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Ocean eddy signature on SAR-derived sea ice drift and vorticity

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Scientific Question : How can eddies propagating under the sea ice cover be detected by satellite images ?

Cassianides et al., 2021, GRL

Eddies in the Arctic Ocean : a detection problem

Several studies have observed oceanic eddies at all depths over the Arctic basin (e.g. Zhao et al., 2014).

Problem: The sea ice cover prevents us to characterise the eddy field as it is done through automatic detection in ice-free regions by satellite (i.e. anomaly of SSH or SST, Kozlov et al. 2019).

How can we detect eddies under sea ice with satellite images ?

Sea ice may carry an eddy signature (swirling movements on Figure 1), induced by dynamics and thermodynamics interactions between eddies and ice (e.g. Manucharyan & Thompson, 2017).

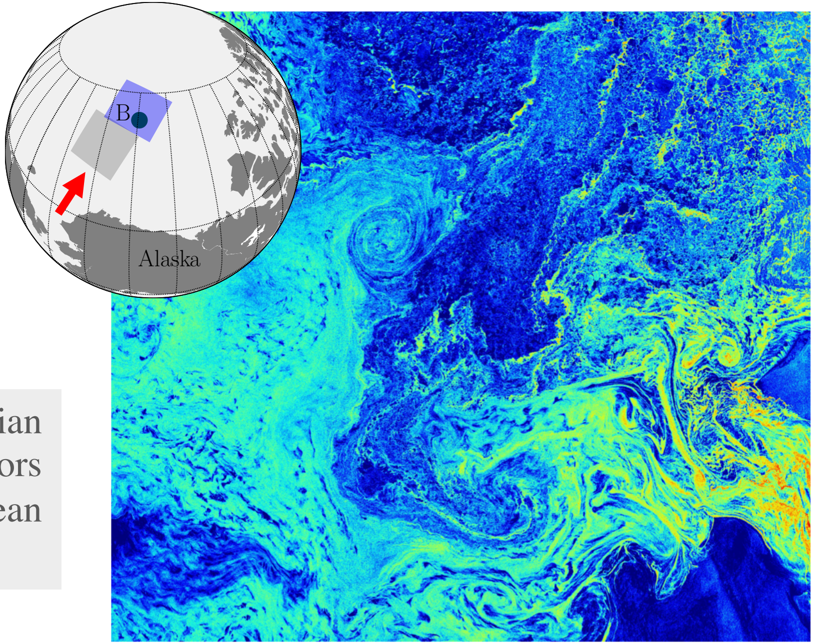


Figure 1 : SAR image in the Marginal Ice Zone of the Canadian Basin for October 19th 2018 (grey shading on the map). Colors visualise the SAR backscatter, with dark blue indicating ocean and green and yellow the presence of sea ice.

Eddies in the Arctic Ocean : a detection problem

Since sea ice conditions (and especially the drift) are driven by various forcings, how the eddy signature could be identified when it is not always visible at first sight ?

Here we focus on a period at the beginning of October 2017 at the Beaufort Gyre Exploration Project mooring B (green dot on the map), where an eddy imprints its signature, not directly identified by visual inspection, but revealed after further processing of Synthetic Aperture Radar (SAR) images.

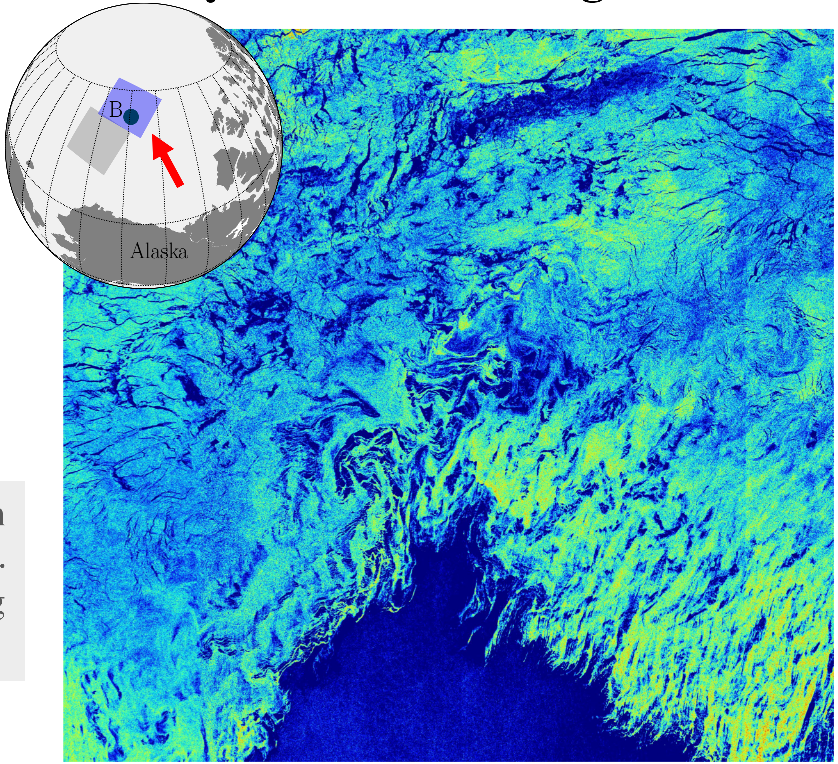


Figure 2 : SAR image in the Marginal Ice Zone of the Canadian Basin for October 12th 2017 (purple shading on the map). Colors visualise the SAR backscatter, with dark blue indicating ocean and green and yellow the presence of sea ice.

Observation data

SAR imagery from Sentinel-1
The data product is the Level-1 Extra-Wide swath mode ground range detected with medium resolution, available at the Copernicus Open Access Hub (scihub.copernicus.eu). The swath width is 400 km and the pixels are spaced by 40 m×40 m. The time interval between two images varies from a few hours to a few days.

Mooring B from the Beaufort Gyre Exploration Project at 78°N-150°W
ADCP collects data in the top ~ 30 m of the water column, with a resolution of one hour and 2 m.
McLane Moored Profiler (MMP) provides temperature, salinity and velocity profiles below 50 m depth.
Upward Looking Sonar (ULS) is installed on the same mooring and provides a time series of ice draft.

Polar Pathfinder Sea Ice Motion Vectors version 4
From the National Snow and Ice Center (NSIDC, https://nsidc.org), which provides daily sea ice drift at the pan-Arctic scale with a resolution of 25 km over 1978 to 2019.

ERA5 reanalysis data
Wind speed using the hourly averaged u and v wind speed at 10 m with a spatial resolution of ~ 0.25°.

OSISAF sea ice concentration
Sea ice concentration from DMSP/SSMIS satellite provided every day with a spatial resolution of 10 km.

How do we get the ice drift from SAR images ?

1) 8 SAR images are retrieved over October 7-13 2017 at the mooring position

2) Consecutive pairs of raw SAR images are processed with an algorithm based on the combination of **feature-tracking** and **pattern-matching** (Muckenhuber *et al.*, 2016; Korosov & Rampal, 2017) to compute the sea ice drift on a regular grid of 4 km.

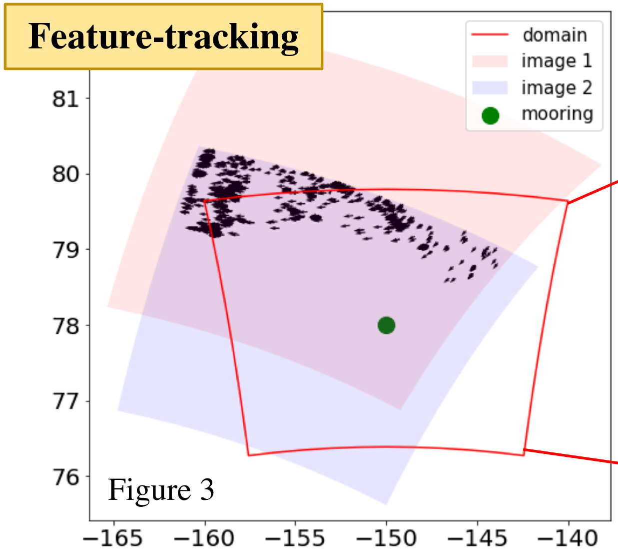


Figure 3

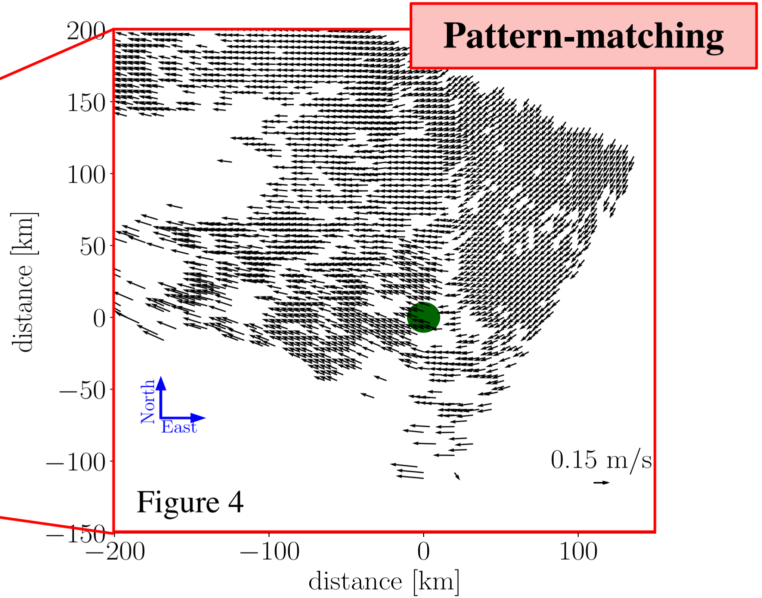


Figure 4

The sea ice vorticity from SAR images

3) We compute the relative vorticity of sea ice with u_{ice} and v_{ice} the horizontal components :

$$\zeta_{ice} = \frac{\partial vic_e}{\partial x} - \frac{\partial uic_e}{\partial y}$$

Example for 12-13 October:

A cyclonic signal (positive vorticity) with an intensity > 2.10^{-6} s^{-1} and a horizontal scale of ~ 80 km west of the mooring.

An anticyclonic background (negative vorticity) with an intensity varying between $-2\times10^{-7} s^{-1}$ to -6×10^{-6} s^{-1}.

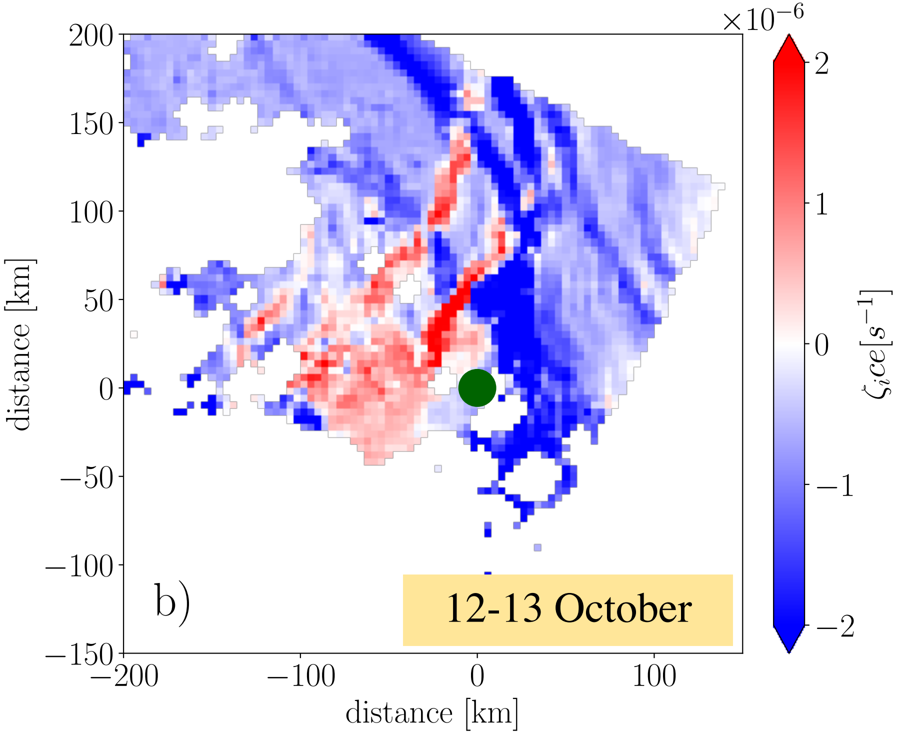


Figure 5 : Sea ice vorticity from one pair of SAR images for October 12-13. The green dot indicates the position of the mooring

The sea ice vorticity from SAR images

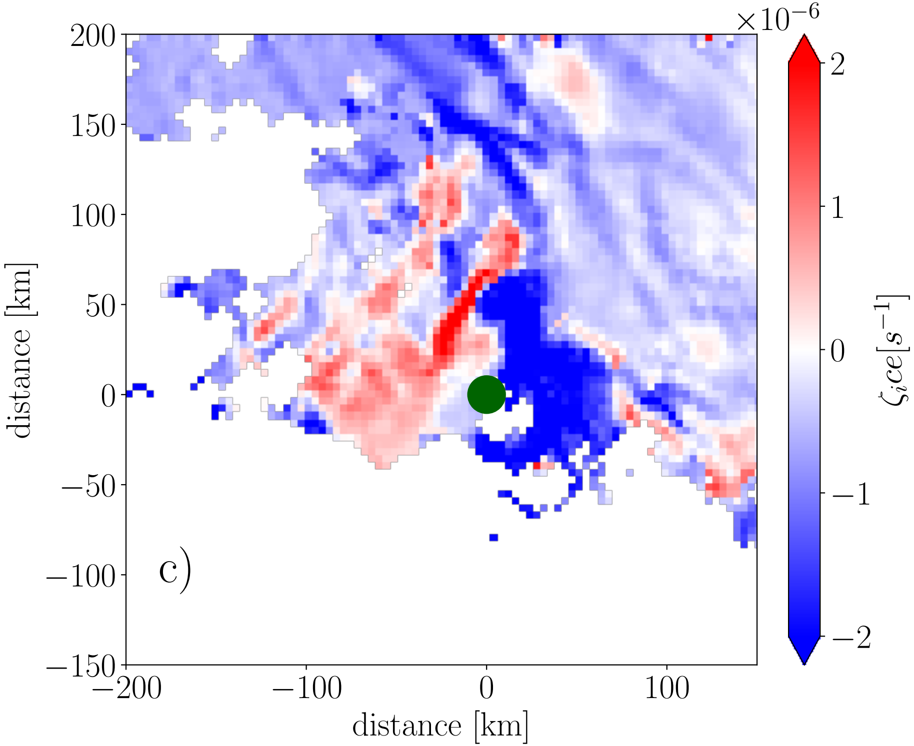


Figure 6 : Average of sea ice vorticity from 5 pairs of SAR images for October 7-13. The green dot indicates the position of the mooring

After averaging the sea ice vorticity from all the SAR images available over October 7-13 :

We observe two strong anomalies : a cyclonic vorticity West of the mooring and an anticyclonic signal to the East, both with a horizontal scale of ~ 80 – 100 km.

→ What did cause these anomalies ?

Did the wind form these anomalies ?

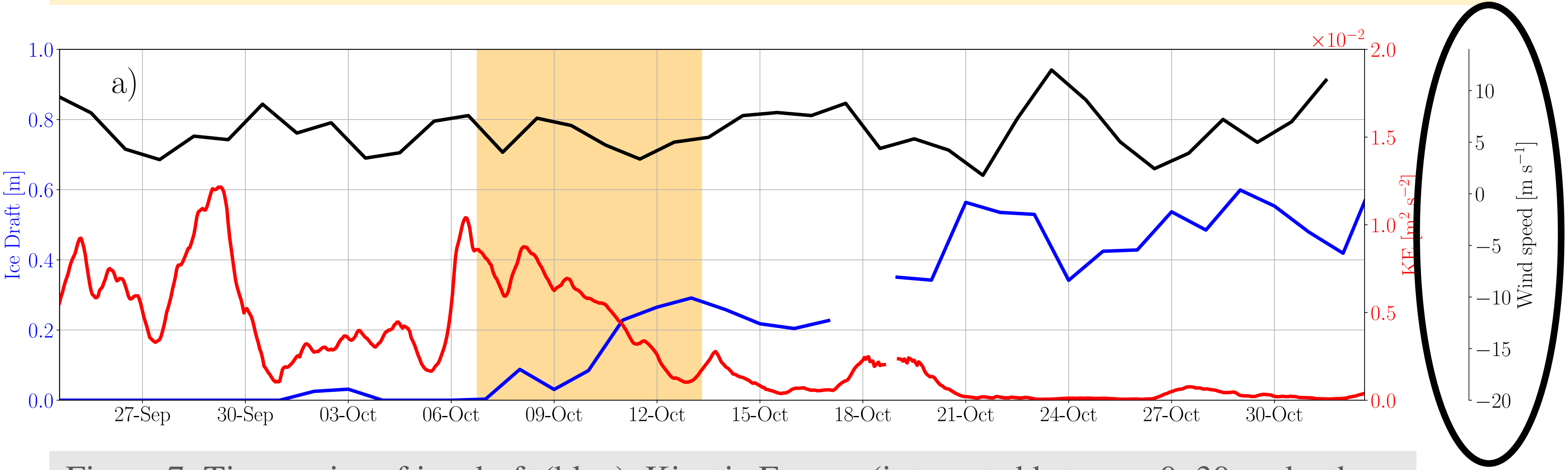


Figure 7: Time series of ice draft (blue), Kinetic Energy (integrated between 0–30 m depth , red) from the Acoustic Doppler Current Profiler (ADCP) and wind speed (black) in 2017.

Between September 25–October 30, wind speed = **constant** and **weak** at the mooring location, with an average of 6 ms^{-1} directed southwestward and no storm.

Did the wind form these anomalies?

Scaling comparison

1. The most intense mesoscale atmospheric eddies called Polar Lows have spatial scales ranging from 200 – 1000 km **>** to the horizontal scale of ice vorticity anomalies.
2. We compute the sea ice drift solely driven by the ERA5 wind product (Thorndike & Colony, 1982) and we obtain a sea ice vorticity $\zeta_{wind} \sim -2\times10^{-7}s^{-1}$ **weaker** than the anomalies but it **matches** the background sea ice vorticity in SAR images.

➔ **The scale and intensity of the wind forcing do not match those of sea ice anomalies.**

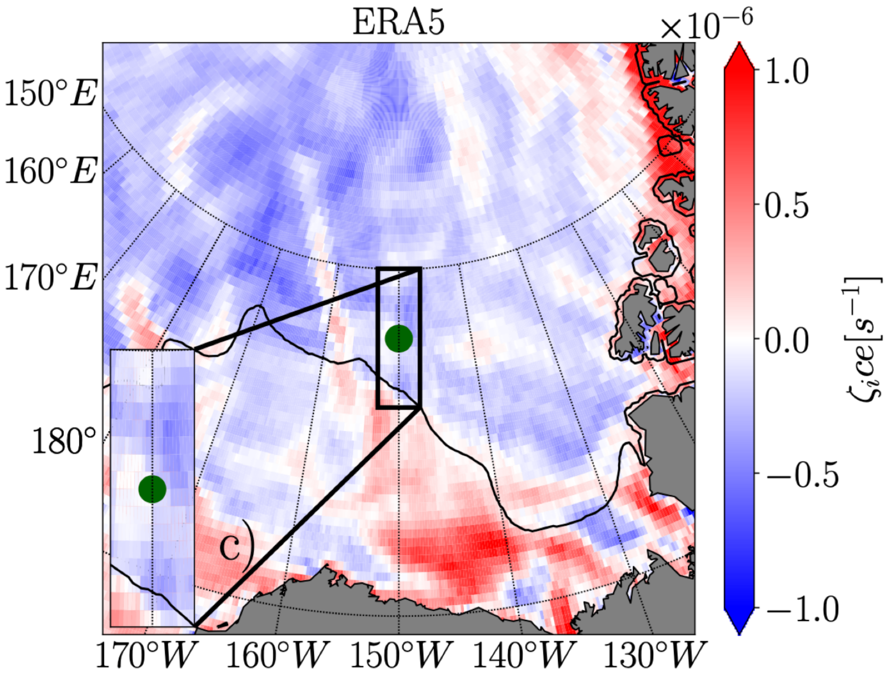


Figure 8 : Average of sea ice vorticity driven solely by the ERA5 wind for October 7-13. The green dot indicates the position of the mooring and the dark line is the limit of OSISAF sea ice concentration at 20%.

Could it be an ocean eddy ?

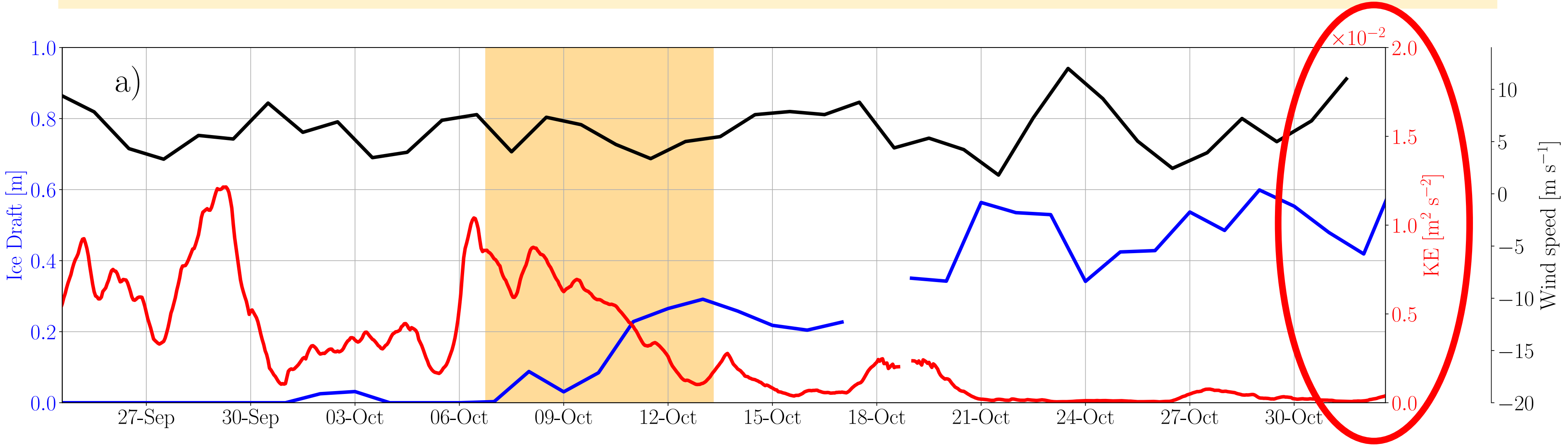
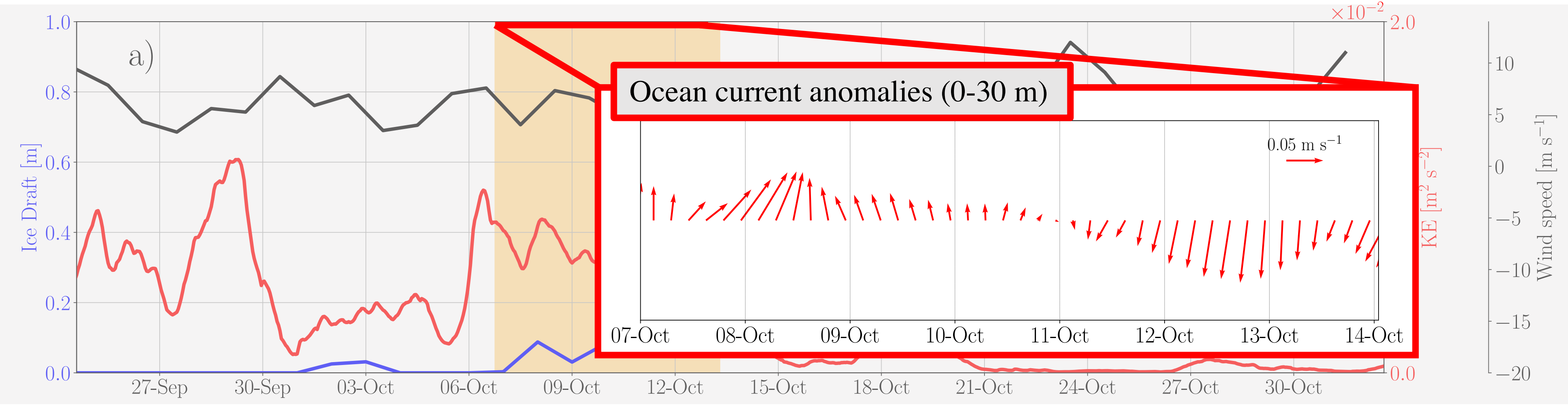


Figure 9: Time series of ice draft (blue), Kinetic Energy (integrated between 0–30 m depth , red) from the Acoustic Doppler Current Profiler (ADCP) and wind speed (black) in 2017.

The anomaly in Kinetic Energy (KE) between October 7-13 suggests that the mooring is sampling an eddy passing by in the surface layer.

Could it be an ocean eddy ?



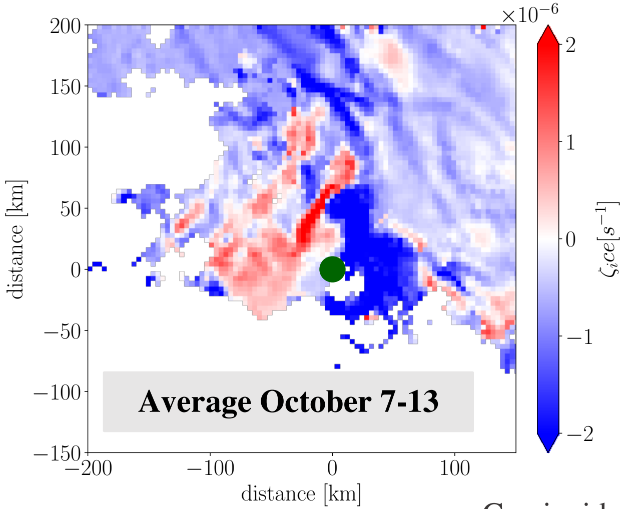
The stick diagram of the ocean current anomalies reveals a sign change, typical of the structure found in the core of an eddy ➔ **an eddy is passing by the mooring!**

MMP data confirms the presence of an anticyclone below the mixed-layer (not shown here) ➔ **an eddy dipole is passing by**.

Based on CTD and mooring data, the eddy length scale is ~ 82 km, with a relative vorticity of ζ_{eddy} = 1.5.10^{-5} s^{-1} **>** to the ice vorticity anomalies ➔ **the ocean eddy is the most plausible driver.**

Conclusion

We present a detection method of surface ocean eddies based on their signature in the sea ice vorticity, using high spatial resolution SAR images. Although the eddy could not be identified by visual inspection of the SAR images, its signature is revealed as a dipole anomaly in sea ice vorticity, composed of a cyclone and an anticyclone, with a horizontal scale of 80-100 km and persisted over a week. This work demonstrates that processing are required for identifying the signature of eddies in sea ice, which is not always obvious at first sight.



Limitation of the method :

- SAR image availability
- Sea ice conditions

Perspectives : What are the dynamical and thermodynamical processes involved in this signature ?

Cassianides, A., Lique, C., & Korosov, A. (2021). Ocean eddy signature on SAR-derived sea ice drift and vorticity. *Geophysical Research Letters*, *48*, e2020GL092066. https://doi.org/10.1029/2020GL092066

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Ocean Eddy Signature on SAR-Derived Sea Ice Drift and Vorticity

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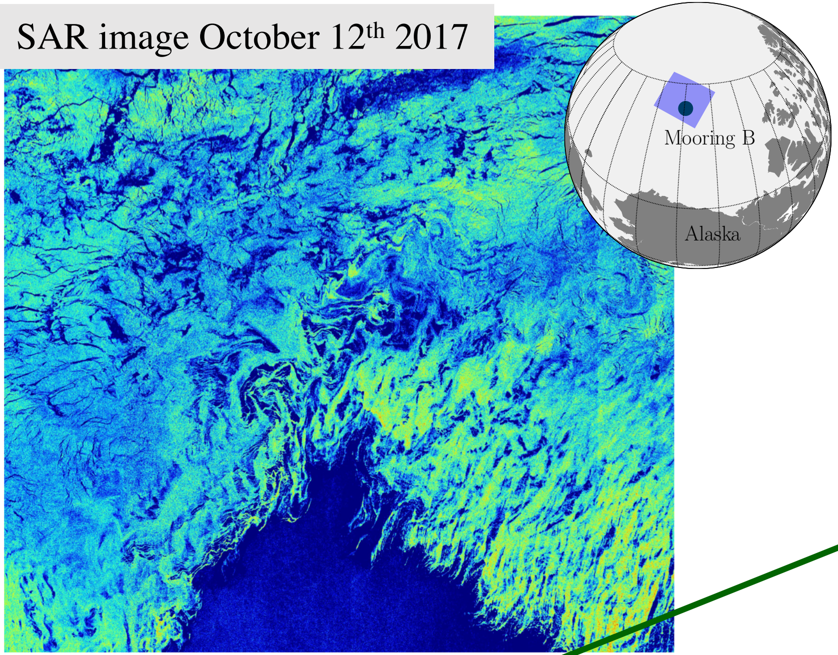
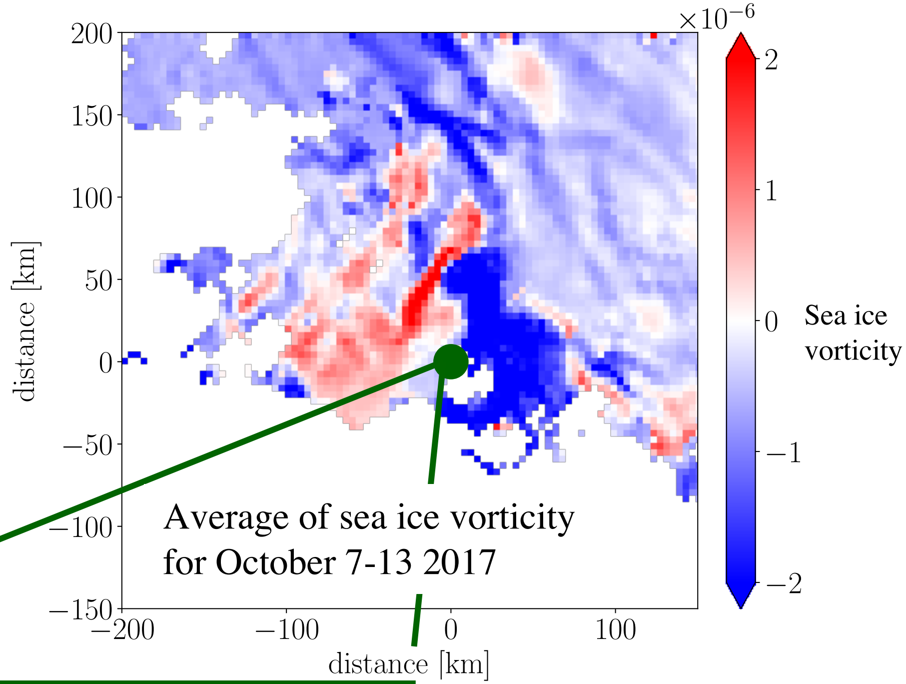
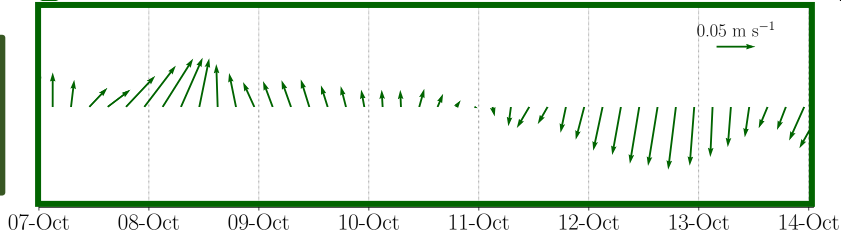
SAR image October 12th 2017





Average of sea ice vorticity for October 7-13 2017



Ocean current anomalies from the mooring (0-30 m) : the typical structure of an eddy.

Cassianides et al. (2021).