

1 **New insights on mesoscale activity in the western Mediterranean**  
2 **Sea**

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**Abstract.** Mesoscale ocean variability plays a crucial role in regional circulation, heat transport, and the distribution of tracers such as nutrients, biological material, and pollutants. Mesoscale eddies are key drivers of these ocean dynamics, and their observation (particularly of small-scale and coastal structures) has been limited by the resolution of conventional altimetry products. The Surface Water and Ocean Topography (SWOT) mission provides unprecedented high-resolution sea surface height data, offering new opportunities to refine mesoscale observations and improve our understanding of their impact on surface ocean dynamics. In this study, we assess the potential of a new gridded altimetry product that incorporates SWOT wide-swath data (MIOST-K) and its differences with respect to the reference and widely used Copernicus Marine Environment Monitoring Service (CMEMS) product DUACS-OI, based solely in nadir altimetry. We analyze the eddy field in the western Mediterranean region, important for many different socio-economic activities like tourism, maritime transport, and fisheries and aquaculture. Compared to DUACS-OI, MIOST-K identifies a larger number of mesoscale eddies, particularly in coastal regions, and generally exhibits higher eddy kinetic energy (EKE) associated with the detected structures. We identify differences not only in the number of eddies, but also in their characteristics: e.g. size and associated EKE. This is relevant for defining optimum marine traffic routes, but also for operational activities such as marine pollution management. To evaluate the implications of these differences for transport and retention processes, we analyse the retention capacity of Algerian Eddies, which in the past have been found relevant in the transport of marine debris between the North African coast and the Balearic Islands. MIOST-K leads to substantially different particle retention estimates for some eddies, highlighting the sensitivity of transport processes to mesoscale circulation representation. Our findings evaluate how well SWOT-enhanced data affects the representation of mesoscale eddies and their velocity structures, showing important implications for ocean monitoring, climate studies, and marine ecosystem management.

**Table 1: Product table.**

| Product ref. no. | Product ID & type                                                                                                                  | Data access                                  | Documentation                                                                                                  |
|------------------|------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|----------------------------------------------------------------------------------------------------------------|
| 1                | SEALEVEL_EUR_PHY_L4_NRT_008_060<br>; satellite observations                                                                        | EU Copernicus Marine Service Product (2025a) | Quality Information Document (QUID): Ballarotta et al. (2025a)<br><br>Product User Manual (PUM): Pujol (2025a) |
| 2                | SEALEVEL_EUR_PHY_L4_MY_008_068<br>; satellite observations                                                                         | EU Copernicus Marine Service Product (2025b) | QUID: Ballarotta et al. (2025b)<br><br>PUM: Pujol (2025b)                                                      |
| 3                | Gridded Sea Level Height and geostrophic velocities computed with Multiscale Interpolation; MIOST-K v2.0.1; satellite observations | AVISO (2025)                                 | PUM: Ballarotta (2025c)                                                                                        |

## 45 1 Introduction

46 As the ocean continues to undergo rapid physical and ecological change, the ability to monitor and understand its dynamics  
47 at finer scales is increasingly critical. This study presents emerging approaches and technologies that are advancing our  
48 capacity to observe ocean processes. Among these, the enhanced detection and characterization of mesoscale features (such  
49 as eddies) represents an unprecedented leap forward, particularly in regions like the western Mediterranean Sea, where such  
50 structures strongly influence circulation, ecosystem connectivity, and pollutant dispersion (e.g. Suaria and Aliani, 2014;  
51 Cotroneo et al., 2021).

52 Conventional mesoscale monitoring has relied primarily on satellite altimetry products such as the Copernicus Marine  
53 Environment Monitoring Service (CMEMS), Sea Level - Thematic Assembly Centre (SL-TAC) dataset (e.g. Le Traon et al.,  
54 1998; Sánchez-Román et al., 2023). However, the launch of the Surface Water and Ocean Topography (SWOT) mission, and  
55 its Ka-band Radar Interferometer (KaRIn) instrument, has opened new observational pathways (Morrow et al., 2019; Fu et  
56 al., 2024). Recent studies have demonstrated that mesoscale eddies can be directly identified from SWOT wide-swath SSH  
57 observations, particularly in regions with small Rossby radius of deformation (e.g., Verger-Miralles et al., 2025; de Marez et  
58 al., 2026; Han et al., 2026; Fu et al., 2026). However, direct swath-based detection is more limited for larger mesoscale  
59 eddies extending beyond the instantaneous SWOT swath coverage. Gridded products integrating SWOT observations,  
60 provide a complementary approach by reconstructing spatially continuous fields, allowing both smaller-scale structures and  
61 larger mesoscale eddies to be characterized. This study evaluates the added value of a new pre-operational Level-4 (L4)  
62 surface product (MIOST with KaRIn; Ballarotta et al., 2025c), which integrates SWOT KaRIn data during the science phase  
63 (September 2023–December 2024), by comparing it with existing CMEMS products based solely on nadir altimetry.

64 Using an eddy detection method based on Mason et al., 2014, we assess differences in the eddy field across both products.  
65 We focus on key properties of eddies detected in both datasets, particularly Eddy Kinetic Energy (EKE). We center our  
66 comparison in a case study focused on the Algerian eddies and their potential to transport floating marine debris towards  
67 environmentally vulnerable areas of high biodiversity importance, such as the Cabrera National Park marine protected area  
68 (Compa et al., 2020) and nearby regions (e.g. Ruiz-Orejón et al., 2019). In this region, mesoscale dynamics have been  
69 identified as key facilitators of plastic pollution transport from the southern Mediterranean coast (Compa et al., 2020).  
70 Several media reports (e.g. 20minutos, 2015; Última Hora, 2015; Diario de Mallorca, 2022) have documented large  
71 quantities of marine debris reaching Cabrera National Park, underscoring the vulnerability of this protected area to the spread  
72 of pollution. As bio-physical hotspots, eddies with longer retention times may enhance exposure risks for sensitive  
73 ecosystems. The important role of Algerian eddies in transport and retention processes makes them a compelling target for  
74 evaluating the added value of high-resolution SWOT-based surface current products in tracking and forecasting marine

debris transport. Therefore, we evaluate the retention rate of particles inside Algerian eddies and thus the risk of marine debris reaching the park's vicinity. Algerian eddies have been found to also be a very important dynamic structure for heat, water masses and matter transport in the basin (e.g. Taupier-Letage et al., 2003; Escudier et al., 2016). In contrast to cyclonic eddies, anticyclonic Algerian eddies last longer and are known to travel farther from their origin and play a stronger role in regional connectivity (Pessini et al., 2018; Cotroneo et al., 2021). Their ability to trap and retain floating material has important implications for both ecological impact and the dispersion of pollutants (Suaria and Aliani, 2014).

This study evaluates how SWOT KaRIn observations affect the representation of surface mesoscale activity in gridded altimetric products over the western Mediterranean. By comparing eddy fields derived from legacy and SWOT-enhanced datasets, we assess differences in the representation of surface circulation, focusing particularly on EKE and eddy retention capacity. More accurate surface mesoscale information can support route planning strategies aimed at reducing ship emissions (e.g. Wang et al., 2023) and improve the identification of pollutant transport pathways toward ecologically sensitive areas such as Cabrera National Park. Beyond improving our understanding of mesoscale dynamics, the overarching objective is to evaluate the added value of high-resolution SWOT-enhanced altimetry for applications ranging from marine pollution mitigation to improved maritime operations and ecosystem management.

## 2 Data

### 2.1 DUACS optimal interpolation (DUACS-OI)

The *European Seas Gridded L4 Sea Surface Height* dataset (Table 1, product reference 1 and 2) from the Copernicus Marine Service, provides Sea Level Anomaly (SLA) fields at  $1/8^\circ$  resolution over European regional seas, at a daily temporal frequency. The product is generated by the Data Unification and Altimeter Combination System (DUACS) system ( *Centre National d'Etudes Spatiales/Collecte Localisation Satellites*; CNES/CLS) using optimal interpolation of along-track altimeter measurements from multiple satellites (Le Traon et al., 1998). It includes SLA, Absolute Dynamic Topography (ADT), and derived surface geostrophic currents. ADT is obtained by adding the Mean Dynamic Topography (MDT) to SLA. The MDT used is the Mediterranean 2020 product (MDT\_CMEMS\_2020\_MED, Jousset et al., 2022). The dataset, is available in Near-Real-Time (NRT, product reference 1) and delayed-time (DT, product reference 2), and supports studies of mesoscale and large-scale sea level variability (e.g. Pascual et al., 2007; 2009; Marcos et al., 2015; Taburet et al., 2018; Ballarotta et al., 2019; Sánchez-Román et al., 2023). The NRT data is updated daily, and at the moment of the study had a temporal coverage from 04/10/2022 to 25/11/2024, while the delayed-time data from 01/01/1992 to 31/12/2023. Therefore, the DT product is only used for the analysis of the mean circulation (fig. 1), and the NRT product is used for the rest of analyses as it covers 2024.

## 104 2.2 MIOST with SWOT KaRIn (MIOST-K)

105 The Multiscale Inversion of Ocean Surface Topography (MIOST) product (Table 1, product reference 3) is a new-generation  
106 gridded altimetry dataset that incorporates SWOT KaRIn data, i.e., two-dimensional swath (SSHA) observations. This global  
107 product is available at a spatial resolution of  $1/8^\circ$  and at daily temporal frequency. We utilized the experimental L4  
108 multimission sea level product distributed by AVISO v2.0.1, which combines SWOT swath altimetry with conventional  
109 nadir altimeter measurements. The dataset relies on the MIOST method (Ubelmann et al., 2021, 2022), a statistical technique  
110 that reconstructs sea surface height fields by decomposing variability across multiple spatial and temporal scales. The  
111 reconstruction combines SWOT KaRIn wide-swath observations, SWOT nadir data, and conventional nadir altimeter  
112 measurements within broad spatio-temporal windows around the target date. In Delayed-Time (DT) mode, both past and  
113 future observations are incorporated to constrain the interpolation process, with decreasing weights assigned to observations  
114 farther away in time. This allows mesoscale structures sampled during nearby overpasses to contribute to the reconstructed  
115 daily fields beyond the instantaneous SWOT and nadir ground-track coverage (see Fig. A1 for an example of the SWOT  
116 coverage contributing to the reconstruction of day 20/04/24) (Ballarotta et al., 2025c). The MDT product used is also the  
117 MDT\_CMEMS\_2020\_MED (Jousset et al., 2022). More details can be found in Ballarotta et al., (2025c). These products  
118 were processed by SSALTO/DUACS and distributed by AVISO (<https://www.aviso.altimetry.fr>) supported by CNES.

119 The inclusion of SWOT's Ka-band Radar Interferometer (KaRIn) observations improves the resolution of SSH fields,  
120 allowing finer-scale ocean dynamics (such as mesoscale and submesoscale structures) to be resolved. This experimental  
121 product (from hereinafter MIOST-K) provides daily gridded maps of SSH and derived geostrophic velocities, offering new  
122 opportunities to study ocean surface variability at unprecedented detail. (Ballarotta et al., 2025c)

## 123 3 Methods

### 124 3.1 Py-eddy tracker

125 The py-eddy-tracker is an eddy tracking algorithm based on geometric and physical techniques. It was firstly developed by  
126 Mason et al. (2014) and later updated by Delepouille et al. (2022). Since then, it has been widely used to study eddies and for  
127 the generation of updated eddy field datasets (e.g. Pegliasco et al. 2022). In this study, we use version 3.6.1 of the algorithm  
128 (Delepouille et al., 2022) to identify eddies from daily snapshots of Absolute Dynamic Topography (ADT) fields. Two types  
129 of contours are identified by the algorithm: the effective contour (outermost closed contour defining the eddy extent) and the  
130 speed contour (inner contour corresponding to the region of maximum mean azimuthal geostrophic velocity). Further details  
131 can be found in Mason et al. (2014). Compared to SLA, ADT provides more reliable eddy identification, especially in the  
132 Mediterranean Sea (Pegliasco et al., 2021, 2022), because it includes both the mean dynamic topography and its temporal  
133 variability, helping distinguish mesoscale eddies from variations in persistent jets and recurrent circulation patterns included

134 in the MDT. A pre-processing and set of parameterizations are necessary to implement the py-eddy tracker (see Mason et al.,  
135 2014; Pegliasco et al., 2022 for further details):

- 136 1) The ADT fields are filtered with a Bessel high-pass filter of 500 km to remove the background large-scale signal  
137 and isolate the eddies (Pegliasco et al., 2022).
- 138 2) A detection step of 0.002 m was used between consecutive isolines. This corresponds to the height difference  
139 between contour levels used to identify eddy boundaries. Starting from the eddy center (defined by a minimum  
140 value for cyclonic eddies and a maximum value for anticyclonic eddies), closed ADT isolines are identified outward  
141 at intervals of 0.002 m until the eddy edge is reached (Cui et al., 2025).
- 142 3) A maximum shape error of 55% is allowed for a detected contour to be identified as an effective eddy. This metric  
143 is defined as the ratio between the circle fit and identified outermost contour. This shape error (Kurian et al., 2011)  
144 limits the identification to eddies, and removes other elongated closed-contour structures like filaments (Mason et  
145 al., 2019).

### 146 3.2 Particle simulations and eddy retention calculation

147 We calculate the eddy particle retention to quantify how differences in eddy properties, such as size, intensity, and associated  
148 EKE, influence particle transport and trapping. For this analysis, Lagrangian simulations are performed using the  
149 OceanParcels Lagrangian framework v2.4.2 (Delandmeter and van Sebille, 2019) to simulate 2D trajectories of virtual  
150 particles at the sea surface. Particles are advected using the velocity fields of the two datasets (DUACS-OI and MIOST-K).  
151 A fourth order Runge-Kutta particle advection scheme is used with a run-time time-step (dt) of 25 minutes. Particles are  
152 treated as infinitesimal, passive and buoyant tracers transported exclusively by horizontal advection, with no additional  
153 physical processes included. Simulations are performed with particles released within a 2 by 2° box around identified  
154 Algerian eddies' contours separated by 1/30° (~3.5 km) with an advection time (T) of 20 days. The inner (speed) eddy  
155 contour is used here, to keep the eddy's more coherent inner core. This timescale represents a trade-off between the  
156 minimum lifetime of the Algerian eddies (~60 days) and the requirement that enough particles remain within the eddy core  
157 during the simulation. Particles which leave the domain are removed from the analysis. Here we showcase the impact on the  
158 retention capacity by selecting 3 Algerian eddies as representative examples. Further details are shown in Table C1.

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160 Next, the eddy retention is calculated as the relative difference in the number of particles enclosed by the eddy contour  
161 between the release day and 20 days later. The Eddy Retention Percentage (ERP) is then calculated as:

$$162 \text{ ERP} = \frac{N_T - N_0}{N_0} \times 100, \quad (1)$$

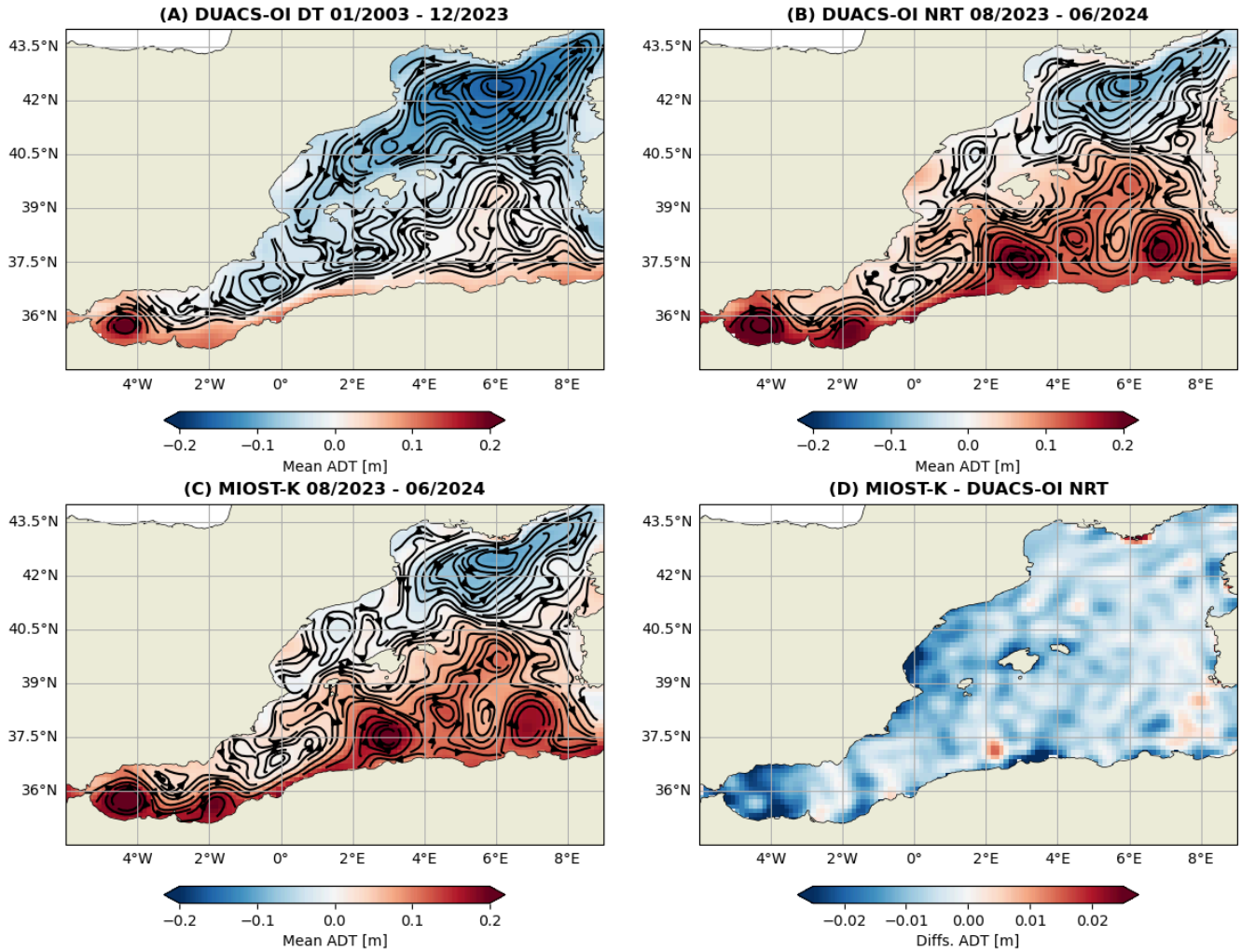
163 where  $N_T$  and  $N_0$  are the number of particles at the final and the release days, respectively.

## 164 4 Results

165 The general circulation of the western Mediterranean has been thoroughly studied in the past. The new SWOT data is  
166 unveiling smaller oceanic scales and partially or even unobserved dynamics, but the impact of this on the general circulation  
167 patterns will be better understood when we have more years of SWOT data. Currently, with more than one year of SWOT  
168 data during the science phase, we can already infer a first estimate of how and if these general circulation patterns are  
169 affected by this new dataset, and thus the consequences this could have for different monitoring efforts (Fig. 1). Fig. 1A is  
170 included as a reference representation of the mean circulation over 20 years in the western Mediterranean. The main  
171 circulation features shown in Fig. 1A are also observed in the shorter-term averages shown in panels B and C, indicating that  
172 the large-scale circulation is consistently represented in both datasets. Differences between Figs. 1B and C arise mainly at the  
173 smaller-scale features and in the characteristics of the mesoscale structures, already suggesting that the inclusion of SWOT  
174 observations impacts the representation of mesoscale circulation. Although part of these differences may also arise from  
175 intrinsic methodological differences between the DUACS-OI and MIOST reconstruction approaches, previous comparisons  
176 based solely on nadir altimetry showed relatively small differences between the two products in the Mediterranean  
177 (Ballarotta et al., 2023; Verbrugge et al., 2024). This suggests that the higher differences observed here are strongly  
178 influenced by the inclusion of SWOT wide-swath observations in MIOST-K. These differences are further highlighted in the  
179 mean ADT difference field shown in Fig. 1D, particularly in coastal regions and along energetic circulation pathways (e.g.  
180 Alboran Sea and Algerian Current). However, the magnitude of these differences is about an order of magnitude smaller  
181 than the values in the ADT field (note the limits of colorbar in Figures 1B, 1C and 1D). This is expected from the enhanced  
182 spatial sampling provided by SWOT wide-swath observations compared to conventional nadir altimetry (e.g.  
183 Lopez-Radcenco et al., 2019; Ballarotta et al., 2025), particularly for mesoscale and coastal structures (e.g. Dibarboure et al.,  
184 2024). In contrast to the effectively one-dimensional along-track sampling of nadir altimeters, SWOT provides  
185 two-dimensional swath measurements, and the implications of these differences are further explored through the analysis of  
186 daily eddy variability in the following sections.

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190 **Figure 1: General circulation represented by the mean Absolute Dynamic Topography (ADT) and the mean velocity field**  
 191 **(streamlines) calculated from the different altimetric products: (A) 20 years mean from DUACS-DT (product reference 2), (B) 11**  
 192 **months mean of DUACS-NRT (product reference 1), (C) 11 months mean of MIOST-K (product reference 3) and (D) mean ADT**  
 193 **difference between MIOST-K and DUACS-OI ( (C) - (B) ).**

194 We obtain the daily eddy identification fields for both datasets from August 2023 to June 2024 (inclusive), and calculate the  
 195 total number of cyclonic (blue) and anticyclonic (red) eddies. An example of all the eddies identified daily during April 2024  
 196 is shown in panels (A) and (B) in Fig. 2 for DUACS-OI and MIOST-K, respectively. The spatial distribution of eddy centre  
 197 counts, computed in 1 by 1° bins over the full study period, is shown in panels (C) and (D). Both products identify high eddy  
 198 activity in the central and northwestern Mediterranean, and the Alboran Sea, although MIOST-K generally detects a larger  
 199 number of eddies, particularly in coastal regions such as west of Corsica (also observed in Fig. 2A and B). Complementary  
 200 observations, including satellite chlorophyll data, support the presence of coastal eddies in this region (Fig. B1; Fortunato et  
 201 al., 2025). Moreover, the DUACS-OI product appears to merge multiple nearby cyclonic eddies into one larger structure,

202 particularly in areas such as the Gulf of Lion, thereby reducing the number of identified eddies. The daily temporal  
203 variability of anticyclonic and cyclonic eddy counts is shown in panels (E) and (F), respectively. Despite high temporal  
204 variability, MIOST-K consistently identifies a larger number of eddies than DUACS-OI throughout most of the analysis  
205 period. For anticyclonic eddies, MIOST-K detects on average  $19.0 \pm 2.0$  eddies per day (mean  $\pm$  standard deviation),  
206 compared to  $12.5 \pm 2.0$  for DUACS-OI. For cyclonic eddies, the mean daily counts are  $20.4 \pm 3.1$  and  $16.6 \pm 2.4$  for  
207 MIOST-K and DUACS-OI, respectively. The temporal correlation between the two daily eddy-count time series is low for  
208 both anticyclonic ( $r = 0.253$ ) and cyclonic eddies ( $r = 0.165$ ). This likely reflects the sensitivity of daily eddy counts to  
209 product-dependent differences not only in eddy detection, but also splitting, merging, and lifetime, rather than fundamental  
210 differences in the temporal variability of mesoscale activity.

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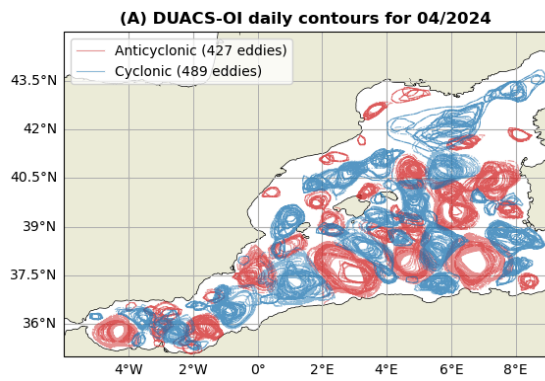
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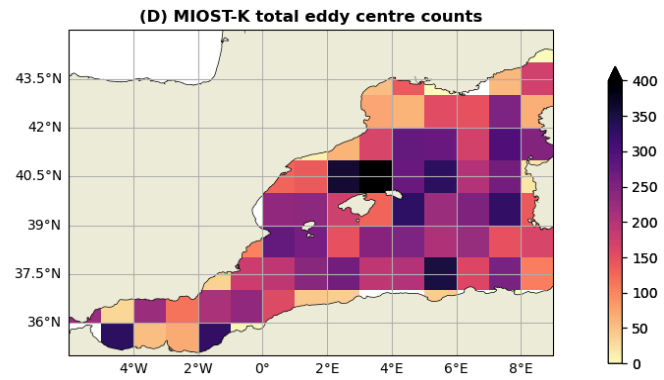
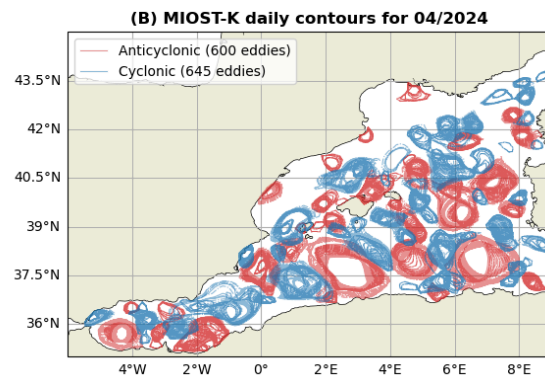
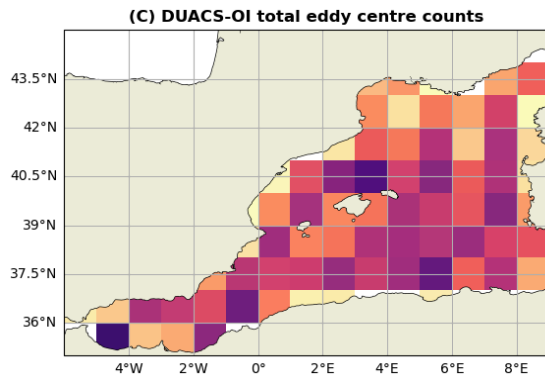
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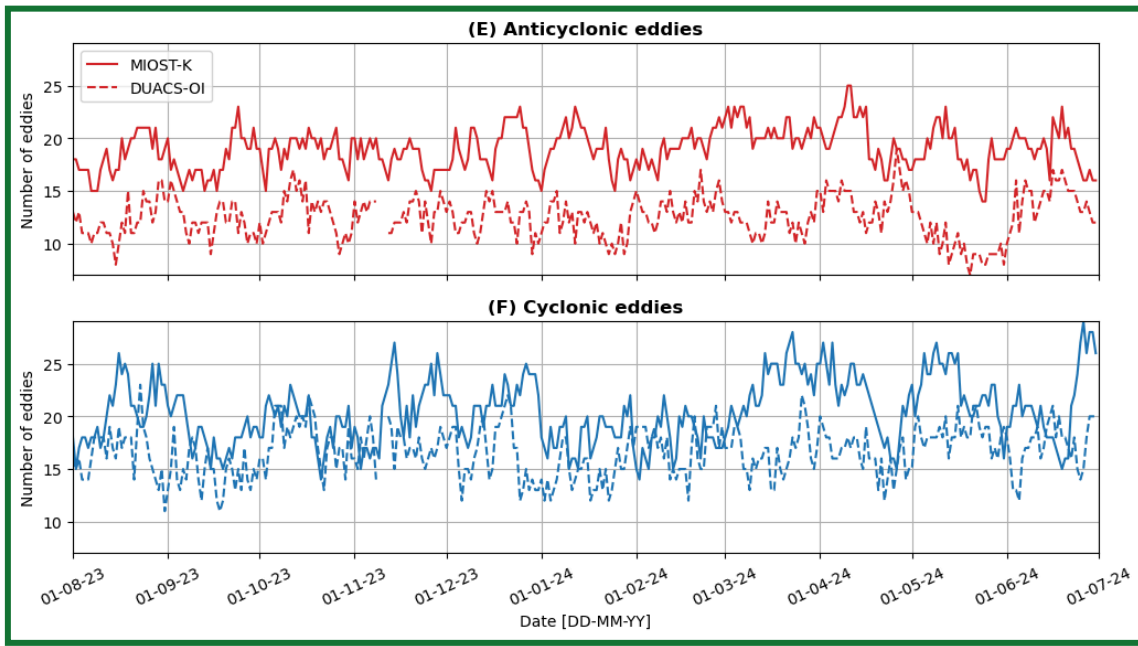
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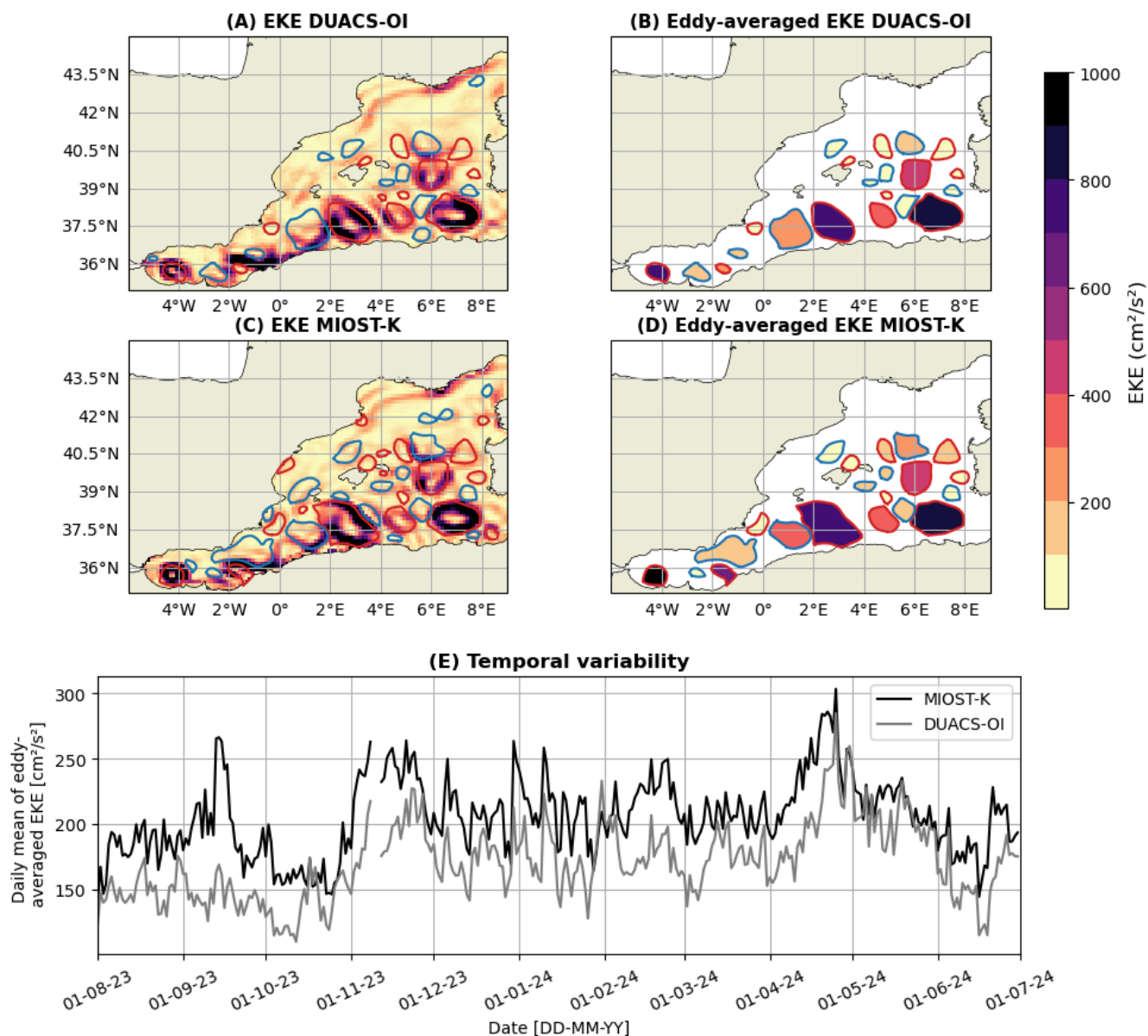
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229 **Figure 2: Number of daily eddy identifications. Panels (A) and (B) show all the daily eddies (outer contours) identified during**  
 230 **April 2024 for DUACS-OI (product reference 1) and MIOST-K (product reference 3), respectively. Panels (C) and (D) show the**  
 231 **eddy centre counts in  $1\times 1^\circ$  bins, for DUACS-OI and MIOST-K, respectively. Panels (E) and (F) show the temporal variability of**  
 232 **the anticyclones and cyclones, respectively, identified throughout the study period.**

233 With the inclusion of the SWOT data, we also observe changes in the already observed big mesoscale eddies of the  
 234 DUACS-OI product. An important change is in the EKE associated with these eddies. Firstly, the EKE field is retrieved  
 235 (Delepoulle et al., 2022) for each daily field (Figs. 3A and 3C). Then we find the eddies that match for both datasets and

calculate the mean EKE associated to these eddies. i.e., the eddy-averaged EKE (Figs. 3B and 3D). Fig. 3E shows the temporal variability of the daily mean of eddy-averaged EKE (daily mean EKE) of all the matching eddies identified. MIOST-K shows a higher daily mean throughout the majority of the study's time period. Both datasets reach their maximum during the same energetic event on 25/04/2024, although the MIOST-K value is approximately 6% higher than in DUACS-OI. More importantly, specific daily differences between the products can be substantially larger, with MIOST-K exhibiting increases of up to 78% relative to DUACS-OI during certain energetic mesoscale events, such as on 16/09/23. On 96% of the days, the daily mean in MIOST-K is higher than in DUACS-OI (we also checked the differences in the daily maximum of eddy-averaged EKE, and these are higher 93% of the time). This enhanced EKE representation is likely associated with the improved spatial sampling, two-dimensional swath geometry, and enhanced representation of higher-wavenumber variability enabled by SWOT observations. Furthermore, SWOT observations are expected to exhibit substantially lower noise levels than conventional nadir altimeters (Vergara et al., 2023), which may also contribute to the differences observed. This has important implications for KE trend studies (e.g. Martínez-Moreno et al., 2019; Barcelo-Llull et al., 2025), which in turn also can mean a challenge for current climate model projections (Barcelo-Llull et al., 2025). For example, Hogg et al. (2015) mention the significant impact EKE trend variations have on the ocean's carbon and heat sinks in regions like the Southern Ocean, where increasing EKE has been associated with changes in the efficacy of these sinks and the consequent global climatic implications. In the western Mediterranean Sea, where mesoscale eddies strongly influence transport and exchanges between subbasins, the enhanced EKE representation identified in MIOST-K may similarly have important implications for regional heat, salt, and carbon-related transport processes. For example, the higher EKE observed in the energetic Alboran Sea eddies shown in Fig. 3 could affect the representation of heat and salt exchanges through the Strait of Gibraltar (e.g. Bryden et al., 1994; Tsimplis and Bryden, 2000; Sánchez-Román et al., 2009; Hargous et al., 2026). Such differences in EKE and mesoscale structure representation may also influence particle transport and retention estimates, with implications for marine pollution management and offshore spatial planning, as explored in the Algerian eddy case study presented in the following section.

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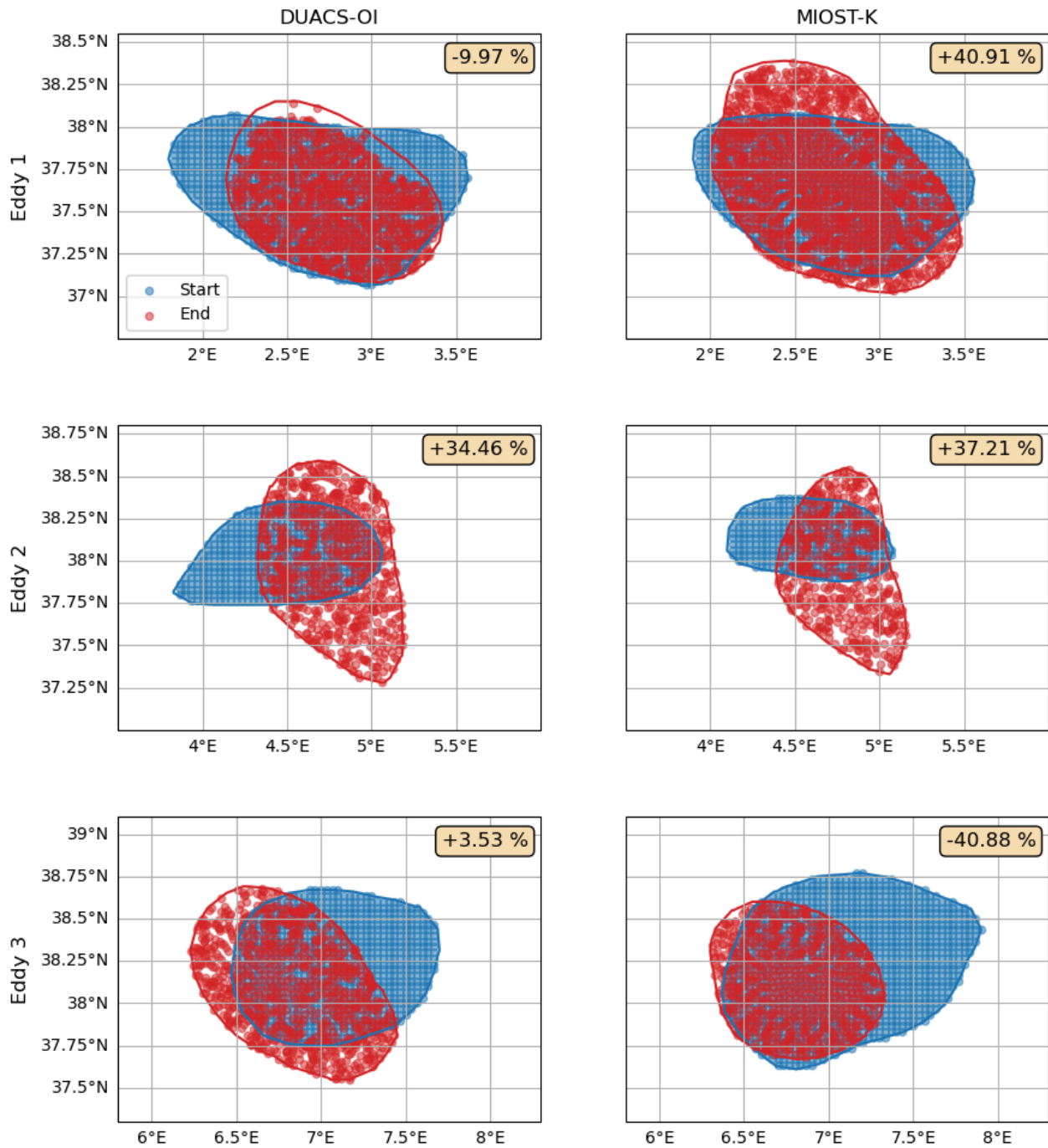


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261 Figure 3: Temporal variability of Eddy Kinetic Energy (EKE) associated with the detected eddies. Panels (A) and (C) show the  
 262 EKE field on 20/04/2024 and all the identified anticyclonic (red) and cyclonic (blue) outer eddy contours, for DUACS-OI (product  
 263 reference 1) and MIOST-K (product reference 3), respectively. Panels (B) and (D) show the individual eddy-averaged EKE of only  
 264 the eddies identified in both datasets on that date. (E) shows the temporal variability of the spatially averaged EKE within  
 265 detected, matching eddy contours and averaged across all eddies for each day for DUACS-OI (dashed) and MIOST-K (solid).

266 Figure 4 illustrates three examples of Algerian Eddies and their retention capacity. All three eddies were observed in  
 267 different regions of the Algerian Basin during multiple SWOT KaRIn overpasses throughout their respective 20-day  
 268 advection periods (approximately five overpasses for each case), supporting the use of these examples to assess the influence

269 of SWOT-enhanced reconstruction on particle retention estimates. After 20 days, the eddies retain substantially different  
270 percentages of particles, reflecting the strong variability in mesoscale transport and retention processes across the subbasin.  
271 Such differences are expected between Algerian eddies, as their retention capacity can depend on their dynamical state,  
272 including eddy intensity, coherence, deformation, interaction with the surrounding circulation, and eddy lifetime stage. We  
273 therefore consider three different eddy examples to illustrate how differences in mesoscale representation between  
274 DUACS-OI and MIOST-K can impact transport and retention estimates under different dynamical conditions. In Eddy 1, the  
275 DUACS-OI eddy shows leakage, while the MIOST-K eddy retains and even increases the number of particles inside the  
276 eddy contour. In Eddy 2, both products retain more particles, although retention is slightly higher in MIOST-K. In contrast,  
277 Eddy 3 exhibits stronger leakage in MIOST-K, while DUACS-OI retains slightly more particles. This demonstrates an  
278 important impact of the differences in eddy properties identified between the operational DUACS-OI and the new dataset,  
279 MIOST-K. Despite only subtle qualitative differences in eddy contours (Fig. 2), the particle retention over just 20 days shows  
280 high variability, likely linked to the higher EKE structures observed in the SWOT-enhanced product (Fig. 3). These  
281 differences are not only scientifically relevant but may also have practical implications for environmental monitoring and  
282 marine spatial planning. The same eddy can exhibit opposite retention and leakage behaviours depending on the product  
283 used. If applied operationally, such contrasting representations could lead to substantially different estimates of the transport  
284 and accumulation of pollutants, marine litter, nutrients, fish larvae, or aquaculture-derived waste, potentially influencing  
285 pollutant dispersion assessments, aquaculture site suitability, or ecosystem management strategies.



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287 Figure 4: Eddy retention capacity of three Algerian Eddies examples for DUACS-OI (left panels, product reference 1) and  
 288 MIOST-K (right panels, product reference 3). Blue (red) particles and contours (inner eddy contours) correspond to the initial  
 289 (final) dates (see Table C1). Only particles inside the eddy contours are shown. The top right box indicates the eddy retention  
 290 percentage, with positive (negative) values indicating retention (leakage).

## 291 5 Discussion

292 In this study, we highlight the value of incorporating wide-swath altimetric observations for advancing the representation of  
293 mesoscale ocean dynamics. A key dynamic property of mesoscale eddies is their associated EKE. Results indicate a notable  
294 increase in signal strength, with MIOST-K capturing regional means of daily EKE up to 1.8 times greater than DUACS-OI.  
295 This result is important due to its link with the understanding of atmosphere-ocean interactions, especially in the current  
296 climate change scenario. Better monitoring these structures, not only their occurrence, but their characteristics, is key for  
297 related monitoring studies of for example sea surface temperature, and marine operational activities such as forecasts of  
298 extreme events and marine fisheries management.

299

300 The increase in eddy detections with MIOST-K is more pronounced for anticyclonic eddies than for cyclonic eddies.  
301 Although the origin of this eddy asymmetry was not specifically investigated here, it may be related to the improved  
302 detection of smaller-scale and coastal eddies, where the differences between the products are strongest. In the western  
303 Mediterranean, anticyclonic eddies tend to be more persistent, coherent, and longer-lived than cyclonic eddies (Stegner et al.,  
304 2021), potentially increasing their detectability in SWOT products. Similar asymmetries have also been observed by SWOT  
305 in other regions, and are generally explained by the greater stability and propagation capacity of anticyclonic eddies,  
306 allowing them to persist longer and propagate farther (de Marez et al., 2026). This enhanced detection of anticyclonic eddies  
307 may also be relevant for the monitoring of long-lasting surface temperature anomalies associated with these structures, which  
308 could contribute to the development of local marine heatwaves (Aguilar et al., 2022).

309

310 We also observe clear changes in the retention capacity of Algerian eddies with MIOST-K over a 20-day period. This result  
311 has important consequences for marine pollution management strategies, namely those that can affect marine protected areas  
312 like the Cabrera National Park (Compa et al., 2020). This also influences the transport properties of these eddies related to  
313 the redistribution of temperature, salinity and nutrients, which influence the circulation of the area, and the nutrient inputs in  
314 other regions of the western Mediterranean Sea (e.g. Bryden et al., 1994; Hargous et al., 2026).

315

316 The eddy identification algorithm used to identify eddies is quite sensitive to pre-processing choices and parameterizations  
317 (e.g. Pegliasco et al., 2021), and could be refined in follow-up studies. Here it is used to compare 2 datasets, so the impact on  
318 the conclusions obtained should be minimal. The Eulerian method used here is commonly implemented in the community,  
319 namely in altimetry. Many other eddy identification and tracking techniques exist which use an Eulerian framework (e.g.  
320 Ioannou et al., 2024), but also Lagrangian ones, which could help to better capture retention capabilities, as Lagrangian  
321 structures could assess material coherence in space and time simultaneously (e.g. Beron-Vera et al., 2013; Haller et al., 2016;  
322 Liu et al., 2019; Cortes-Morales et al., in prep.). To further validate the robustness of our retention findings, future work could  
323 extend the Lagrangian analysis to a larger ensemble of eddies. Statistical comparison across datasets would help quantify

whether observed differences are consistent and significant, and whether eddy properties such as size or eccentricity correlate with retention efficiency. This would also support the operational use of eddy-based transport estimates in pollution risk forecasting and coastal marine management. Lastly, we take advantage of a very novel dataset (MIOST-K), but it is under continuous improvement due to the young age of SWOT. It will be interesting to continue this study with a longer series of data to further evaluate these mesoscale eddies in the Mediterranean region and look further into the improvement of the coastal eddy field in the region (Fortunato et al., 2025).

It is worth mentioning that, by design, conventional interpolation methods tend to filter out small-scale features detected by SWOT, leading to an underrepresentation of fine-scale eddies (typically around 50 km in diameter, or <100 km in wavelength) in Level-4 products such as DUACS and MIOST. Moreover, SWOT captures a broader range of high-resolution ocean dynamics, including nonlinear eddies and internal waves, that are beyond the reach of nadir altimeters and not resolved by current mapping techniques. Recent studies have shown that mesoscale eddies can be identified directly from SWOT wide-swath SSH observations (e.g. Verger-Miralles et al., 2025; de Marez et al., 2026; Han et al., 2026; Fu et al., 2026). This direct approach is less suited to larger eddies that extend beyond the swath, but preserves the fine-scale information contained in SWOT observations and avoids the smoothing introduced by Level-4 mapping. However, a key limitation lies in the coarse temporal sampling imposed by the 21-day repeat cycle of the science phase, which hinders the analysis of rapidly evolving fine-scale dynamics (Archer et al., 2025). To fully exploit SWOT's potential, especially at submesoscales, new frameworks are needed. Promising advances in this direction are emerging from data- and model-driven mapping approaches (e.g., Fablet et al., 2021; Le Guillou et al., 2023, 2024) and in the development of robust validation strategies tailored to SWOT observations (Coadou-Chaventon et al, 2025; Verger-Miralles et al, 2025).

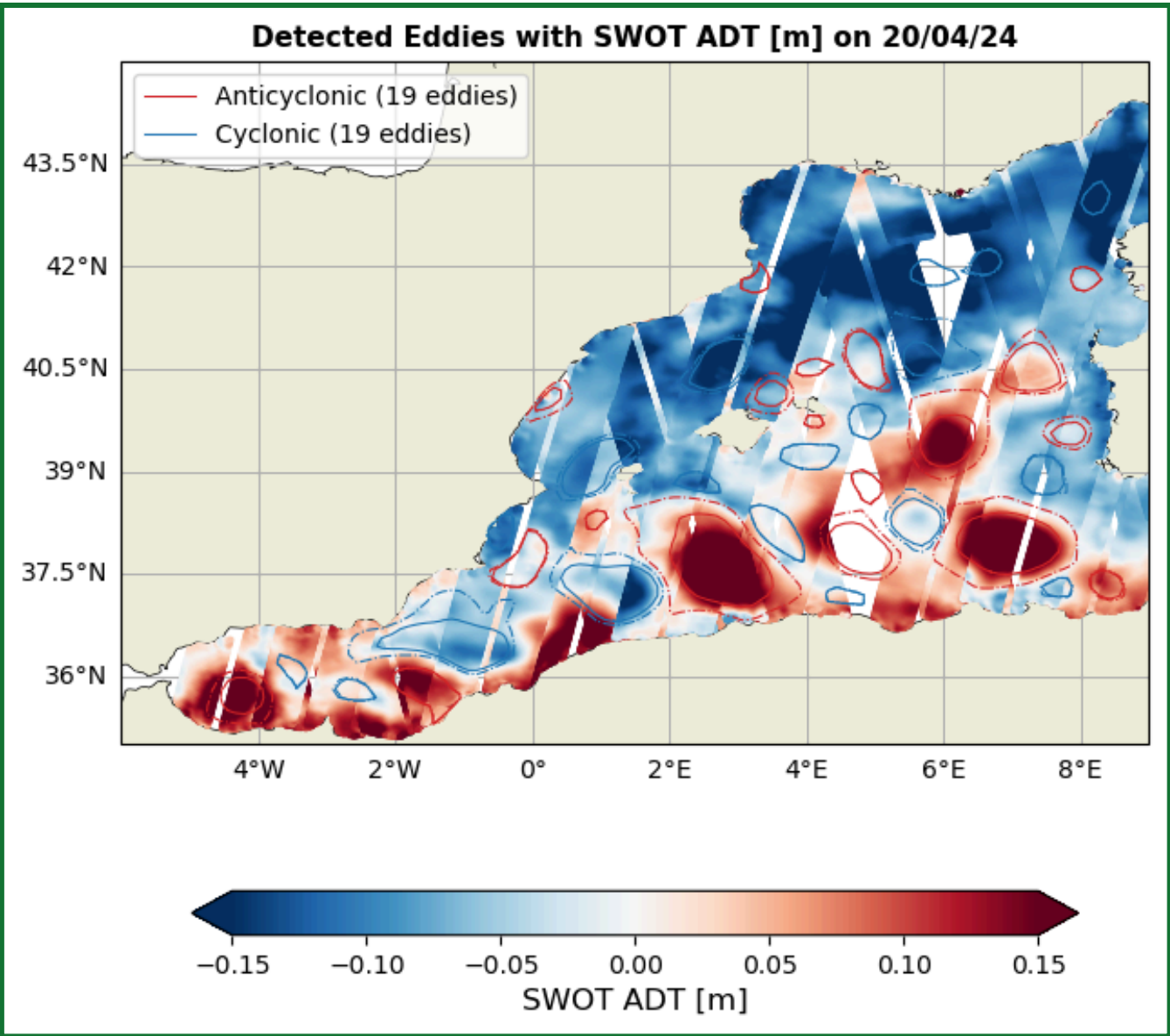
## 6 Conclusions

This study provides new insights on how the monitoring capabilities of surface circulation, namely mesoscale activity, will improve with the new wide-swath satellites such as SWOT. This is relevant to improve operational oceanography services, for example in managing and forecasting marine pollution events. The objective is to assess changes in the mesoscale eddy field by quantifying eddy count, variability, and associated kinetic energy. We then examine how the detected eddy properties affect their retention capacity. While this study is not intended as a comprehensive intercomparison of the DUACS-OI and MIOST-K products, it does show how the surface currents monitoring scenario might change in the near future, opening the door to a better representation of the different processes involved and its implications.

The results show the promising potential of new wide-swath products to better understand the eddy field, achieving specific capacities, particularly for observing small mesoscale eddies and resolving features in coastal areas. We also find that the already observed mesoscale eddy field by conventional products (DUACS-OI) has notable differences when compared to

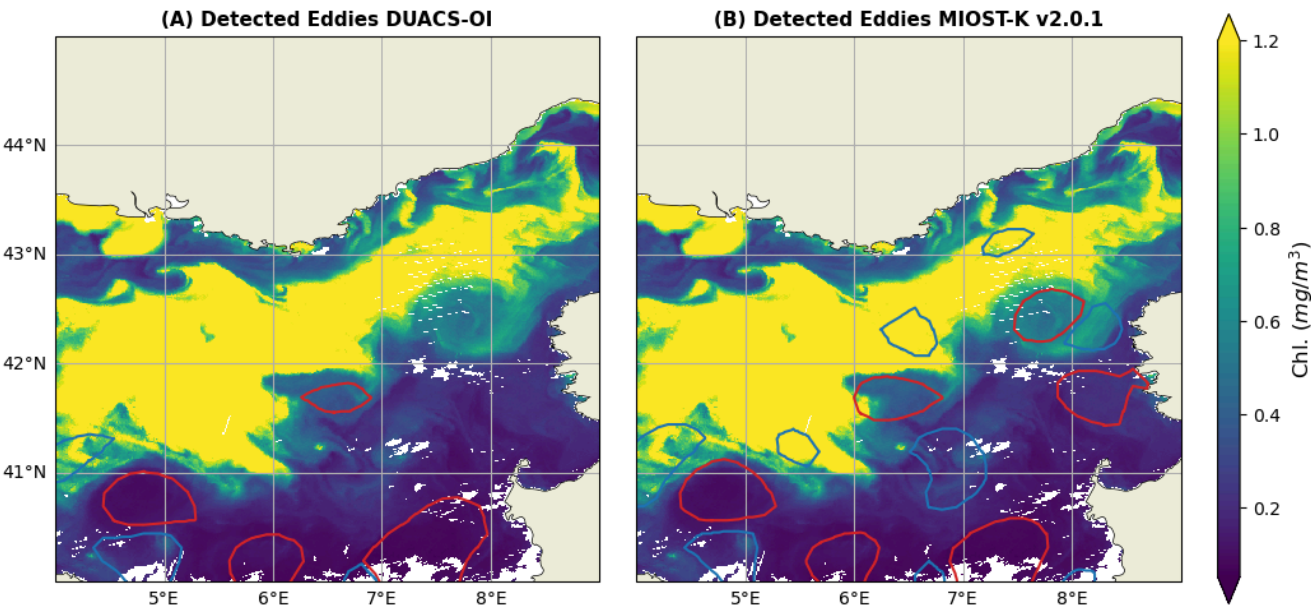
new products including SWOT (MIOST-K). An increase in Eddy Kinetic Energy (EKE) is found, which plays a vital role in the Mediterranean Sea by driving the variability of ocean circulation, redistributing heat, salt, and nutrients, and supporting marine productivity in this climatically sensitive region. Mesoscale eddies, which contribute to EKE, influence biological hotspots, the dispersion of pollutants, marine heatwaves and local weather patterns such as Mediterranean cyclones. Monitoring EKE is therefore essential for improving ocean forecasting, managing fisheries, and understanding the impacts of climate change. This requires high-resolution observations from satellites, autonomous platforms, and regional cooperation to effectively track these dynamic processes and inform environmental management and policy. With this new dataset, the gap of high-resolution satellite data is further filled. The retention capacity of the eddies is strongly affected with this new data, meaning that once this data is incorporated into the operational products, a better estimation of marine pollution impacts will be possible. This will be of importance for different marine management strategies, especially those related to marine pollution and fisheries management.

Our findings demonstrate that incorporating SWOT wide-swath observations affects the representation of surface mesoscale features in the western Mediterranean, including in regions where conventional altimetry has limitations. By comparing eddy characteristics such as associated EKE and retention capacity, we show how these improvements can directly support marine applications such as pollution risk assessment for the protection of marine reserves. Looking ahead, the integration of next-generation satellite technologies and data-processing methodologies will be essential to further refine surface current products. This work contributes to a framework for ongoing monitoring and evaluation of regional circulation patterns, and underscores the importance of sustained innovation in ocean observing systems.



376  
377 Figure A1: Outer (dashed) and inner (solid) eddy contours identified with MIOST-K on 20/04/24. The background fields are all the  
378 SWOT L3 ADT (filtered) [m] observations on 20/04/24 +/- 10 days.

379 SWOT L3 LR ADT 2 km (Expert v2.0.1) data was obtained from AVISO (AVISO/DUACS, 2024).



383

384 **Figure B1:** Chlorophyll fields (Chl.) on 02/04/24 with the corresponding eddy outer contours (anticyclonic red, cyclonic blue) for  
385 DUACS-OI (left) and MIOST-K (right).

386 Daily level-3 chlorophyll-*a* concentrations at 1 km spatial resolution were obtained from the multi-sensor dataset  
387 cmems\_obs-oc\_med\_bgc-plankton\_my\_l3-multi-1km\_PID, distributed within the Copernicus Marine product  
388 *Mediterranean Sea, Bio-Geo-Chemical, L3, daily Satellite Observations (1997–ongoing)* (product ID:  
389 OCEANCOLOUR\_MED\_BGC\_L3\_MY\_009\_143; DOI: 10.48670/moi-00299). Last accessed on: 17/05/2026. (Berthon  
390 and Zibordi, 2004; Volpe et al., 2019)

391 Appendix C

392 **Table C1.** Eddy retention information.

|        | Date       |            | Number of particles<br>(DUACS-OI; <b>MIOST-K</b> ) |                   |
|--------|------------|------------|----------------------------------------------------|-------------------|
|        | Initial    | End        | Initial                                            | End               |
| Eddy 1 | 01/04/2024 | 21/04/2024 | 1123; <b>1078</b>                                  | 1011; <b>1519</b> |
| Eddy 2 | 01/02/2024 | 21/02/2024 | 502; <b>344</b>                                    | 675; <b>472</b>   |
| Eddy 3 | 01/02/2024 | 21/02/2024 | 821; <b>1140</b>                                   | 850; <b>674</b>   |

393

### 394 **Code availability**

395 The codes used in this study are available on GitHub:  
396 [https://github.com/LauraGomezNavarro/paper-OSR10\\_Gomez-Navarro\\_etal\\_2026](https://github.com/LauraGomezNavarro/paper-OSR10_Gomez-Navarro_etal_2026), and the version used for the manuscript  
397 is published on Zenodo: <https://doi.org/10.5281/zenodo.16940147> — <https://doi.org/10.5281/zenodo.22659162>  
398 (Gómez-Navarro, ~~2026~~2026).

### 399 **Data availability**

400 The data used in this study can be downloaded directly from the Copernicus Marine Service and the AVISO websites. The  
401 exact product names are given in Table 1, and the associated DOIs are indicated in the references.

### 402 **Author contribution**

403 LGN, AP, MIP, MB, DCM, and LF contributed to the conceptualization of the study. LGN carried out the formal analysis,  
404 investigation, and prepared the original draft of the manuscript. DCM, AP, and LGN developed the methodology. MIP and  
405 MB curated the data. All authors contributed to the review and editing of the manuscript.

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## 419 References

- 420 20minutos: El GOB denuncia la presencia de numerosos residuos plásticos en aguas del parque Nacional de Cabrera.  
421 [https://www.20minutos.es/noticia/2517637/0/gob-denuncia-presencia-numerosos-residuos-plasticos-aguas-parque-nacional-c-](https://www.20minutos.es/noticia/2517637/0/gob-denuncia-presencia-numerosos-residuos-plasticos-aguas-parque-nacional-c-abrera/)  
422 [abrera/](https://www.20minutos.es/noticia/2517637/0/gob-denuncia-presencia-numerosos-residuos-plasticos-aguas-parque-nacional-c-abrera/), last access: 9 July 2025, 2015.
- 423
- 424 Aguiar, E., Mourre, B., Alvera-Azcárate, A., Pascual, A., Mason, E., and Tintoré, J.: Strong Long-Lived Anticyclonic  
425 Mesoscale Eddies in the Balearic Sea: Formation, Intensification, and Thermal Impact, *Journal of Geophysical Research:*  
426 *Oceans*, 127, e2021JC017589, <https://doi.org/10.1029/2021JC017589>, 2022.
- 427
- 428 Archer, M., Wang, J., Klein, P., Dibarboure, G., and Fu, L.-L.: Wide-swath satellite altimetry unveils global submesoscale  
429 ocean dynamics, *Nature*, 640, 691–696, <https://doi.org/10.1038/s41586-025-08722-8>, 2025.
- 430
- 431 AVISO/DUACS. SWOT level-3 KaRIn low rate SSH expert (v2.0.1) dataset. CNES.  
432 <https://doi.org/10.24400/527896/A01-2023.018>, 2024.
- 433
- 434 Ballarotta, M., Ubelmann, C., Pujol, M., Taburet, G., Fournier, F., Legeais, J., Faugère, Y., Delepouille, A., Chelton, D.,  
435 Dibarboure, G., and Picot, N.: On the resolutions of ocean altimetry maps, 2018, 1091–1109,  
436 <https://doi.org/10.5194/os-15-1091-2019>, 2019.
- 437
- 438 Ballarotta, M., Pujol, M.-I. and SL-TAC team: EU Copernicus Marine Service Quality Information Document for the  
439 European Seas Gridded L4 Sea Surface Heights And Derived Variables NRT, , SEALEVEL\_EUR\_PHY\_L4\_NRT\_008\_060,  
440 Issue 13.0, Mercator Ocean International,  
441 <https://documentation.marine.copernicus.eu/QUID/CMEMS-SL-QUID-008-032-068.pdf>, last access: 16 July 2025, 2025a.
- 442
- 443 Ballarotta, M., Pujol, M.-I. and SL-TAC team: EU Copernicus Marine Service Quality Information Document for the  
444 European Seas Gridded L4 Sea Surface Heights And Derived Variables Reprocessed 1993 Ongoing,  
445 SEALEVEL\_EUR\_PHY\_L4\_MY\_008\_068, Issue 13.0, Mercator Ocean International,  
446 <https://documentation.marine.copernicus.eu/QUID/CMEMS-SL-QUID-008-032-068.pdf>, last access: 16 July 2025, 2025b.
- 447
- 448 Ballarotta, M., Ubelmann, C., Bellemin-Laponnaz, V., Le Guillou, F., Meda, G., Anadon, C., Laloue, A., Delepouille, A.,  
449 Faugère, Y., Pujol, M.-I., Fablet, R., and Dibarboure, G.: Integrating wide-swath altimetry data into Level-4 multi-mission  
450 maps, *Ocean Science*, 21, 63–80, <https://doi.org/10.5194/os-21-63-2025>, 2025c.
- 451
- 452 Ballarotta, M.: SSALTO/DUACS Experimental Product Handbook: Gridded Sea Level Heights and geostrophic velocities  
453 computed with SWOT Level-3 products (using both KaRIn and nadir instruments) with MIOST Version 2.0.1., Issue 2.1.,

454 AVISO, [https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk\\_duacs\\_experimental\\_miost\\_swot\\_v2.1.pdf](https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_duacs_experimental_miost_swot_v2.1.pdf), last  
 455 access: 22 April 2026, 2025.

456

457 Barceló-Llull, B., Rosselló, P., Combes, V., Sánchez-Román, A., Pujol, M. I., and Pascual, A.: Kuroshio Extension and Gulf  
 458 Stream dominate the Eddy Kinetic Energy intensification observed in the global ocean, *Sci Rep*, 15,  
 459 <https://doi.org/10.1038/s41598-025-06149-9>, 2025.

460

461 Beron-Vera, F. J., Wang, Y., Olascoaga, M. J., Goni, G. J., and Haller, G.: Objective Detection of Oceanic Eddies and the  
 462 Agulhas Leakage, *Journal of Physical Oceanography*, 43, <https://doi.org/10.1175/JPO-D-12-0171.1>, 2013.

463

464 Berthon, J.-F. and Zibordi, G.: Bio-optical relationships for the northern Adriatic Sea, *International Journal of Remote  
 465 Sensing*, 25, 1527–1532, <https://doi.org/10.1080/01431160310001592544>, 2004.

466 Compa, M., Alomar, C., Mourre, B., March, D., Tintoré, J., and Deudero, S.: Nearshore spatio-temporal sea surface trawls of  
 467 plastic debris in the Balearic Islands, *Marine Environmental Research*, 158, 104945,  
 468 <https://doi.org/10.1016/j.marenvres.2020.104945>, 2020.

469

470 Coadou-Chaventon, S., Swart, S., Novelli, G., and Speich, S.: Resolving Sharper Fronts of the Agulhas Current Retroflection  
 471 Using SWOT Altimetry, *Geophysical Research Letters*, 52, <https://doi.org/10.1029/2025gl115203>, 2025.

472

473 Cortés-Morales, D. and Hernández-Carrasco, I.: Lagrangian coherent rate as an indicator of transport properties associated  
 474 with eddies in the Mediterranean sea (in preparation).

475

476 Cotroneo, Y., Celentano, P., Aulicino, G., Perilli, A., Olita, A., Falco, P., Sorgente, R., Ribotti, A., Budillon, G., Fusco, G.,  
 477 and Pessini, F.: Connectivity Analysis Applied to Mesoscale Eddies in the Western Mediterranean Basin, *Remote Sensing*,  
 478 13, 4228, <https://doi.org/10.3390/rs13214228>, 2021.

479

480 Cui, A., Zhang, Z., Yan, H., and Han, B.: Spatial and Temporal Characteristics of Mesoscale Eddies in the North Atlantic  
 481 Ocean Based on SWOT Mission, *Remote Sensing*, 17, 1469, <https://doi.org/10.3390/rs17081469>, 2025.

482

483 de Marez, C., Bendinger, A., and Dilmahamod, A. F.: High-latitude eddy statistics from SWOT compared with in situ  
 484 observations, *Ocean Science*, 22, 1515–1528, <https://doi.org/10.5194/os-22-1515-2026>, 2026.

485

486 Delepoulle, A., Mason, E., Busché, C., Pegliasco, C., Capet, A., Troupin, C., and Koldunov, N.: AntSimi/pyeddy-tracker:  
 487 v3.6.1, Zenodo [code], <https://doi.org/10.5281/zenodo.6333988>, 2022.

488

489 Diario de Mallorca: Casi la totalidad de los residuos de Cabrera son plásticos.  
 490 <https://www.diariodemallorca.es/mallorca/2022/04/18/totalidad-residuos-cabrera-son-plasticos-65095274.html>, last access: 9  
 491 July 2025, 2022.

492

493 Dibarboure, G., Anadon, C., Briol, F., Cadier, E., Chevrier, R., Delepouille, A., Faugère, Y., Laloue, A., Morrow, R., Picot,  
 494 N., Prandi, P., Pujol, M.-I., Raynal, M., Treboutte, A., and Ubelmann, C.: Blending 2D topography images from SWOT into  
 495 the altimeter constellation with the Level-3 multi-mission DUACS system, EGU sphere, 1–64,  
 496 <https://doi.org/10.5194/os-21-283-2025>~~<https://doi.org/10.5194/egusphere-2024-1501>~~, 2024.

497

498 Escudier, R., Mourre, B., Juza, M., and Tintoré, J.: Subsurface circulation and mesoscale variability in the Algerian subbasin  
 499 from altimeter-derived eddy trajectories, Journal of Geophysical Research: Oceans, <https://doi.org/10.1002/2016JC011760>,  
 500 2016.

501

502 EU Copernicus Marine Service Product: European Seas Gridded L4 Sea Surface Heights And Derived Variables NRT,  
 503 Mercator Ocean International [data set], <https://doi.org/10.48670/moi-00142>, 2025a

504

505 EU Copernicus Marine Service Product: European Seas Gridded L4 Sea Surface Heights And Derived Variables  
 506 Reprocessed 1993 Ongoing, Mercator Ocean International [data set], <https://doi.org/10.48670/moi-00141>, 2025b.

507

508 Fortunato, L., Gómez-Navarro, L., Combes, V., Cotroneo, Y., Aulicino, G., and Pascual, A.: Coastal Eddy Detection in the  
 509 Balearic Sea: SWOT Capabilities, Remote Sensing, 17, 2552, <https://doi.org/10.3390/rs17152552>, 2025.

510

511 Fu, C., Han, X., Wang, Q., Pennelly, C., and Myers, P. G.: Wide-swath satellite altimetry reveals hotspots of small mesoscale  
 512 eddies in the western Arctic Ocean, Commun Earth Environ, 7, 344, <https://doi.org/10.1038/s43247-026-03498-9>, 2026.

513

514 Fu, L., Pavelsky, T., Cretaux, J., Morrow, R., Farrar, J. T., Vaze, P., Sengenes, P., Vinogradova-Shiffer, N., Sylvestre-Baron,  
 515 A., Picot, N., and Dibarboure, G.: The Surface Water and Ocean Topography Mission: A Breakthrough in Radar Remote  
 516 Sensing of the Ocean and Land Surface Water, Geophysical Research Letters, 51, e2023GL107652,  
 517 <https://doi.org/10.1029/2023GL107652>, 2024.

518

519 Gómez-Navarro, L.: LauraGomezNavarro/paper-OSR10\_Gomez-Navarro\_etal\_2026: First ~~pre-release-update~~ (Version  
 520 v1.0.0). Zenodo [code]. <https://doi.org/10.5281/zenodo.22659162> Retrieved from doi: ~~[10.5281/zenodo.16940147](https://doi.org/10.5281/zenodo.16940147)~~, 2026.

521

522 Haller, G., Hadjighasem, A., Farazmand, M., and Huhn, F.: Defining coherent vortices objectively from the vorticity, Journal  
 523 of Fluid Mechanics, 795, 136–173, <https://doi.org/10.1017/jfm.2016.151>, 2016.

524

525 Han, X., Wang, Q., Stewart, A. L., Wang, Z., Yang, Q., Ni, Q., Liu, C., and Chen, D.: High coastal eddy activity around  
526 Antarctica revealed by SWOT, *National Science Review*, 13, nwag181, <https://doi.org/10.1093/nsr/nwag181>, 2026.

527

528 Hogg, A. McC., Meredith, M. P., Chambers, D. P., Abrahamsen, E. P., Hughes, C. W., and Morrison, A. K.: Recent trends in  
529 the Southern Ocean eddy field, *JGR Oceans*, 120, 257–267, <https://doi.org/10.1002/2014JC010470>, 2015.

530

531 Ioannou, A., Guez, L., Laxenaire, R., and Speich, S.: Global Assessment of Mesoscale Eddies with TOEddies: Comparison  
532 Between Multiple Datasets and Colocation with In Situ Measurements, *Remote Sensing*, 16, 4336,  
533 <https://doi.org/10.3390/rs16224336>, 2024.

534

535 Jousset, S., Aydogdu, A., Ciliberti, S., Clementi, E., Escudier, R., Jansen, E., Lima, L., Menna, M., Mulet, S., Nigam, T.,  
536 Sanchez-Roman, A., Tarry, D. R., Pascual, A., Peneva, E., Poulain, P.-M., and TaupierLetage, I.: New Mean Dynamic  
537 Topography of the Mediterranean Sea from altimetry, gravity and in-situ data, *Prep*, 2022.

538

539 Le Traon, P. Y., Nadal, F., and Ducet, N.: An Improved Mapping Method of Multisatellite Altimeter Data, *Journal of*  
540 *Atmospheric and Oceanic Technology*, 15, 522–534,  
541 [https://doi.org/10.1175/1520-0426\(1998\)015<0522:AIMMOM>2.0.CO;2](https://doi.org/10.1175/1520-0426(1998)015<0522:AIMMOM>2.0.CO;2), 1998.

542

543 Lopez-Radcenco, M., Pascual, A., Gómez-Navarro, L., Aissa-El-Bey, A., Chapron, B., and Fablet, R.: Analog Data  
544 Assimilation of Along-Track Nadir and Wide-Swath SWOT Altimetry Observations in the Western Mediterranean Sea,  
545 *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 12, 2530–2540,  
546 <https://doi.org/10.1109/JSTARS.2019.2903941>, 2019.

547

548 Liu, T., Abernathey, R., Sinha, A., and Chen, D.: Quantifying Eulerian Eddy Leakiness in an Idealized Model, *Journal of*  
549 *Geophysical Research: Oceans*, 124, 8869–8886, <https://doi.org/10.1029/2019JC015576>, 2019.

550

551 Marcos, M., Pascual, A., and Pujol, I.: Improved satellite altimeter mapped sea level anomalies in the Mediterranean Sea: A  
552 comparison with tide gauges, *Adv. Space Res.*, 56, 596–604, <https://doi.org/10.1016/j.asr.2015.04.027>, 2015.

553

554 Martínez-Moreno, J., Hogg, A. McC., Kiss, A. E., Constantinou, N. C., and Morrison, A. K.: Kinetic Energy of Eddy-Like  
555 Features From Sea Surface Altimetry, *Journal of Advances in Modeling Earth Systems*, 11, 3090–3105,  
556 <https://doi.org/10.1029/2019MS001769>, 2019.

557

558 Mason, E., Pascual, A., and McWilliams, J. C.: A New Sea Surface Height–Based Code for Oceanic Mesoscale Eddy  
559 Tracking, *Journal of Atmospheric and Oceanic Technology*, 31, 1181–1188, <https://doi.org/10.1175/JTECH-D-14-00019.1>,  
560 2014.

561

562 Morrow, R., Fu, L.-L., Arduin, F., Benkiran, M., Chapron, B., Cosme, E., d’Ovidio, F., Farrar, J. T., Gille, S. T., Lapeyre,  
563 G., Le Traon, P.-Y., Pascual, A., Ponte, A., Qiu, B., Rasche, N., Ubelmann, C., Wang, J., and Zaron, E. D.: Global  
564 Observations of Fine-Scale Ocean Surface Topography With the Surface Water and Ocean Topography (SWOT) Mission,  
565 *Frontiers in Marine Science*, 6, 232, <https://doi.org/10.3389/fmars.2019.00232>, 2019.

566

567 Pascual, A., Pujol, M.-I., Larnicol, G., Le Traon, P.-Y., and Rio, M.-H.: Mesoscale mapping capabilities of multisatellite  
568 altimeter missions: First results with real data in the Mediterranean Sea, *J. Mar. Syst.*, 211, 65:190,  
569 <https://doi.org/10.1016/j.jmarsys.2004.12.004>, 2007.

570

571 Pascual, A., Boone, C., Larnicol, G., and Le Traon, P.-Y.: On the Quality of Real-Time Altimeter Gridded Fields:  
572 Comparison with In Situ Data, *Journal of Atmospheric and Oceanic Technology*, 26, 556–569,  
573 <https://doi.org/10.1175/2008jtecho556.1>, 2009.

574

575 Pegliasco, C., Chaigneau, A., Morrow, R., and Dumas, F.: Detection and tracking of mesoscale eddies in the Mediterranean  
576 Sea: A comparison between the Sea Level Anomaly and the Absolute Dynamic Topography fields, *Advances in Space*  
577 *Research*, 68, 401–419, <https://doi.org/10.1016/j.asr.2020.03.039>, 2021.

578

579 Pegliasco, C., Delepouille, A., Mason, E., Morrow, R., Faugère, Y., and Dibarboure, G.: META3.1exp: A new Global  
580 Mesoscale Eddy Trajectories Atlas derived from altimetry, *Earth System Science Data*, 14, 1087–1107,  
581 <https://doi.org/10.5194/essd-14-1087-2022>, 2022.

582

583 Pessini, F., Olita, A., Cotroneo, Y., and Perilli, A.: Mesoscale eddies in the algerian basin: Do they differ as a function of  
584 their formation site?, *Ocean Science*, 14, 669–688, <https://doi.org/10.5194/os-14-669-2018>, 2018.

585

586 Pujol, M.-I.: EU Copernicus Marine Service Product User Manual for the European Seas Gridded L 4 Sea Surface Heights  
587 And Derived Variables NRT, SEALEVEL\_EUR\_PHY\_L4\_NRT\_008\_060, Issue 10.0, Mercator Ocean International,  
588 <https://documentation.marine.copernicus.eu/PUM/CMEMS-SL-PUM-008-032-068.pdf>, last access: 16 July 2025, 2025a.

589

590 Pujol, M.-I.: EU Copernicus Marine Service Product User Manual for the European Seas Gridded L 4 Sea Surface Heights  
591 And Derived Variables Reprocessed 1993 Ongoing, SEALEVEL\_EUR\_PHY\_L4\_MY\_008\_068, Issue 10.0, Mercator

592 Ocean International, <https://documentation.marine.copernicus.eu/PUM/CMEMS-SL-PUM-008-032-068.pdf>, last access: 16  
593 July 2025, 2025b.

594

595 py-eddy-tracker: Welcome to py-eddy-tracker's documentation!, <https://py-eddy-tracker.readthedocs.io/en/v3.3.1/>, last  
596 access: 8 July 2025.

597

598 Ruiz-Orejón, L. F., Mourre, B., Sardá, R., Tintoré, J., and Ramis-Pujol, J.: Quarterly variability of floating plastic debris in  
599 the marine protected area of the Menorca Channel (Spain), *Environmental Pollution*, 252, 1742–1754,  
600 <https://doi.org/10.1016/j.envpol.2019.06.063>, 2019.

601

602 Sánchez-Román, A., Pujol, M. I., Faugère, Y., and Pascual, A.: DUACS DT2021 reprocessed altimetry improves sea level  
603 retrieval in the coastal band of the European Seas, *EGU sphere*, 1–22, <https://doi.org/10.5194/egusphere-2023-63>, 2023.

604

605 Stegner, A., Vu, B. L., Dumas, F., Ghannami, M. A., Nicolle, A., Durand, C., and Faugere, Y.: Cyclone-Anticyclone  
606 asymmetry of eddy detection on gridded altimetry product in the Mediterranean Sea, *Journal of Geophysical Research: Oceans*, n/a, e2021JC017475, <https://doi.org/10.1029/2021JC017475>, 2021.

607

608

609 Suaria, G. and Aliani, S.: Floating debris in the Mediterranean Sea, *Marine Pollution Bulletin*, 86, 494–504,  
610 <https://doi.org/10.1016/j.marpolbul.2014.06.025>, 2014.

611

612 Taburet, G., Sanchez-Roman, A., Ballarotta, M., Pujol, M.-I., Legeais, J.-F., Fournier, F., Faugere, Y., and Dibarbour, G.:  
613 DUACS DT-2018: 25 years of reprocessed sea level altimeter products, *Ocean Sci.* 15, 1207-1224. 675 680 685 690 695 700  
614 <https://doi.org/10.5194/os-15-1207-2019>, 2019.

615

616 Taupier-Letage, I., Puillat, I., Millot, C., and Raimbault, P.: Biological response to mesoscale eddies in the Algerian Basin, *J.*  
617 *Geophys. Res.*, 108, <https://doi.org/10.1029/1999JC000117>, 2003.

618

619 Ubelmann, C., Dibarbour, G., Gaultier, L., Ponte, A., Arduin, F., Ballarotta, M., and Faugère, Y.: Reconstructing Ocean  
620 Surface Current Combining Altimetry and Future Spaceborne Doppler Data, *Journal of Geophysical Research: Oceans*, 126,  
621 e2020JC016560, <https://doi.org/10.1029/2020JC016560>, 2021.

622

623 Ubelmann, C., Carrere, L., Durand, C., Dibarbour, G., Faugère, Y., Ballarotta, M., Briol, F., and Lyard, F.: Simultaneous  
624 estimation of ocean mesoscale and coherent internal tide sea surface height signatures from the global altimetry record,  
625 *Ocean Science*, 18, 469–481, <https://doi.org/10.5194/os-18-469-2022>, 2022.

626

627 Última Hora: Un mar de plásticos. <https://www.ultimahora.es/noticias/local/2015/07/23/157489/mar-plasticos.html>, last  
628 access: 22 July 2025, 2015.

629

630 Verbruggen, N., Greiner E., Augot, J., Sammartino, M., Colella, S., Buongiorno-Nardelli, B., Hernandez-Carrasco, I., Falcini,  
631 F., Rossi, V. and Lacorata, G.: Algorithm Theoretical Baseline Document for 4DMED-SEA Project, version 2, ESA,  
632 [http://ricerca.ismar.cnr.it/4DMED/docs/4DMED-SEA-D2\\_ATBD\\_v2.0-signed.pdf](http://ricerca.ismar.cnr.it/4DMED/docs/4DMED-SEA-D2_ATBD_v2.0-signed.pdf), last access: 15 June 2026, 2024.

633

634 Verger-Miralles, E., Moure, B., Gómez-Navarro, L., Barceló-Llull, B., Casas, B., Cutolo, E., Díaz-Barroso, L., d'Ovidio, F.,  
635 Tarry, D. R., Zarokanellos, N. D., and Pascual, A.: SWOT Enhances Small-Scale Eddy Detection in the Mediterranean Sea,  
636 Geophysical Research Letters, 52, e2025GL116480, <https://doi.org/10.1029/2025GL116480>, 2025.

637

638 Volpe, G., Colella, S., Brando, V. E., Forneris, V., La Padula, F., Di Cicco, A., Sammartino, M., Bracaglia, M., Artuso, F.,  
639 and Santoleri, R.: Mediterranean ocean colour Level 3 operational multi-sensor processing, Ocean Sci., 15, 127–146,  
640 <https://doi.org/10.5194/os-15-127-2019>, 2019.

641

642 Wang, H., Liu, Y., Yang, Y., Yan, R., and Wang, S.: Optimal Shipping Route under the Designation of the Mediterranean  
643 Sulfur Emission Control Area: Mathematical Models and Applications, Mathematics, 11, 4897,  
644 <https://doi.org/10.3390/math11244897>, 2023.