M. Babiker, [A. Bonaduce](#), [R. P. Raj](#), T. Wakamatsu , A. Moiseev, A. Perrin, [J. A. Johannessen](#)

Collaboration with ESA Prodex Project (4000135226)



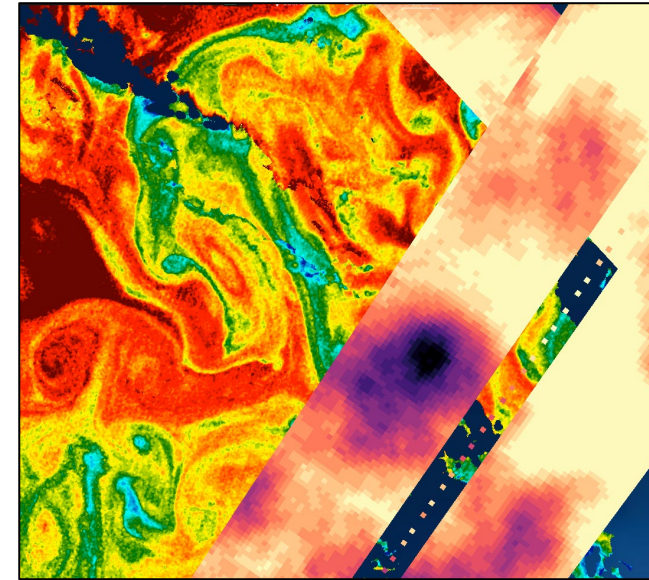
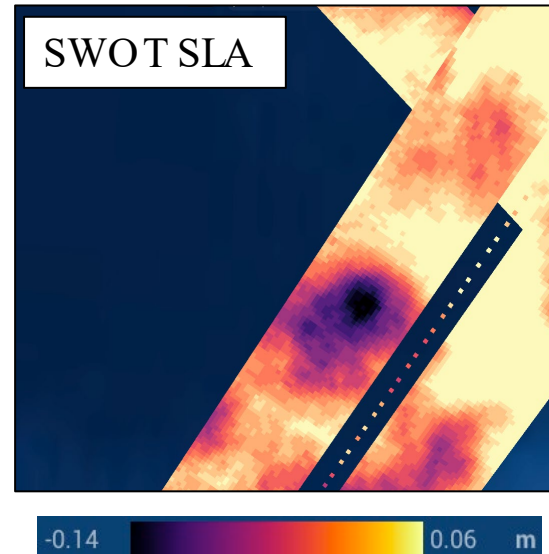
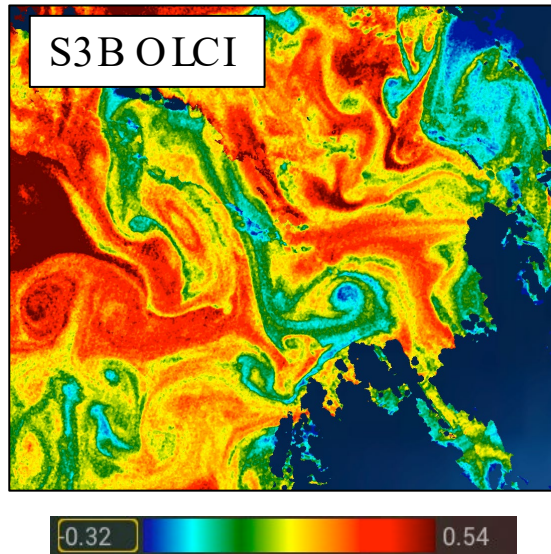
# Specific objective 1: Results:



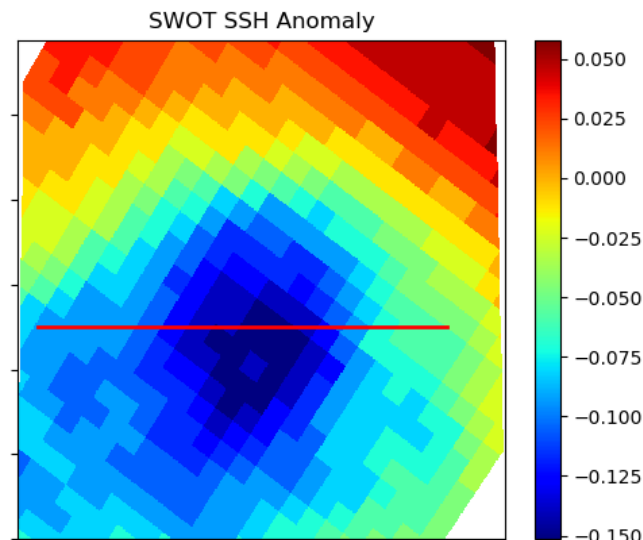
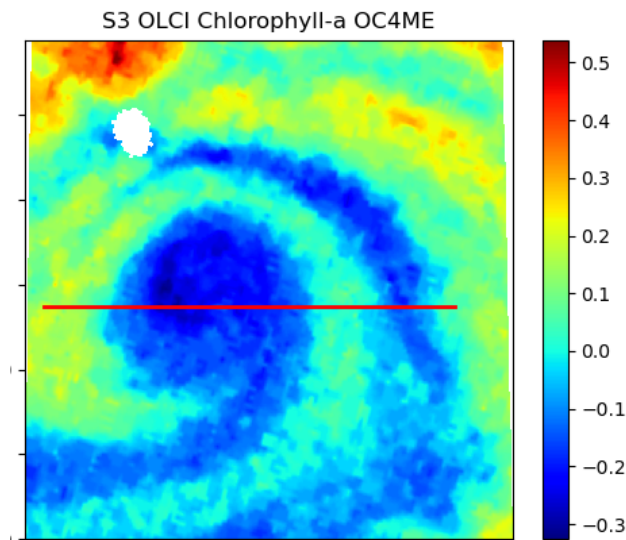
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S3 and SWOT  
time separation  
~ 5 hours



Collocation SWOT and Sentinel-3 Chl-a on 6  
June 2024

Babiker et al., in prep 2025

# Specific objective 1: Results:



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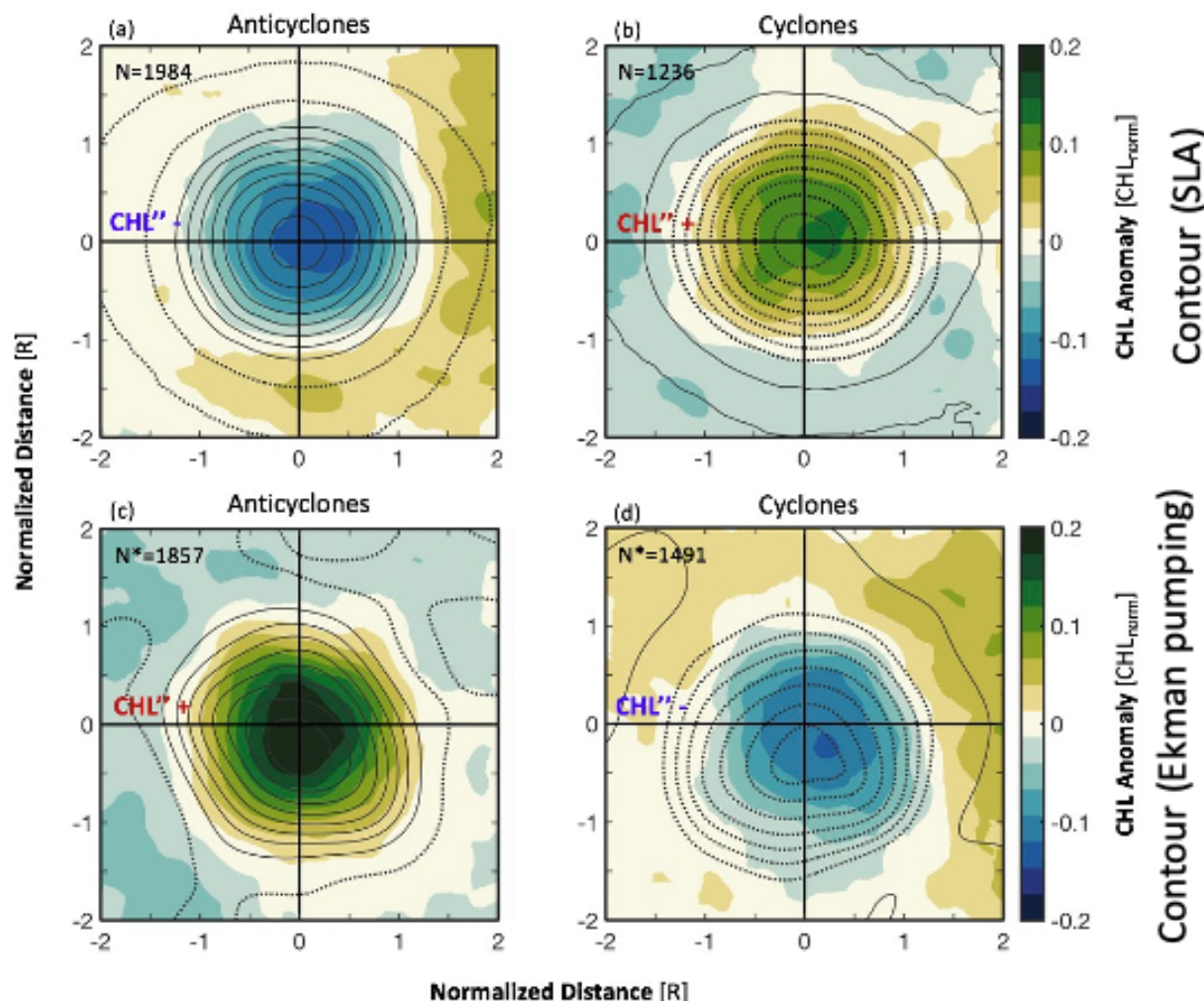


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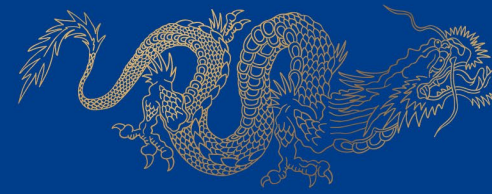
## Eddy-induced Ekman Pumping

Interaction between eddy surface currents and winds, to generate upwelling (downwelling) in anticyclones (cyclones).

**Composite** averages of eddy-centric **CHL anomalies** for (a) Type-I ACE, (b) Type-I CE, (c) Type-II ACE, and (d) Type-II CE for the period 2000-2020. The  $x$  and  $y$  coordinates of the composite averages are normalized by the **eddy radius** ( $R$ ).  $N$  and  $N^*$  represent the **number** of eddy observations for constructing the composite averages in Type-I and Type-II eddies, respectively



Eddy-Ekman pumping (Dong et al., 2022)



## Eddy-Ekman pumping effect

Without wind

Cyclonic Eddy (CE)

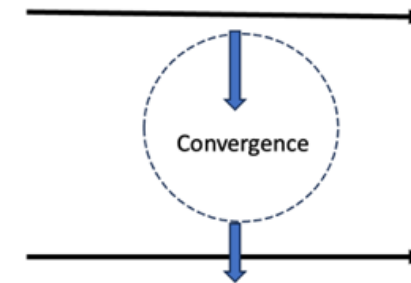


Upwelling, more nutrients  
Positive Chl anomaly

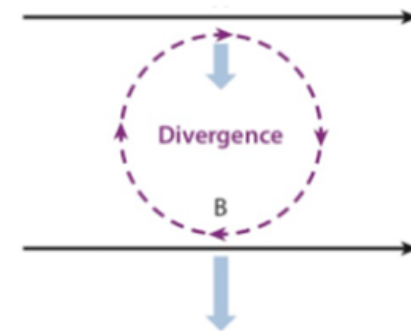
Anti-Cyclonic Eddy (ACE)



Downwelling  
Negative Chl anomaly



→ Wind  
→ Eddy orbital motion  
→ Ekman transport



With wind effect



Downwelling effect  
Negative Chl anomaly



Upwelling effect, more nutrients  
Positive Chl anomaly

Dong et al., 2022

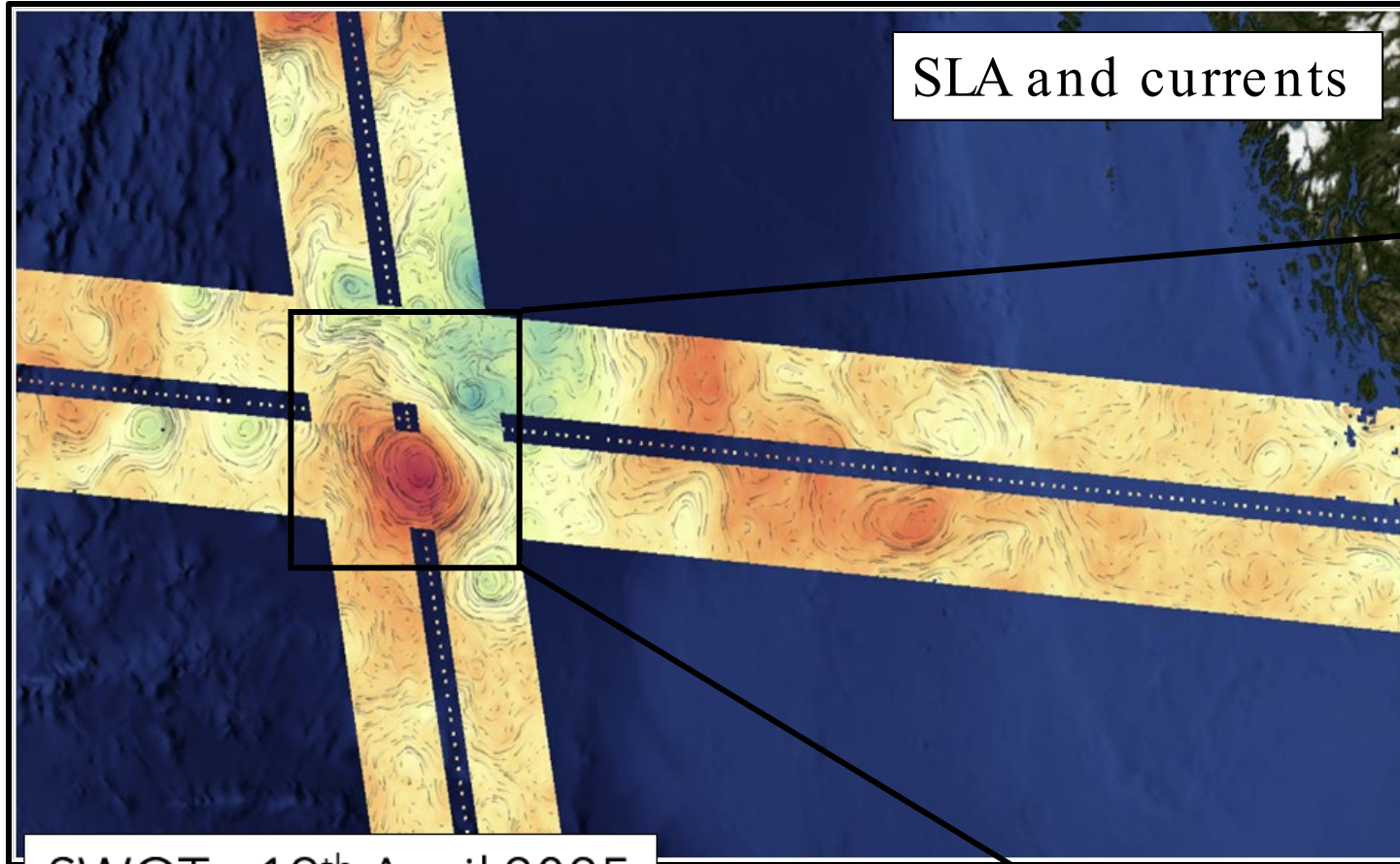
# Specific objective 1: Results:



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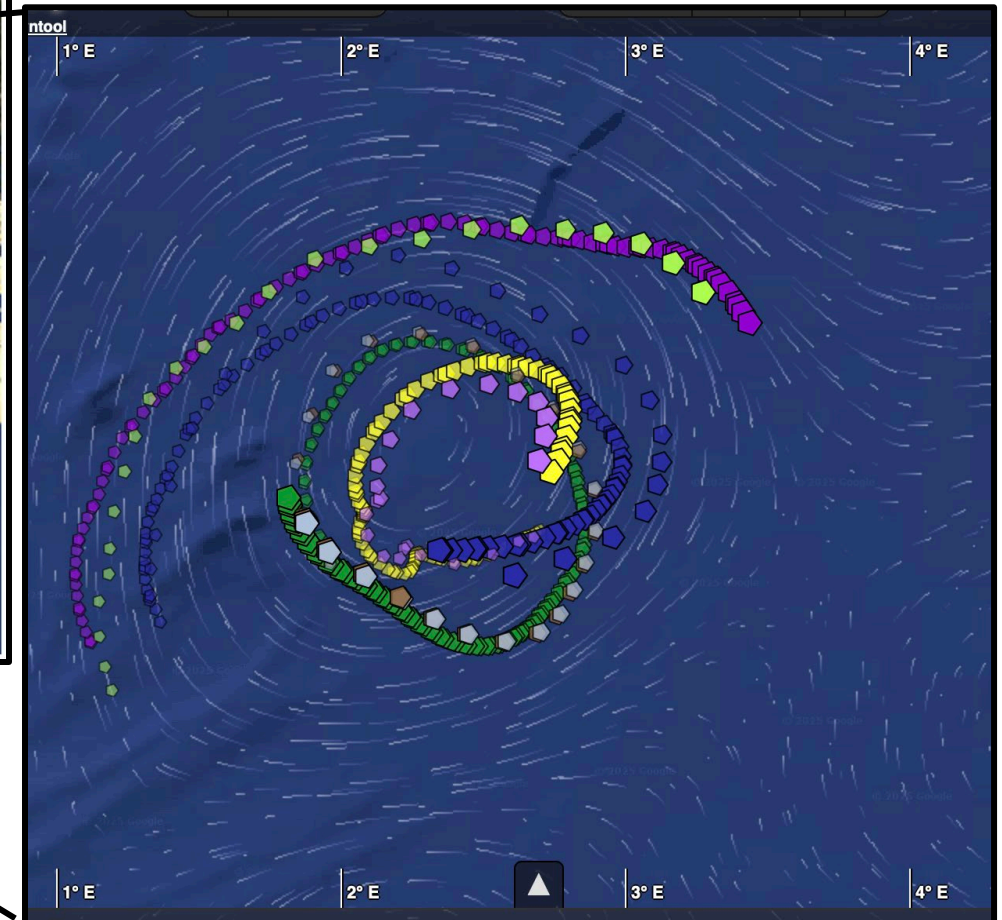
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SWOT - 19<sup>th</sup> April 2025

## Lofoten Vortex – April 2025

Drift pattern of six drifters deployed in the Lofoten gyre centered at 70 N



The Lofoten vortex is long lived mesoscale features, showing a prominent signature in the 2025 data

Babiker et al., in prep 2025

## Specific objective 2:

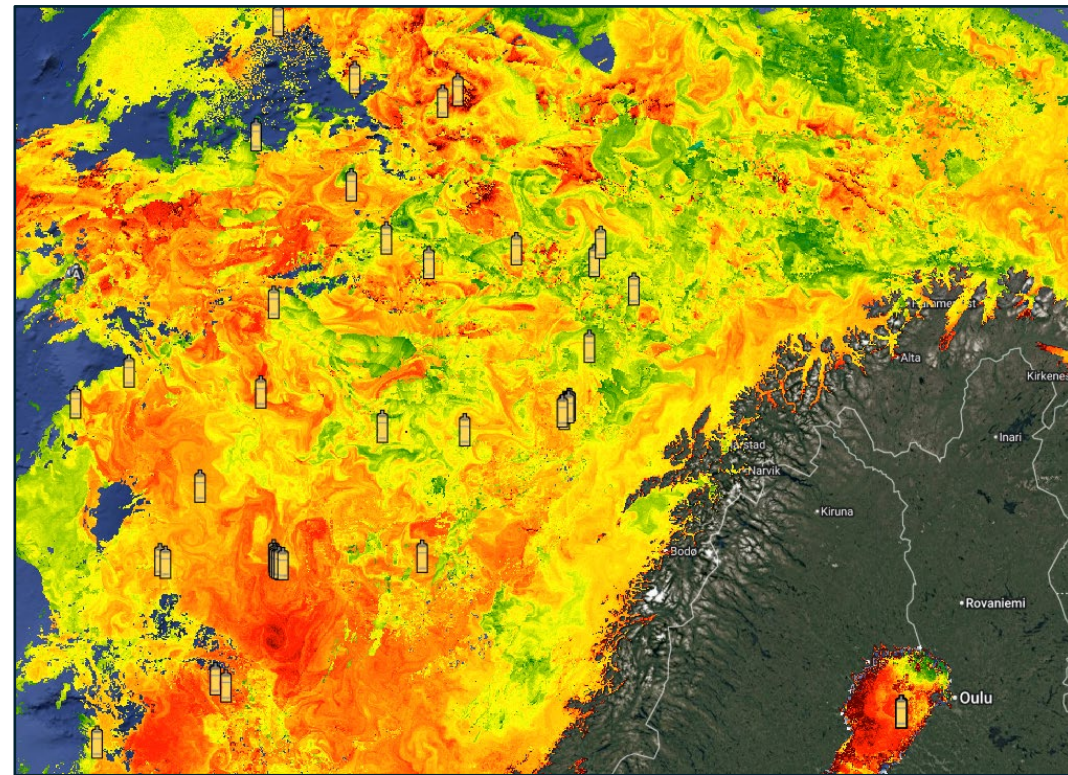
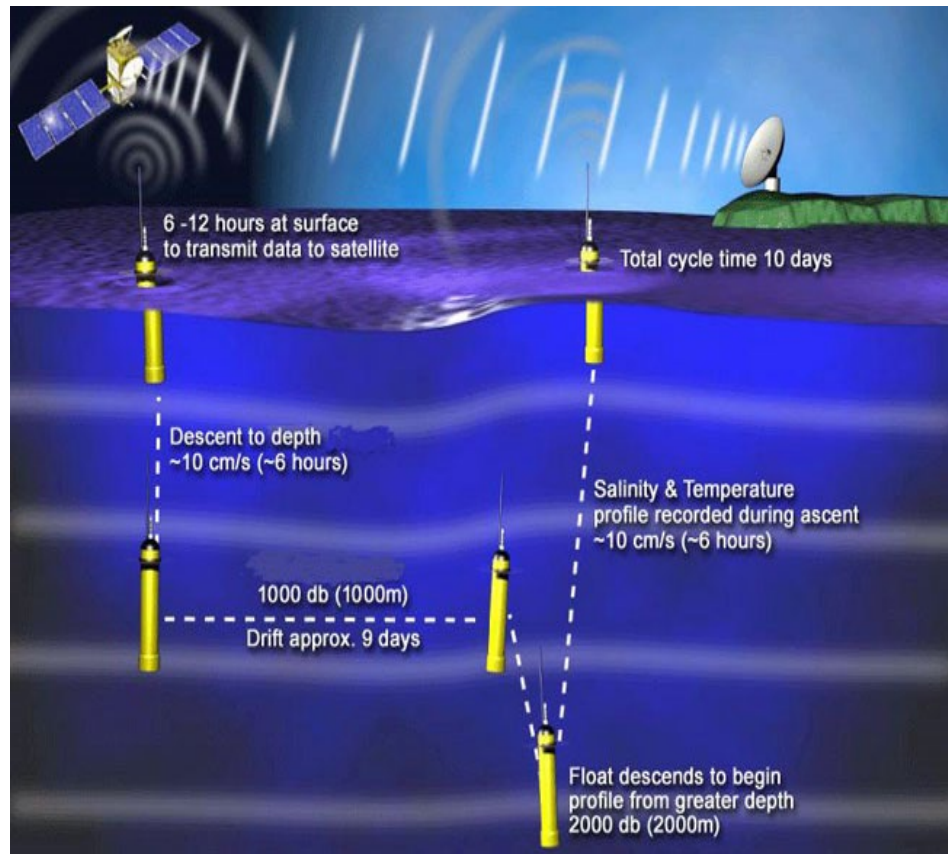


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**Objective 2:** Apply a Data-driven approach to advance the 2D to 3D characterisation of meso- and sub-mesoscale eddies from collocation of satellite observations and Argo profiling floats.



7-day composite Chlorophyll-a concentration (mg/m<sup>3</sup>) from Sentinel-3 OLCI data, centered on June 6, 2024 with Argo float positions overlaid.

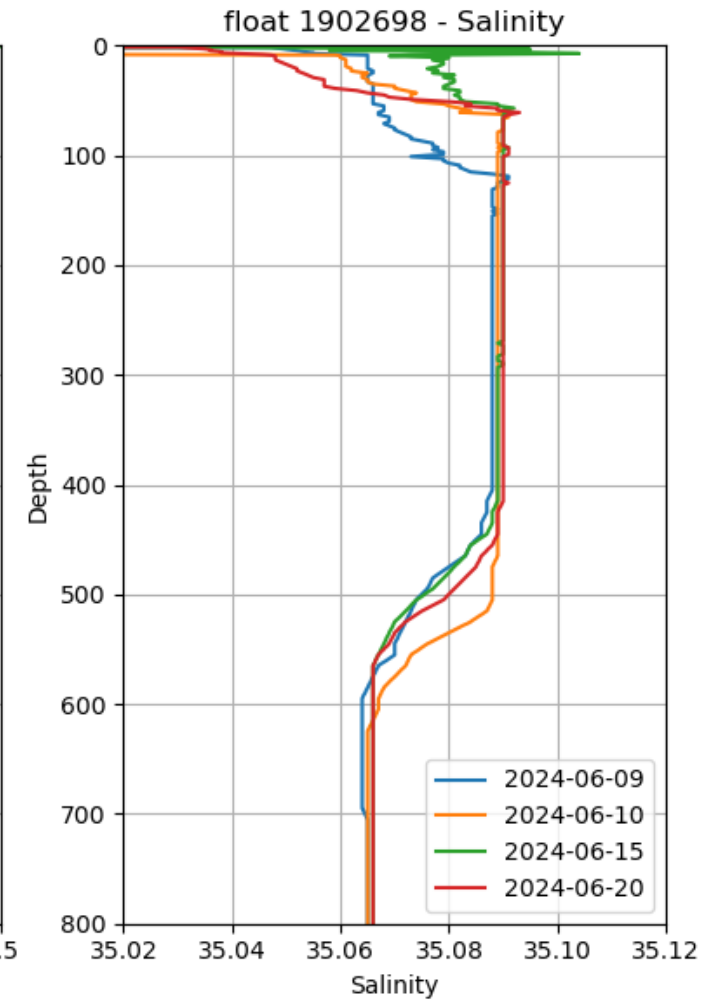
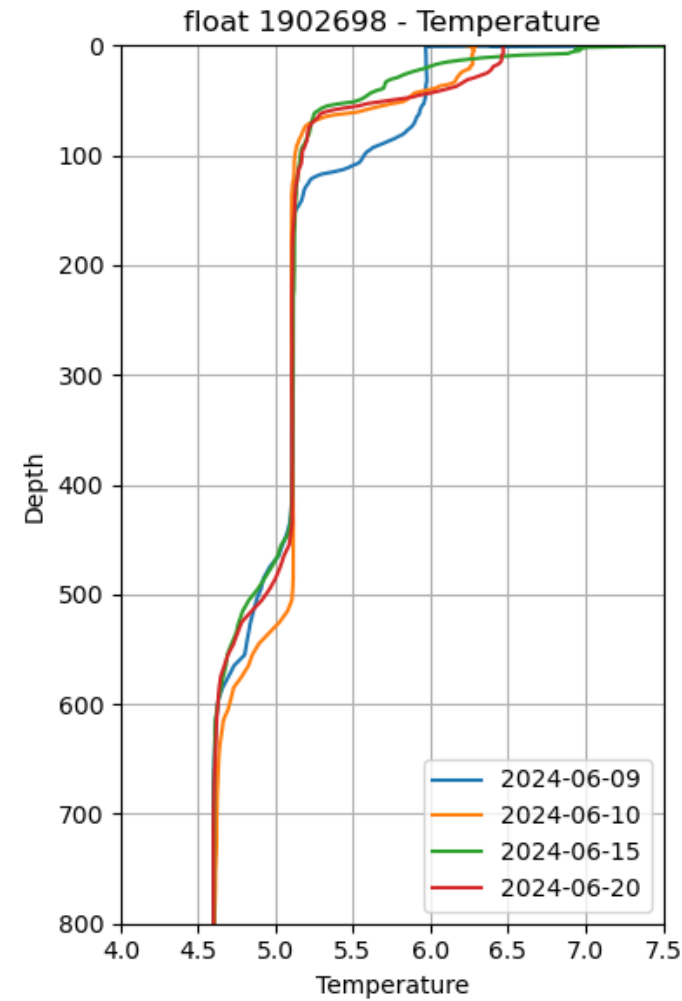
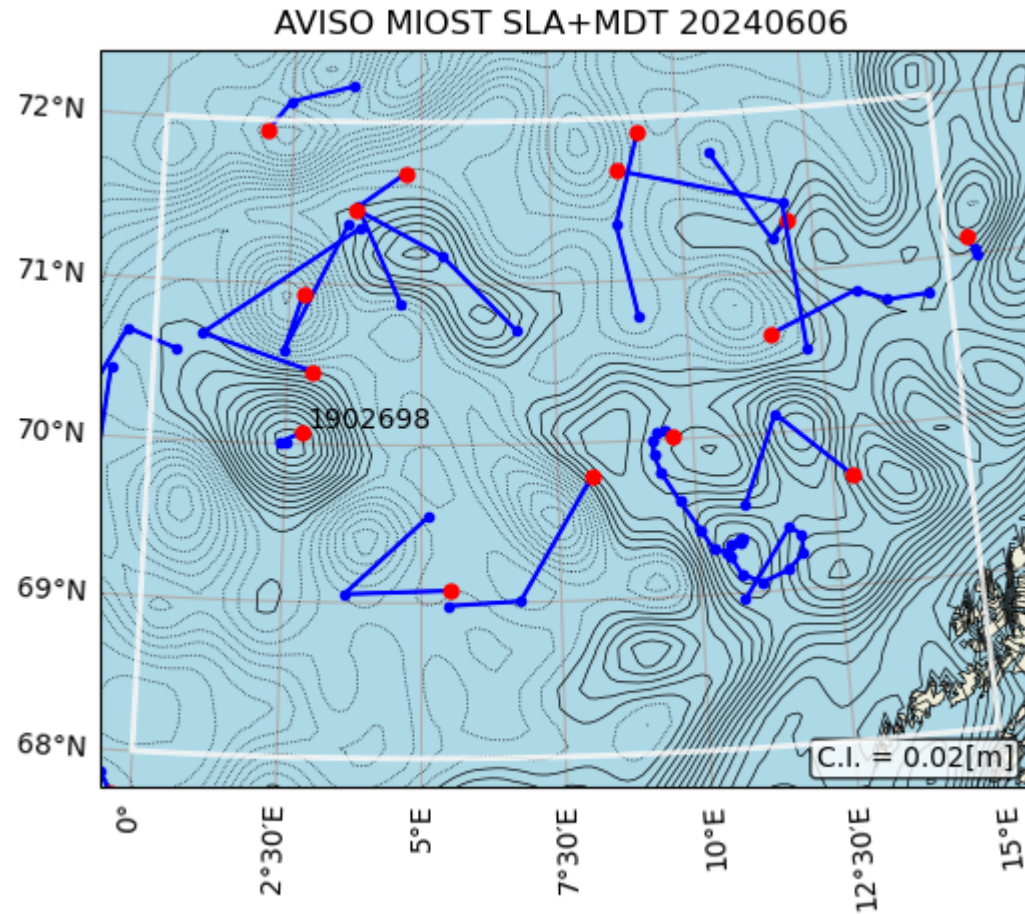
## Specific objective 2: Results:



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Babiker et al., in prep 2025

## Specific objective 2: Results:



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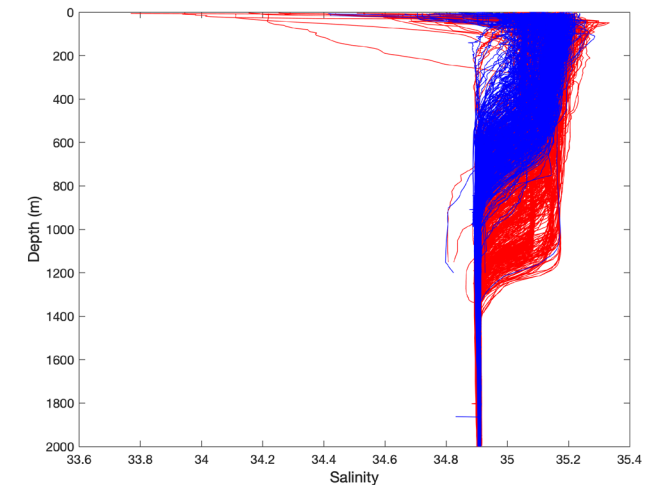
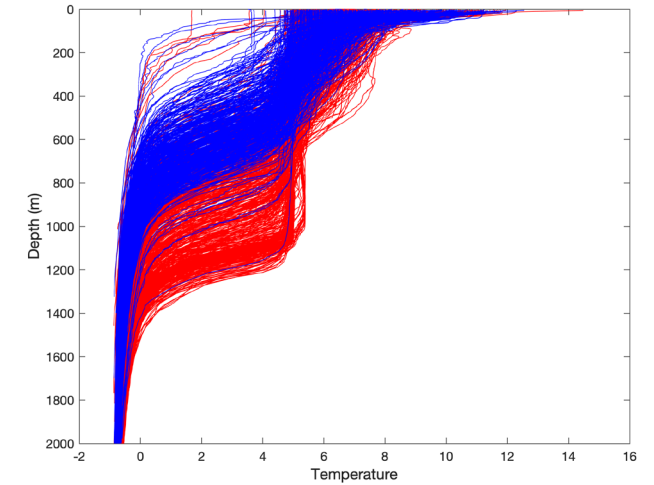
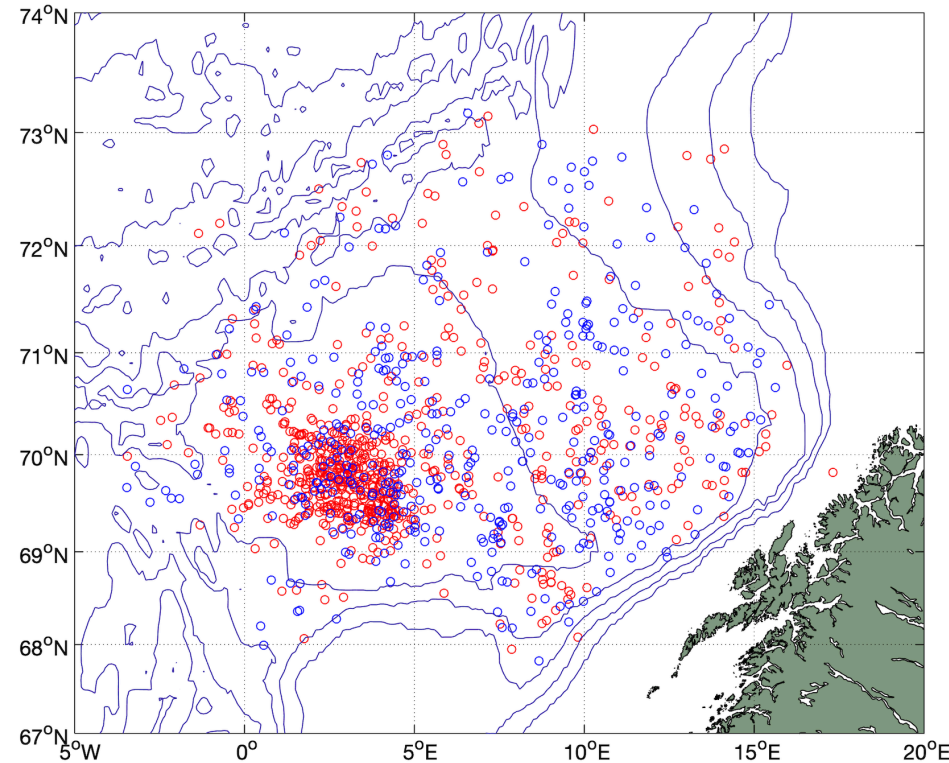
Paper 2 (in prep):

## Freshening of the Lofoten Basin and the role of eddies

R.P. Raj, H. Dong, A. Bonaduce et al.

- Collocation with  
Argo profiling  
floats

Argo floats collocated within  
anticyclonic eddies (red)  
and cyclonic eddies (blue)



## Specific objective 2: Results:

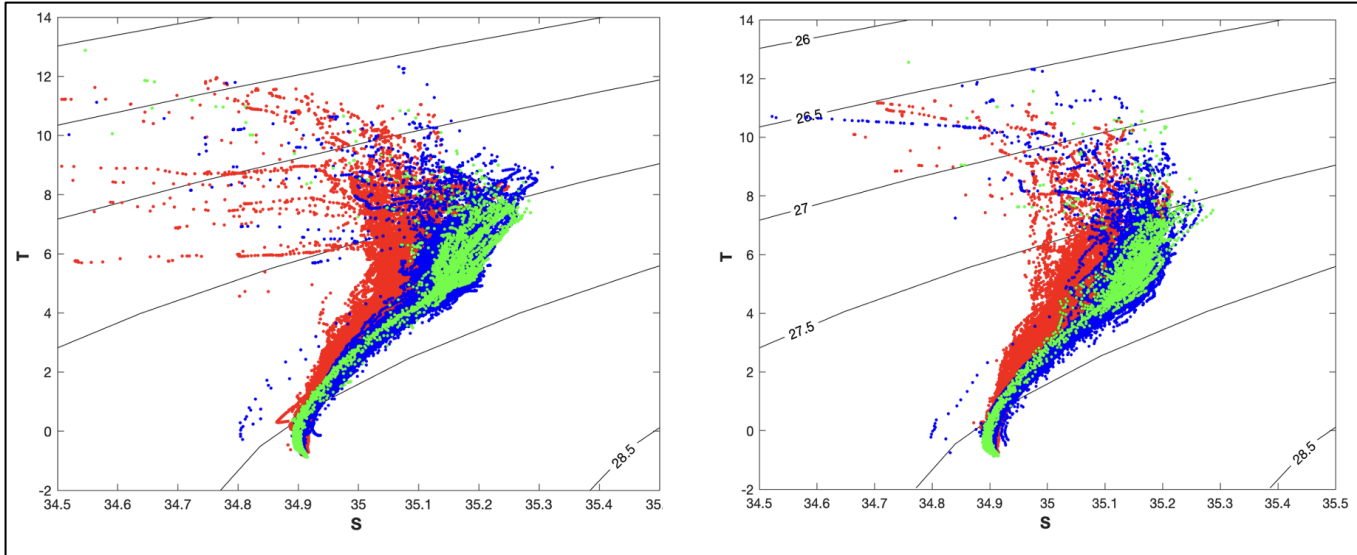


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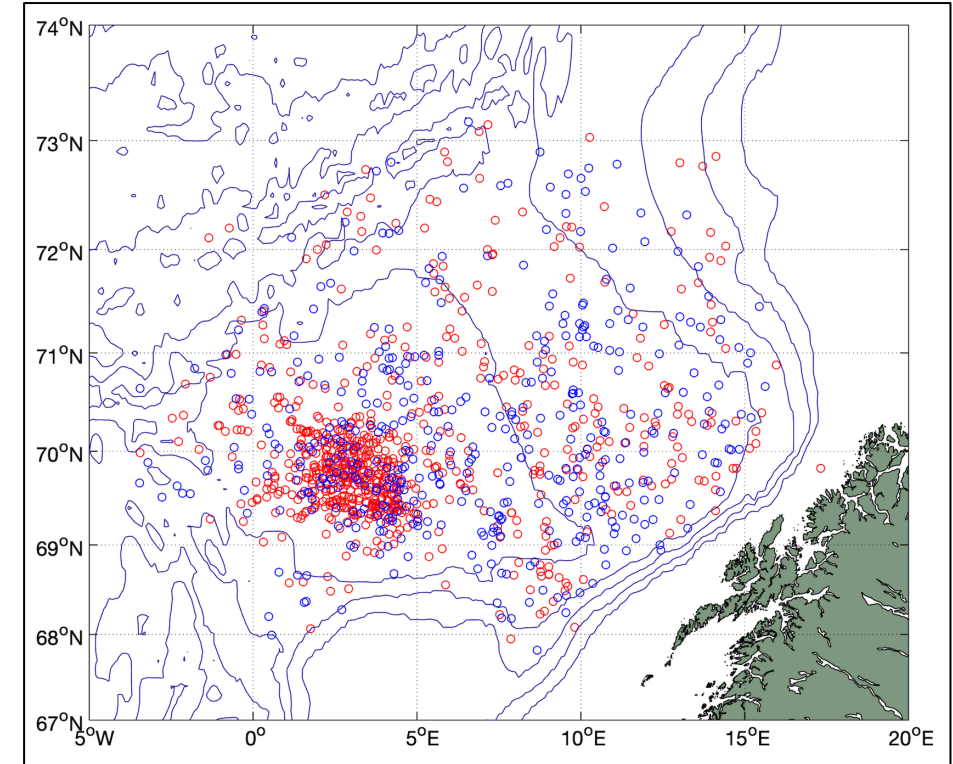
- Collocation with Argo profiling floats  
(Raj et al. 2025 in preparation)



2016-2020

2011-2015

2006-2010

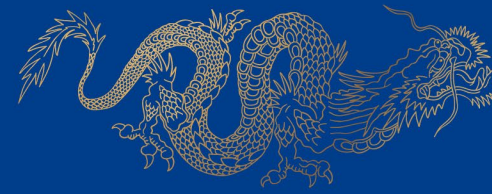


 **Holliday et al., 2020**

ARTICLE  
<https://doi.org/10.1038/s41467-020-14474-y> **OPEN**

Ocean circulation causes the largest freshening event for 120 years in eastern subpolar North Atlantic

# Specific objective 2: Results:



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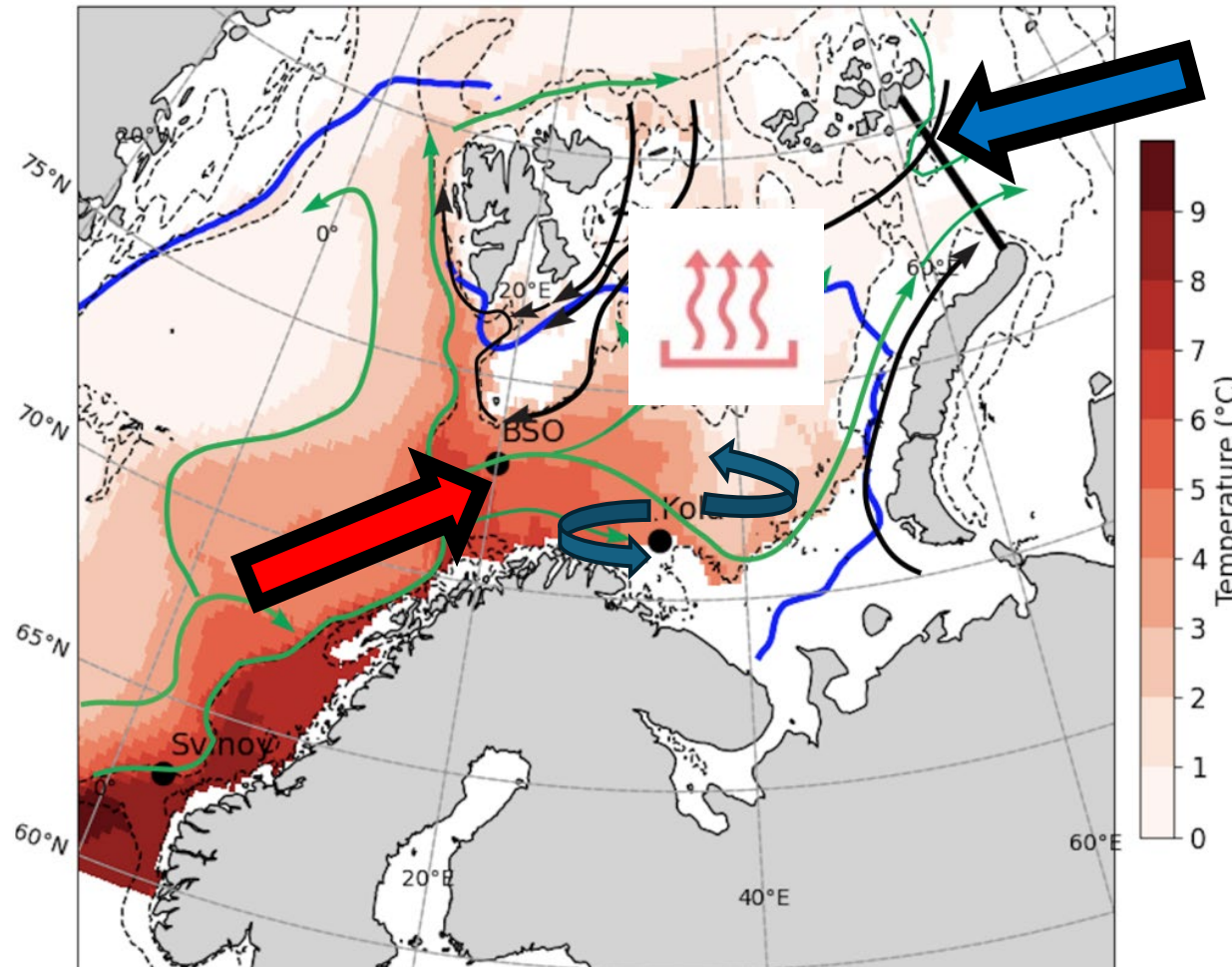


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Paper 3 (in prep): Eddies and Marine Heat Waves in the Barents Sea

X. Gu\*, H. Dong, R. P. Raj et al.

Ocean eddies



## Ocean State Report, 2024

Surface and bottom marine heatwave characteristics  
in the Barents Sea: a model study

Vidar S. Lien ✉, Roshin P. Raj, and Sourav Chatterjee

nature communications



Article

<https://doi.org/10.1038/s41467-023-38811-z>

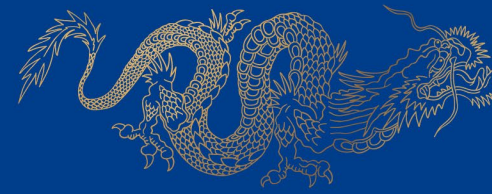
## Oceanic mesoscale eddies as crucial drivers of global marine heatwaves

Received: 5 January 2023

Accepted: 16 May 2023

Ce Bian<sup>1,2</sup>, Zhao Jing<sup>1,2</sup> ✉, Hong Wang<sup>1,2</sup>, Lixin Wu<sup>1,2</sup>, Zhaohui Chen<sup>1,2</sup>,  
Bolan Gan<sup>1,2</sup> & Haiyuan Yang<sup>1,2</sup>

# Specific objective 2: Results:



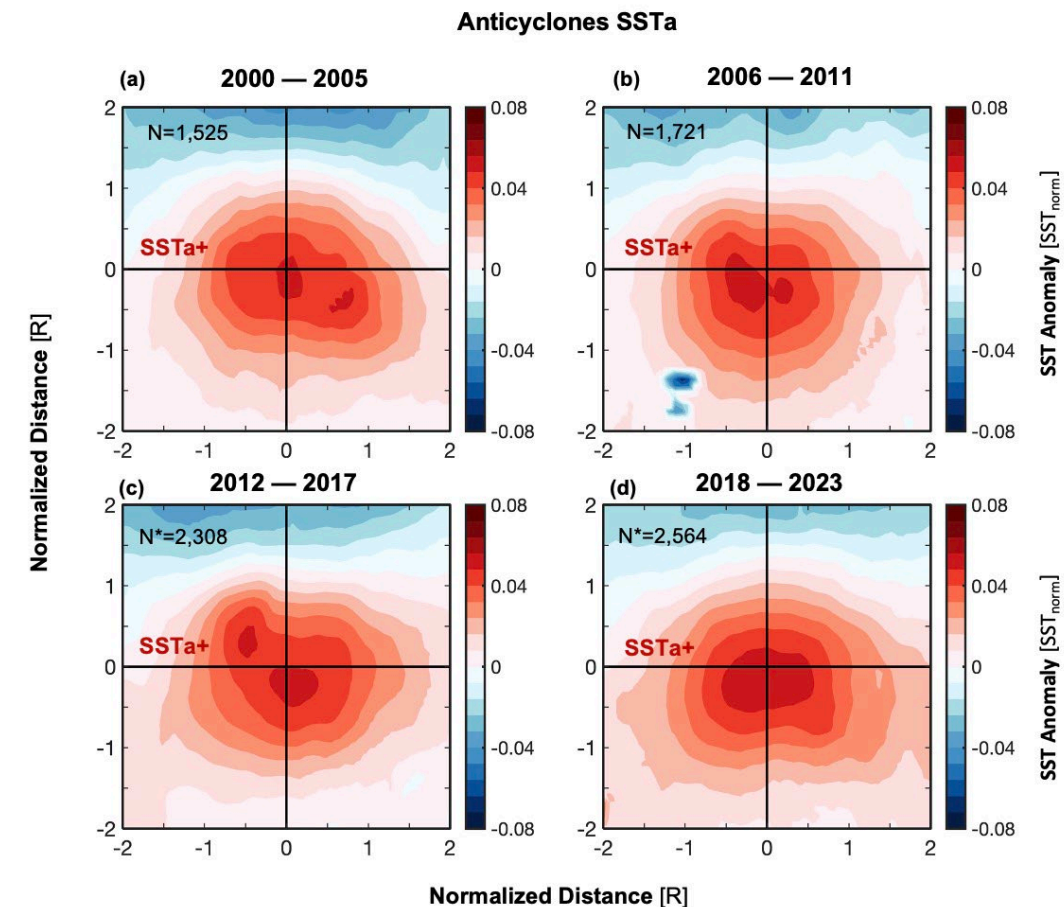
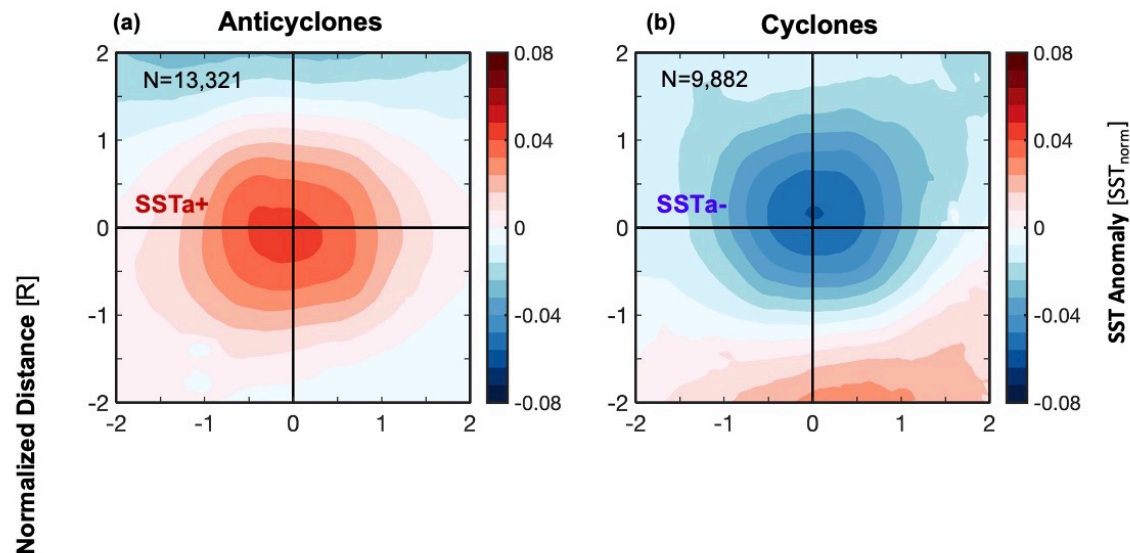
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Hybrid Eddy detection and tracking: Raj et al., 2015, 2016, 2020  
Ekman pumping & Eddy Pumping : Dong et al., 2022

2000-2023 SST anomalies





**Objective (4):** Study the patterns and dynamical processes in the enhancement of submesoscale pumping and vertical heat transport at the edge of eddies induced by geostrophic deformation field

### **Paper 4 (in review) : Warm Rings in Mesoscale Eddies in a Cold Straining Ocean**

Huizi Dong, Meng Zhou, James C. McWilliams, Roshin P. Raj, Francesco d'Ovidio, Ilker Fer, Lixin Qu, Bo Qiu, Lia Siegelman, Zhengguang Zhang, Walker O. Smith, Jr., Ann Kristin Sperrevik

In review (3<sup>rd</sup> round): Nature Communications

# Specific objective 4: Results:

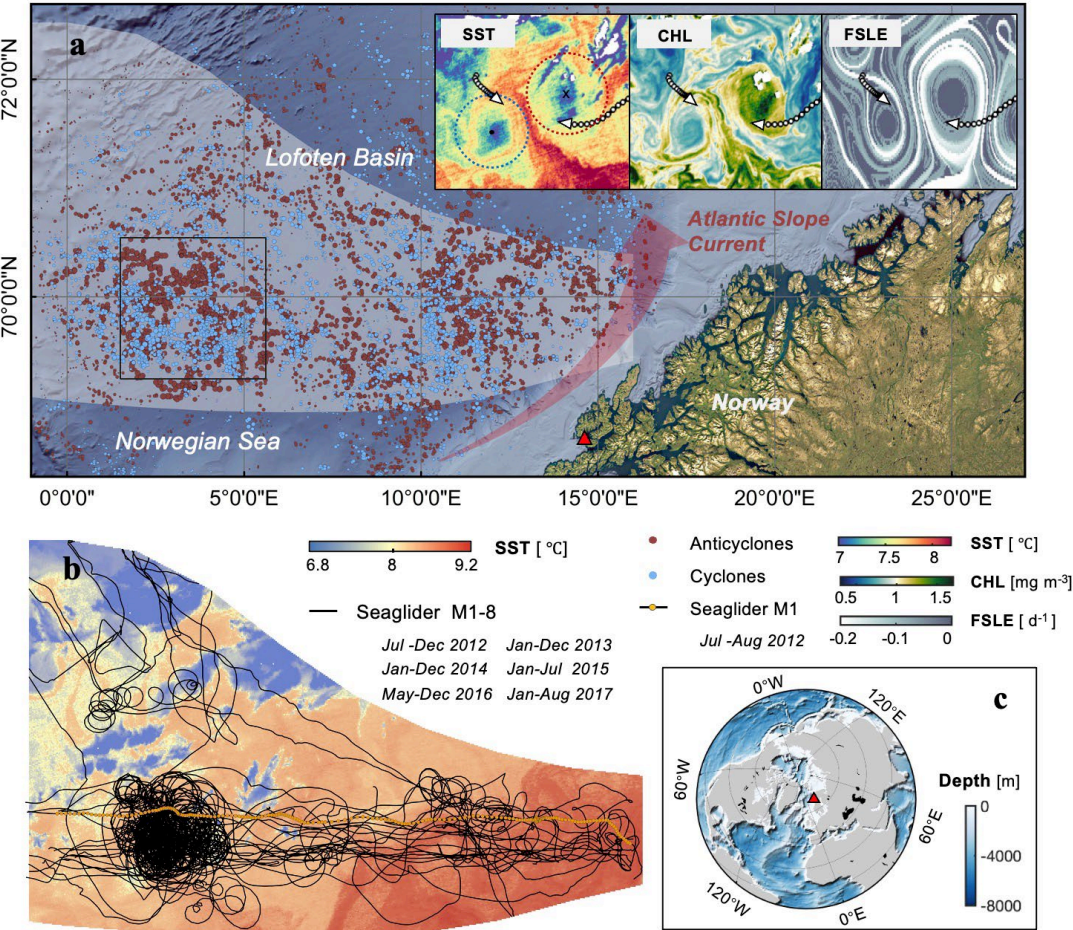


## Distribution of cyclonic and anticyclonic eddies in the Seaglider sampling region.

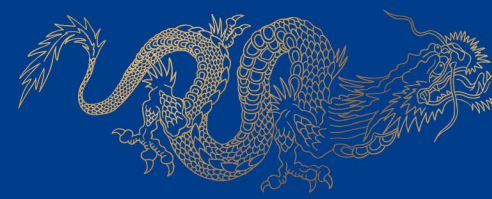
**a**, Map of Lofoten Basin region with the locations of all identified cyclonic (green dots) and anticyclonic (red dots) eddies observed during eight Seaglider missions between July 2012 and August 2017. The light gray shaded area corresponds to the region covered by Seaglider observations. The three insets in **a** show the instantaneous sea surface temperature (SST), chlorophyll (CHL) and finite-size Lyapunov exponent (FSLE) fields as the glider sg559 M1 traversed a pair of eddies within the black boxed regions on 8 June 2017. The white dots and white arrows represent the trajectory and direction of the glider, respectively.

**b**, Trajectories of eight Seaglider missions between 4 July 2012 and 9 August 2017 (black lines) superimposed on a snapshot of satellite-based SST. The trajectory with blue dots represents the first section of the M1 mission between 6 July 2012 and 16 August 2012.

The location of the Lofoten Islands in the study area is marked by red triangles in panels **a** and **c**.



# Specific objective 4: Results:



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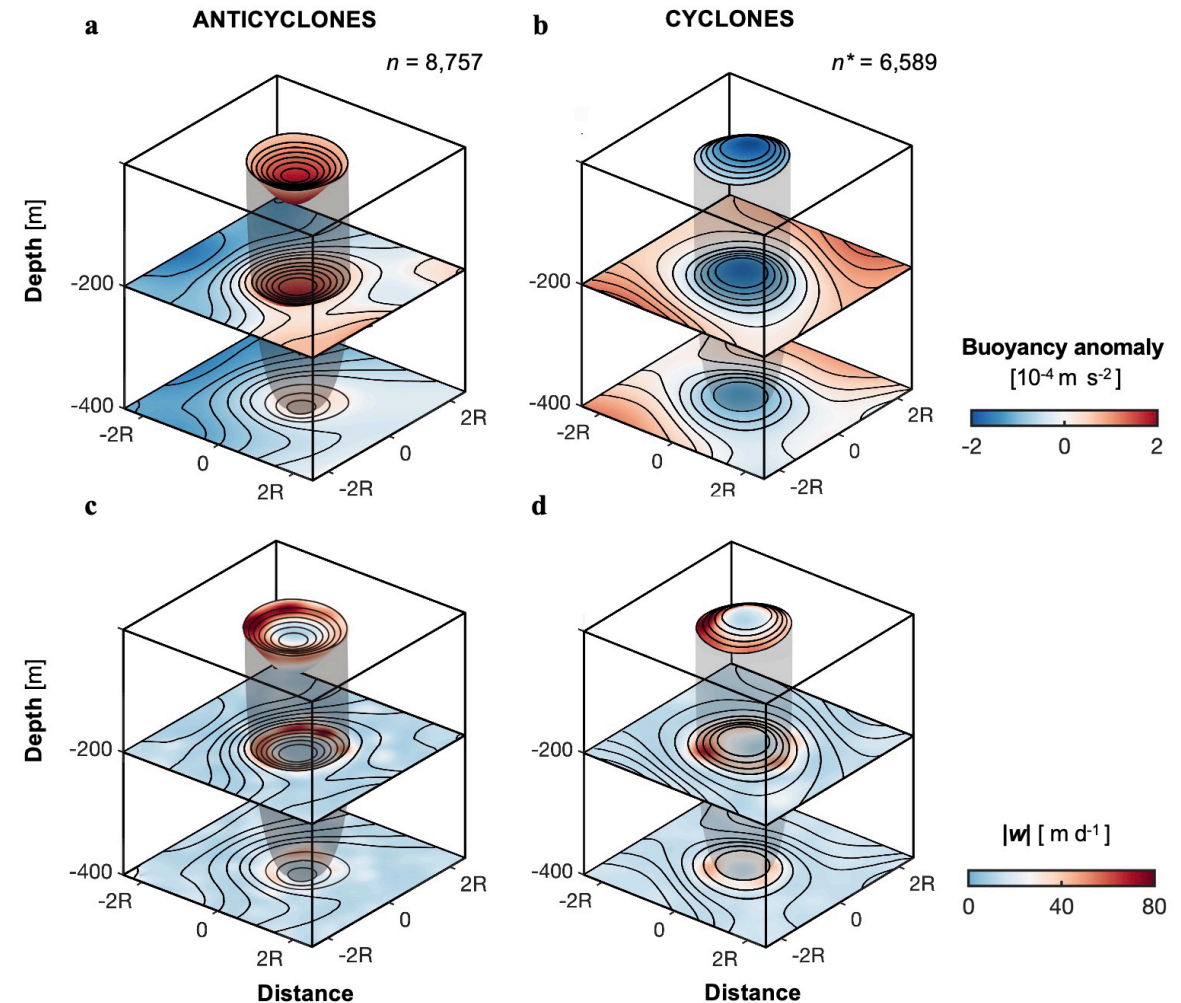


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## 3D structures of buoyancy anomalies and vertical velocities for anticyclonic and cyclonic eddies.

Eddy-centric composite distributions of buoyancy anomalies at 0 m, 200 m and 400 m depth for a anticyclonic and b cyclonic eddies based on five years of Seaglider observations. Positive (negative) buoyancy anomalies within a anticyclonic (b cyclonic) eddies defined by altimetry data represent warm-core (cold-core) structures. The transparent black shading represents the outermost layer of the eddy, defined by closed contours of surface buoyancy anomalies.

c and d are same as a and b except for eddy-centric composite distributions for vertical velocities. The contours in (a, c) and (b, d) represent the buoyancy anomalies (contour interval  $2 \times 10^{-5} \text{ m s}^{-2}$ ) for anticyclonic and cyclonic eddies, respectively.



## Specific objective 3: Future work:



**Objective (3):** Conduct 4D reconstructions based on machine learning experiments combining observations and model fields

**Task 1.** Development of a hybrid-ML methodology, leveraging the GLORYS12V1 data, to more accurately estimate the 3D structure of eddies.

**Task 2.** Conduct Sensitivity experiments to better understand data and parameter dependencies affecting the accuracy of the predicted vertical structure of the eddies.

**Task 3.** Fine-tuning of the hybrid-ML methodology using transfer learning, by supervising the algorithm with the observed EN4 profile data and its application to the 2D fields and vertical profiles, to obtain a multivariate 3D field colocated with eddies.

Young scientist (Norway) ---- MSc University of Bergen (2026-2027)

# Specific objective 5 and 6

## Future work:



**Objective (5):** Study the energy source that sustain the occurrence of submesoscale dynamical processes at the edge of ACEs and CEs, as well as their seasonal characteristics

Expand Collaboration within ESA Dragon 6 programme (e.g., **SADyMaS**)

**Objective (6):** Quantify the AW heat transport in and out of the Lofoten Basin.

Expand Collaboration within ESA Dragon 6 programme  
(Zhang Shengjun, NEU, China; Jungang Yang, FIO, China)

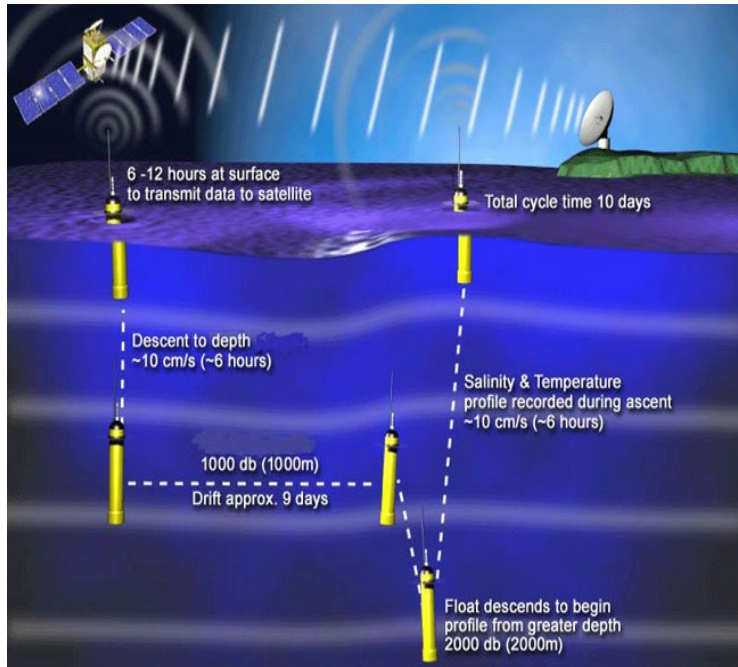
# Dragon 6 EO Data Delivery



Data access (list all missions and issues if any). NB. in the tables please insert cumulative figures (since June 2024) for no. of scenes of high bit rate data (e.g. S1 100 scenes). If data delivery is low bit rate by ftp, insert “ftp”

| ESA /Copernicus Missions | No. Scenes | ESA Third Party Missions | No. Scenes | Chinese EO data | No. Scenes |
|--------------------------|------------|--------------------------|------------|-----------------|------------|
| 1. ERS                   |            | 1. Radarsat              |            | 1.HY            |            |
| 2.ENVISAT                |            | 2.                       |            | 2.              |            |
| 3.Cryosat                |            | 3.                       |            | 3.              |            |
| 4.Sentinel-3             |            | 4.                       |            | 4.              |            |
| 5.SMOS                   |            | 5.                       |            | 5.              |            |
| 6.GOCE                   |            | 6.                       |            | 6.              |            |
| Total:6                  |            | Total:1                  |            | Total:1         |            |
| Issues:                  |            | Issues:                  |            | Issues:         |            |

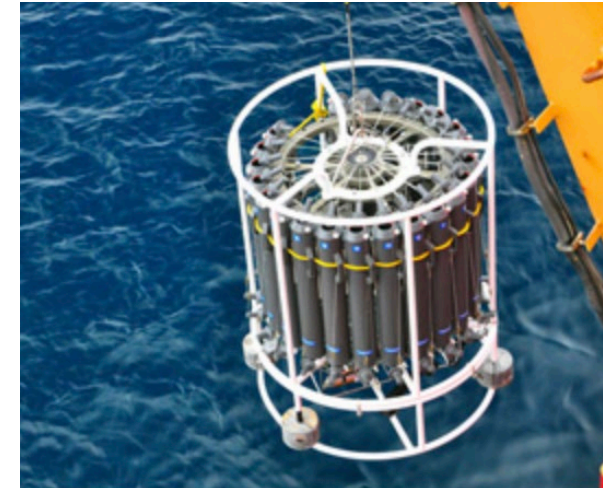
## Argo floats



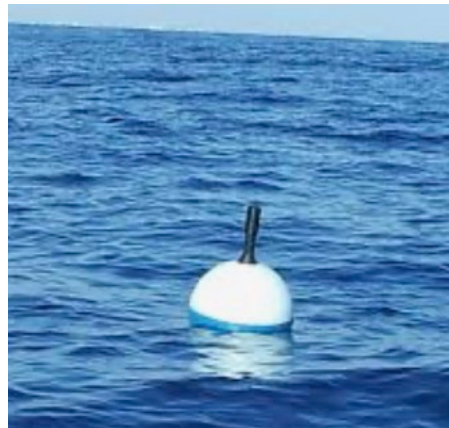
## Gliders



## CTD



## Surface drifters



# European Young Scientists contributions in Dragon 6



| Name | Institution          | Poster title | Contribution including period of research |
|------|----------------------|--------------|-------------------------------------------|
| TBD  | University of Bergen |              | ML, AI.<br>2026-2027                      |
|      |                      |              |                                           |
|      |                      |              |                                           |
|      |                      |              |                                           |
|      |                      |              |                                           |

# Chinese Young Scientists contributions in Dragon 6



| Name         | Institution                          | Poster title | Contribution including period of research |
|--------------|--------------------------------------|--------------|-------------------------------------------|
| HUALING WANG | SHANGHAI JIAO TONG UNIVERSITY, CHINA | -            | Submesoscale eddies                       |
| XINYI GU     | SHANGHAI JIAO TONG UNIVERSITY, CHINA | -            | Eddies and MHW                            |
|              |                                      |              |                                           |
|              |                                      |              |                                           |
|              |                                      |              |                                           |



中国科学技术交流中心  
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→ THE EUROPEAN SPACE AGENCY

“Coming together is a beginning,  
Staying together is progress,  
And working together is success.”

Henry Ford

*Thank  
you!*