Exploring The Mesoscale Eddies In The Nordic Seas With A Multiparameter Eddy Significance Index And Singularity Analysis

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Abstract

In this poster we present results of the studies of Nordic Seas (NS). Two distinct analysis of 11 years (2010-2021) of satellite remote sensed data (interpolated to 25 Km spatial resolution) combined with mesoscale eddy tracking to advance the insight of mesoscale eddy activity and upper ocean circulation have been explored.
The relevance of the results, in turn, is also discussed in relation to the Atlantification of the Arctic Ocean.

Introduction

The increasing influence of the Atlantic Water (AW) in the Arctic, known as "Atlantification", has been of scientific interest for several years. A "missing puzzle" yet to be studied in detail is the role of mesoscale eddies featured in the NS on the Atlantification. Whereby eddies, mean kinetic energy is transformed to eddy kinetic energy and heat and salt are captured and traped from the mean Atlantic Water (AW) flow (Bolenenko et al., 2020), thereby cooling the AW poleward heat transport (Isachsen et al., 2012). In regards to the Atlantification in the Arctic Ocean, the question is therefore related to the occurrences of eddies in the NS over the last decades and if there has been a substantial change on the nature of the eddies.

OBJECTIVES

- **Determine the trend in eddy activity in the NS in the last decade (2011-2021) from altimetry.**
- **Analyse and understand the information provided by the values of the MESI index for the different ocean variables.**
- **Recognize the limitations in terms of both the temporal and spatial resolution inherent in the available data for the identification and characterization of eddies in the NS.**
- **Assess the consistency between the climatology of singularity exponents over remote sensed images and the MESI index.**

(Study area: Climate change)

METHODS

MESOSCALE EDDY TRACKING: Algorithm based on altimetry for the detection of the location, size and lifetime of mesoscale eddies already used in previous studies (1). (See Results 1)

MESI INDEX: Values are calculated using daily satellite data that is regridded onto the SLA grid (0.25° horizontal grid spacing) and normalized to each data set own standard deviation $Z_v = \frac{(V - \bar{v})}{\sigma}$. (See Results 2,3)

$$MESI = Z_{SLA} \cdot abs(Z_{SST}) \cdot abs(Z_{SSS}) \cdot abs(Z_{Chl-a}) \cdot abs(\log_{10} abs(Z_{EKE}))$$

It maintains the integrity of eddy circulation by having the sign of Z_{SLA}.

According to previous studies (2):
- **MESI estimates the impact of mesoscale eddies on the upper ocean, surface processes and marine ecosystems.**
- **MESI highlights eddies which extend into the deeper ocean.**
  - **Higher amplitude MESI values penetrate deeper into the upper ocean than eddies with lower amplitude**
  - **Transient eddies exhibit high MESI values suggesting they have a major impact on the upper ocean and air-sea interactions.**

***To analyse the index we present radialized standardised composites of the values within the circle of to times the radius of every detected eddy.**

SINGULARITY EXPONENTS OF REMOTE SENSED IMAGES OF OCEAN VARIABLES ADVECTED BY DE FLOW: According to previous studies (3), the singularity exponent:

- **Reveals mixture of horizontal transport and dispersion processes of the upper ocean circulation.**
- **Measures the degree of irregularity of the signal. Negative exponents imply regions of divergence**
- **Only suitable for signals presenting multifractality structures such as values of SST, SLA and SSS.**

(See Results 3)

RESULTS 1. Mesoscale eddy tracking

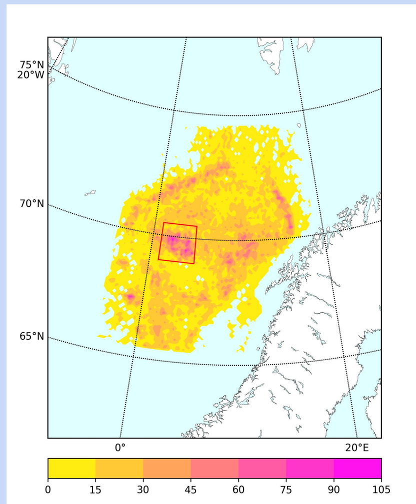

Figure 1: Number of tracked eddies per gridpoint (2010-2021)

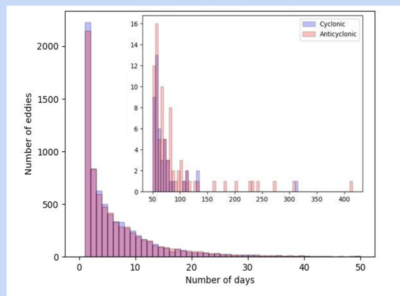

Figure 2: Distribution of the lifetimes of the detected eddies (2010-2021)

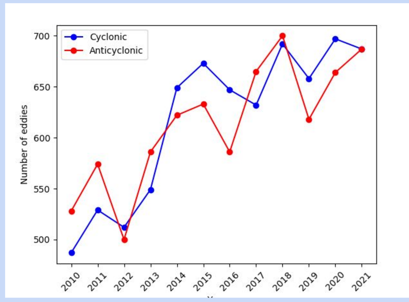

Figure 3: Number of detected eddies per year (2010-2021)

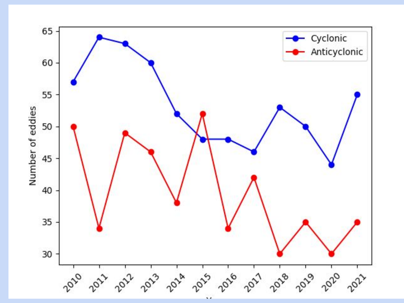

Figure 4: Number of tracked eddies per year in the Lofoten vortex region (red box in Figure 1)

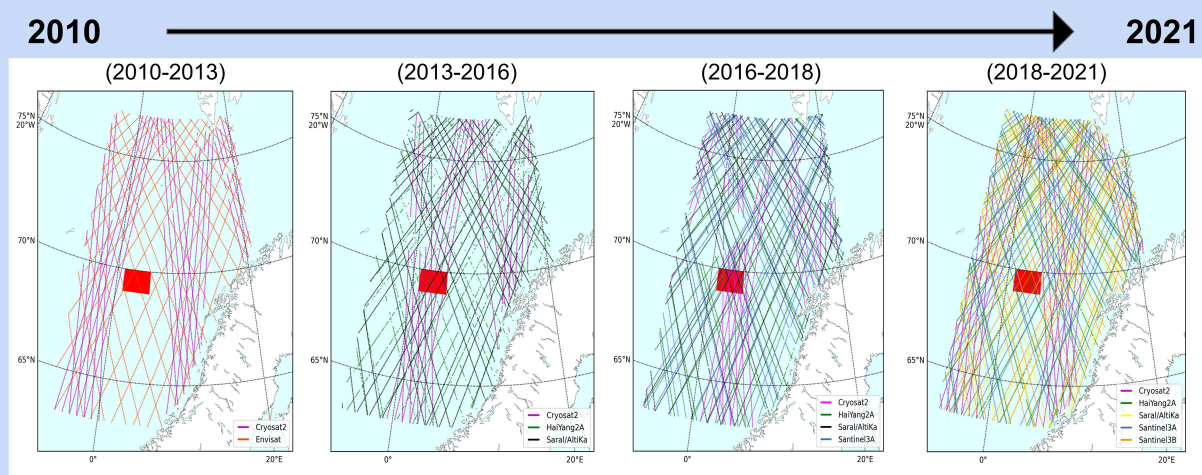

Figure 5, Table1: Available altimetry tracks in different 10 day periods explaining the evolution of the available data with the start and end of phases of new satellites.

Missions	Start of phase	End of phase	Repeat cycle (days)
Envisat (extended mission)	26/10/2010	08/04/2012	30
Cryosat-2	01-02-2011	active	369
HaiYang-2A	16/08/2011	31/12/2021	14
Saral/AltiKa	12/03/2013	active	35
Santinel-3A	01/03/2016	active	27
Santinel-3B	25/04/2018	active	27

Total number of detected eddies:
Cyclones: 34500
Anticyclones: 39000

DETECTED Eddies in the NS:
- **16 Km < Eddy radius < 70 Km**
- **Increasing number of detected eddies per year independent on the minimum lifetimes considered**
- **Only 25% of the detected eddies have lifetimes longer than 10 days and 5% longer than 30 days**

DETECTED Eddies in the Lofoten Basin (red box in Figure 1) :
- **Typically growing to larger dimensions (around 40 Km Radius) and longest lifetimes (up to 400 days).**
- **Slightly decreasing number of detected eddies per year (see Figure 4)**

DISCUSSION:
The frequency of new satellite measurements to retrieve the daily SLA product has grown in the last decade.
- **It can affect the number of detected eddies. (Not explain the decaying tendency in the area of the Lofoten vortex).**
- **Questions the availability to detect eddies with lifetimes shorter than 10 days (see Figure 2).**

More eddies in the NS would imply more heat, salt and energy trapping and would potentially contradict the "Atlantification" of the Arctic

RESULTS 2. Radially standardized composites

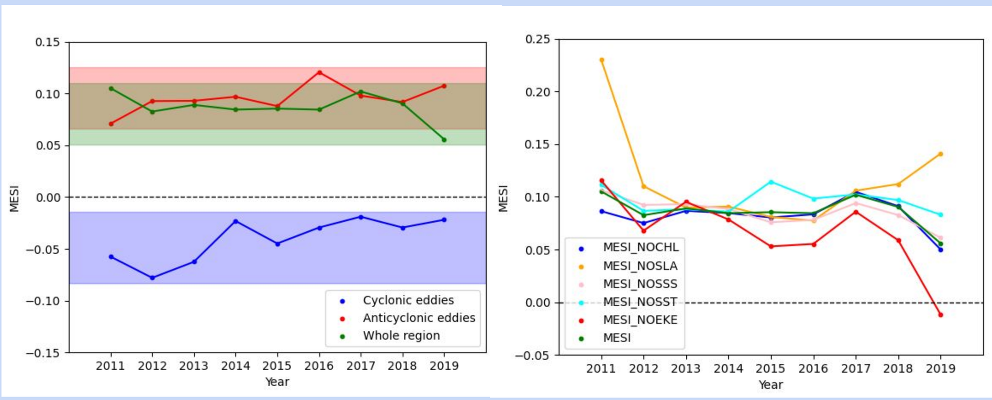

Figure 6: Mean value of the MESI index within the radius of every tracked eddy and in the entire NS region (left) and mean value per year in the entire NS region of the MESI and versions of it (omitting different variables) (right).

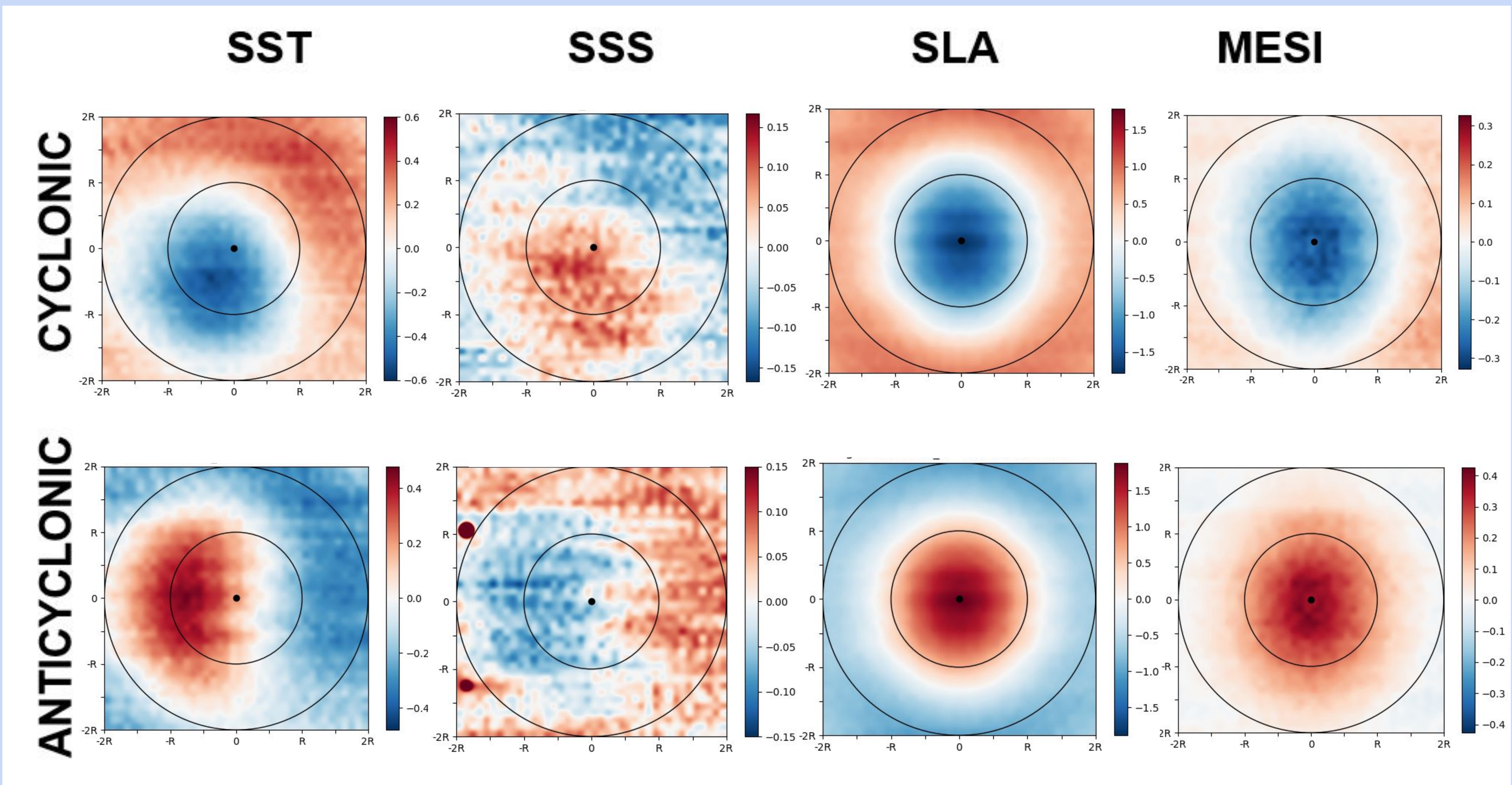

Figure 7: Radialized standardized composites of SST, SSS, SLA and MESI including all the detected eddies. The plots of SST, SSS and SLA correspond to the solution for the standardised values of the variable Z_v after applying a temporal average and a Gaussian high pass filter. The plots of MESI index are only radial composites of the MESI values, without standardizing nor filtering.

DISCUSSION:
- **Anticyclonic eddies (red) present higher amplitude MESI values than cyclonic eddies (blue). This supports the fact that higher amplitude MESI values penetrate deeper into the ocean.**
- **Decreasing tendency of the MESI in absolute value for cyclonic eddies. Indicator that the impact of each cyclonic eddy in the upper ocean has decayed in general during the last decade.**
- **Values of the MESI highly dominated by SLA. The dependency of the mesoscale eddy tracking on altimetry data explains the symmetry of the index around the eddies.**

- **Asymmetric polarization of the SST and SSS signals around the eddy center. Evidence of the eddy stirring phenomena explained in (4). Advection of salinity and temperature gradients.**
- **The distribution of SST, SSS, SLA and MESI around the center of the eddies is not dependent on their sizes. Low filtering or high filtering the radius of the used eddies leads to equivalent results.**

RESULTS 3. MESI Index and singularity exponents

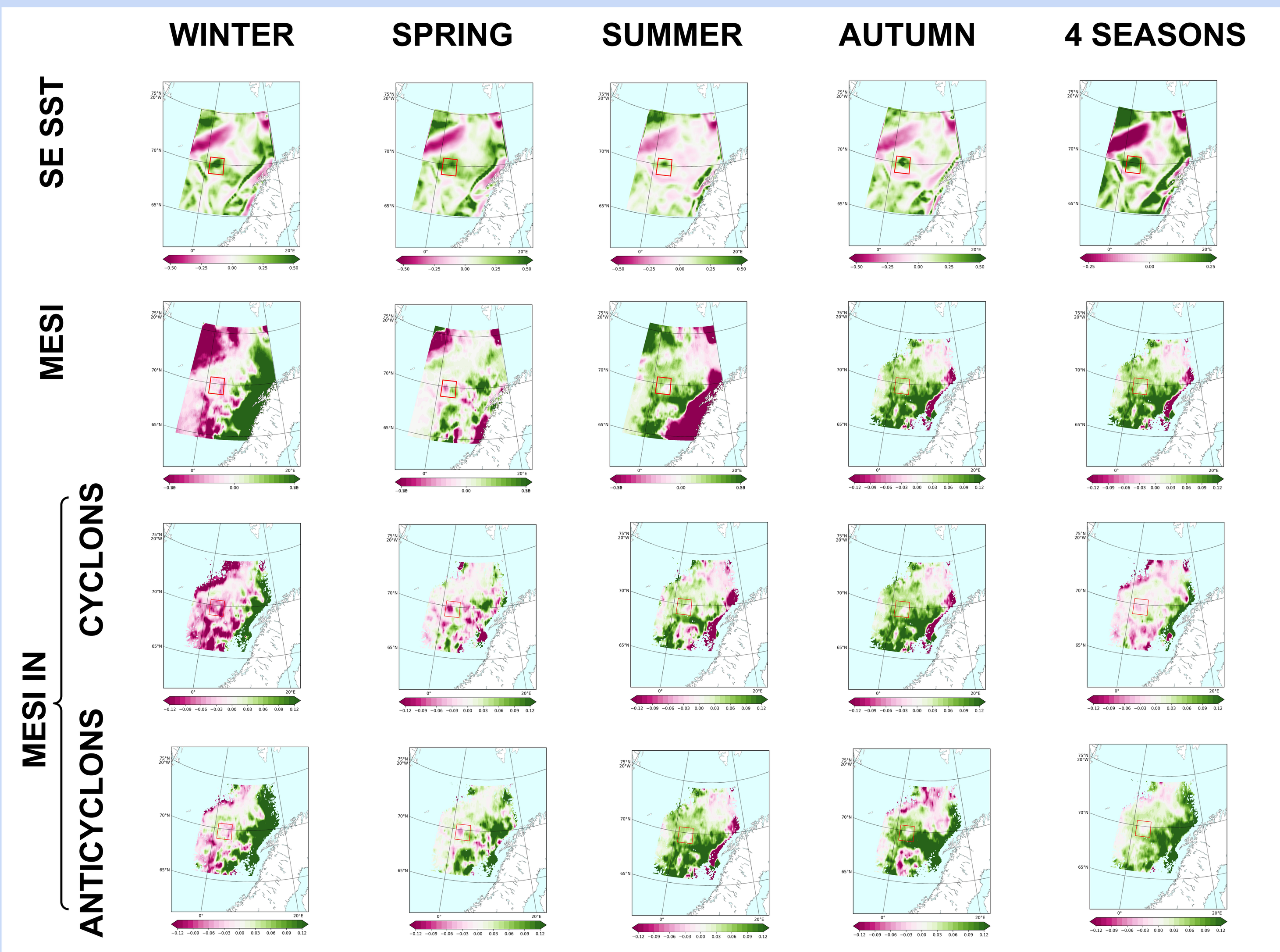

Figure 8: Climatologies of the singularity exponents (first row) and the MESI (second row) in the NS. In third and fourth rows, climatologies only for the detected eddies cyclonic and anticyclonic respectively.

DISCUSSION:
- **The upper layer heating during spring and summer creates a shallow baroclinic structure in the upper ocean (shallow area in surface) which disfavours the MESI values . In winter deeper baroclinic structures are more dominant and we find MESI values with higher amplitude. The singularity signature is also stronger.**
- **SST singularity exponents show agreement with the MESI both highlighting the active region of the Lofoten Basin.**
- **The SSS singularity exponents are not adding more understanding and therefore are not presented.**

Conclusions

- **Mesi climatologies indicate a decay during the last decade of the impact of cyclonic eddies in the upper ocean in the NS (see Figure 6). This would agree with less heat and salt being trapped and therefore the Atlantification of the Arctic ocean.**
- **Regarding the number of detected eddies, the possible effect of the growing frequency of new altimeter observations needs to be evaluated. For now, the mesoscale eddy tracking suggests an increasing tendency of detected eddies in the NS and a decreasing tendency on the subregion where the Lofoten vortex is located.**
- **Mesi index is highly modulated by the SLA and provides stronger and cleaner values during winter for anticyclonic eddies.**

DATA SOURCES

- **SST:** "Product Title. E.U. Copernicus Marine Service Information (CMEMS). Marine Data Store (MDS) DOI: .10.48670/moi-00165 (Accessed on 10-06-2023)"
- **SSS:** smos-bec.icm.csic.es
- **SLA / geostrophic velocities:** "Product Title. E.U. Copernicus Marine Service Information (CMEMS). Marine Data Store (MDS). DOI: 10.48670/moi-00149 (Accessed on 10-06-2023)"
- **CHL:** Sathyendranath, Et Al (2021): ESA Ocean Colour Climate Change Initiative (Ocean_Colour_cci): Version 5.0 Data. NERC EDS Centre for Environmental Data Analysis, 19 May 2021.doi:10.5285/1dbe7a109c0244aaad713e078fd3059a
- **Altimeter tracks:** "Product Title. E.U. Copernicus Marine Service Information (CMEMS). Marine Data Store (MDS). DOI: 10.48670/moi-00146 (Accessed on 01-08-2023)"

Major References

1. Raj, R. P., Et Al. (2016), Quantifying mesoscale eddies in the Lofoten Basin, J. Geophys. Res. Oceans, 121, 4503–4521, doi:10.1002/2016JC011637.
2.Roman-Stork Et Al. (2023). MESI: A Multiparameter Eddy Significance Index. Earth and Space Science,10, e2022EA002583. DOI: 10.1029/2022EA002583
3. Turiel, Et Al (2009). The multifractal structure of satellite Sea Surface Temperature maps can be used to obtain global maps of streamlines. Ocean Science Discussions (OSD). 5. 10.5194/osd-6-129-2009.
4. Gaube, Et Al. (2014), Regional variations in the influence of mesoscale eddies on near-surface chlorophyll, J. Geophys. Res. Oceans, 119, doi:10.1002/2014JC010111.