

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 variability, 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 difference improvements with respect to the reference and widely used current Copernicus Marine Environment Monitoring Service (CMEMS) satellite sea level and derived velocity 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, intensity and associated EKE kinetic energy. This is relevant for defining optimum marine traffic routes, but also for operational activities such as marine pollution management. To evaluate this impact 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 ; satellite observations	EU Copernicus Marine Service Product (2025a)	Quality Information Document (QUID): Ballarotta et al. (2025a) Product User Manual (PUM): Pujol (2025a)
2	SEALEVEL_EUR_PHY_L4_MY_008_068 ; satellite observations	EU Copernicus Marine Service Product (2025b)	QUID: Ballarotta et al. (2025b) PUM: Pujol (2025b)
3	Gridded Sea Level Height and geostrophic velocities computed with Multiscale	AVISO (2025)	PUM: Ballarotta (2025c)

	Interpolation; MIOST-K v2.0.1; satellite observations		
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46 **1 Introduction**

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

53 Conventional mesoscale monitoring has relied primarily on satellite altimetry products such as the Copernicus Marine
54 Environment Monitoring Service (CMEMS), Sea Level - Thematic Assembly Centre (SL-TAC) dataset (e.g. Le Traon et al.,
55 1998; Sánchez-Román et al., 2023). However, the launch of the Surface Water and Ocean Topography (SWOT) mission, and
56 its Ka-band Radar Interferometer (KaRIn) instrument, has opened new observational pathways (Morrow et al., 2019; Fu et
57 al., 2024). This study evaluates the added value of a new pre-operational Level-4 (L4) surface product (MIOST with KaRIn;
58 Ballarotta et al., 2025c), which integrates SWOT KaRIn data during the science phase (September 2023–December 2024),
59 by comparing it with existing CMEMS products based solely on nadir altimetry.

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

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

80 This study evaluates how SWOT KaRIn observations affect the representation of surface mesoscale activity in gridded
81 altimetric products over the western Mediterranean. By comparing eddy fields derived from legacy and SWOT-enhanced
82 datasets, we assess differences in the representation of surface circulation, focusing particularly on EKE and eddy retention
83 capacity. More accurate surface mesoscale information can support route planning strategies aimed at reducing ship
84 emissions (e.g. Wang et al., 2023) and improve the identification of pollutant transport pathways toward ecologically
85 sensitive areas such as Cabrera National Park. ~~Beyond advancing scientific knowledge, this work offers practical value for~~
86 ~~marine operational applications such as maritime transport optimization and marine spatial planning. For instance, more~~
87 ~~accurate surface current information can aid in route planning to reduce ship emissions (e.g. Wang et al., 2023), while~~
88 ~~enhanced mesoscale monitoring can support risk assessments for marine pollution in protected areas. The case of Cabrera~~
89 ~~highlights how new altimetry-driven products can directly inform conservation strategies by more accurately identifying~~
90 ~~exposure pathways to drifting pollutants.~~

91 ~~This study aims to assess the extent to which the integration of SWOT KaRIn data into gridded altimetric products improves~~
92 ~~the characterization of surface mesoscale activity in the western Mediterranean. By comparing eddy fields derived from both~~
93 ~~legacy and SWOT-enhanced datasets, we evaluate how these differences impact the monitoring of surface circulation, with a~~
94 ~~focus on the impact on EKE and the retention capacity of eddies. Beyond improving our understanding of mesoscale~~
95 ~~dynamics, the overarching objective is to evaluate and determine the added value of high-resolution SWOT-enhanced altimetry~~
96 ~~for support applications ranging from marine pollution mitigation to improved maritime operations and ecosystem~~
97 ~~management.~~

98 2 Data

99 2.1 DUACS optimal interpolation (DUACS-OI)

100 The *European Seas Gridded L4 Sea Surface Height* dataset (Table 1, product reference 1 and 2) from the Copernicus Marine
101 Service, provides daily Sea Level Anomaly (SLA) fields at $1/8^\circ$ resolution over European regional seas, at a daily temporal
102 frequency. The product is generated by the Data Unification and Altimeter Combination System (DUACS) system (*Centre*

103 *National d'Etudes Spatiales/Collecte Localisation Satellites*; CNES/CLS) using optimal interpolation of along-track
104 altimeter measurements from multiple satellites (Le Traon et al., 1998). It includes SLA, Absolute Dynamic Topography
105 (ADT), and derived surface geostrophic currents. ADT is obtained by adding the Mean Dynamic Topography (MDT) to
106 SLA. The MDT used is the Mediterranean 2020 product (MDT_CMEMS_2020_MED, Jousset et al., 2022). The dataset, is
107 available in Near-Real-Time (NRT, product reference 1) and delayed-time (DT, product reference 2), and supports studies of
108 mesoscale and large-scale sea level variability (e.g. Pascual et al., 2007; 2009; Marcos et al., 2015; Taburet et al., 2018;
109 Ballarotta et al., 2019; Sánchez-Román et al., 2023). The NRT data is updated daily, and at the moment of the study had a
110 temporal coverage from 04/10/2022 to 25/11/2024 ~~to November 2024~~, while the delayed-time data from 01/01/1992 to
111 31/12/2023. Therefore, the DT product is only used for the analysis of the mean circulation (fig. 1), and the NRT product is
112 used for the rest of analyses as it covers 2024.

113 2.2 MIOST with SWOT KaRIn (MIOST-K)

114 The Multiscale Inversion of Ocean Surface Topography (MIOST) product (Table 1, product reference 3) is a new-generation
115 gridded altimetry dataset that incorporates SWOT KaRIn data, i.e., two-dimensional swath (SSHA) observations. This global
116 product is available at a spatial resolution of $1/8^\circ$ and at daily temporal frequency. We utilized the experimental L4
117 multimission sea level product distributed by AVISO v2.0.1, which combines SWOT swath altimetry with conventional
118 nadir altimeter measurements. The dataset relies on the MIOST method (Ubelmann et al., 2021, 2022), a statistical technique
119 that reconstructs sea surface height fields by decomposing variability across multiple spatial and temporal scales. The
120 reconstruction combines SWOT KaRIn wide-swath observations, SWOT nadir data, and conventional nadir altimeter
121 measurements within broad spatio-temporal windows around the target date. In Delayed-Time (DT) mode, both past and
122 future observations are incorporated to constrain the interpolation process, with decreasing weights assigned to observations
123 farther away in time. This allows mesoscale structures sampled during nearby overpasses to contribute to the reconstructed
124 daily fields beyond the instantaneous SWOT and nadir ground-track coverage (see Fig. A1 for an example of the SWOT
125 coverage contributing to the reconstruction of day 20/04/24) (Ballarotta et al., 2025c). The MDT product used is also the
126 MDT_CMEMS_2020_MED (Jousset et al., 2022). More details can be found in Ballarotta et al., (2025c). These products
127 were processed by SSALTO/DUACS and distributed by AVISO (<https://www.aviso.altimetry.fr>) supported by CNES.

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

132 3 Methods

133 3.1 Py-eddy tracker

134 The py-eddy-tracker is an eddy tracking algorithm based on geometric and physical techniques. ~~It~~
135 ~~algorithm~~ was firstly developed by Mason et al. (2014) ~~and~~. This was later updated by Delepouille et al. (2022). Since then,
136 ~~it~~ and has been widely used to study eddies and for the generation of ~~to release~~ updated eddy field datasets (e.g. Pegliasco et
137 al. 2022). In this study, we use version 3.6.1 of the algorithm (Delepouille et al., 2022) to identify eddies from daily snapshots
138 of Absolute Dynamic Topography (ADT) fields. ~~We identify eddies in daily snapshots of ADT fields (using version 3.6.1.~~
139 ~~(Delepouille et al., 2022))~~. Two types of contours are identified by the algorithm: ~~the provided~~ effective contour (outermost
140 closed contour defining the eddy extent) and the speed contour (inner contour corresponding to the region of maximum mean
141 azimuthal geostrophic velocity), ~~and~~ f. Further details can be found in Mason et al. (2014). Compared to SLA, ADT provides
142 more reliable eddy identification, especially in the Mediterranean Sea (Pegliasco et al., 2021, 2022), because it includes both
143 the mean dynamic topography and its temporal variability, helping distinguish mesoscale eddies from variations in persistent
144 jets and recurrent circulation patterns included in the MDT. A pre-processing and set of parameterizations are necessary to
145 implement the py-eddy tracker (see Mason et al., 2014; Pegliasco et al., 2022 for further details):

- 146 1) The ADT fields are filtered with a Bessel high-pass filter of 500 km to remove the background large-scale signal
147 and isolate the eddies (Pegliasco et al., 2022).
- 148 2) A detection step of 0.002 m was used between consecutive isolines. This corresponds to the height difference
149 between contour levels used to identify eddy boundaries. Starting from the eddy center (defined by a minimum
150 value for cyclonic eddies and a maximum value for anticyclonic eddies), closed ADT isolines are identified outward
151 at intervals of 0.002 m until the eddy edge is reached (Cui et al., 2025). ~~A 0.002 m step between two isolines of~~
152 ~~detection. This refers to the height between two layers, used to identify the eddy contours in which starting from the~~
153 ~~eddy center (minimum value for cyclonic and maximum for anticyclonic eddies), the closed isolines (of ADT in our~~
154 ~~case) are identified outward in steps of 0.002 m till the eddy edge is reached (Cui et al., 2025).~~
- 155 3) A maximum shape error of 55% is allowed for a detected contour to be identified as an effective eddy. This metric
156 ~~is defined as the ratio..., which is~~ defined as the ratio between the circle fit and identified outermost contour. This
157 shape error (Kurian et al., 2011) ~~is to~~ limits the identification to eddies, and removes other elongated closed-contour
158 structures like filaments (Mason et al., 2019).

159 3.2 Particle simulations and eddy retention calculation

160 We calculate the eddy particle retention to quantify ~~how differences in eddy properties, such as size, intensity, and associated~~
161 ~~EKE, influence particle transport and trapping. the impact of the different eddy characteristics.~~ For this analysis, Lagrangian
162 simulations are performed using the OceanParcels Lagrangian framework v2.4.2 (Delandmeter and van Sebille, 2019) to
163 simulate 2D trajectories of virtual particles at the sea surface. Particles are advected using the velocity fields of the two

164 datasets (DUACS-OI and MIOST-K). A fourth order Runge-Kutta particle advection scheme is used with a run-time
 165 time-step (dt) of 25 minutes. ~~Particles are treated as~~ We consider infinitesimal, passive and buoyant tracers ~~particles~~
 166 ~~transport influenced exclusively only by horizontal advection, with no additional physical processes included.~~ Simulations are
 167 performed with particles released within a 2 by 2° box around identified Algerian eddies' contours separated by 1/30° (~3.5
 168 km) with an advection time (T) of 20 days. ~~The inner (speed) eddy contour is used here, to keep the eddy's more coherent~~
 169 ~~inner core.~~ This timescale represents a trade-off between the minimum lifetime of the Algerian eddies (~60 days) and the
 170 requirement that enough particles remain within the eddy core during the simulation. Particles which leave the domain are
 171 removed from the analysis. Here we showcase the impact on the retention capacity by selecting 3 Algerian eddies as
 172 representative examples. Further details are shown in Table CB1.

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

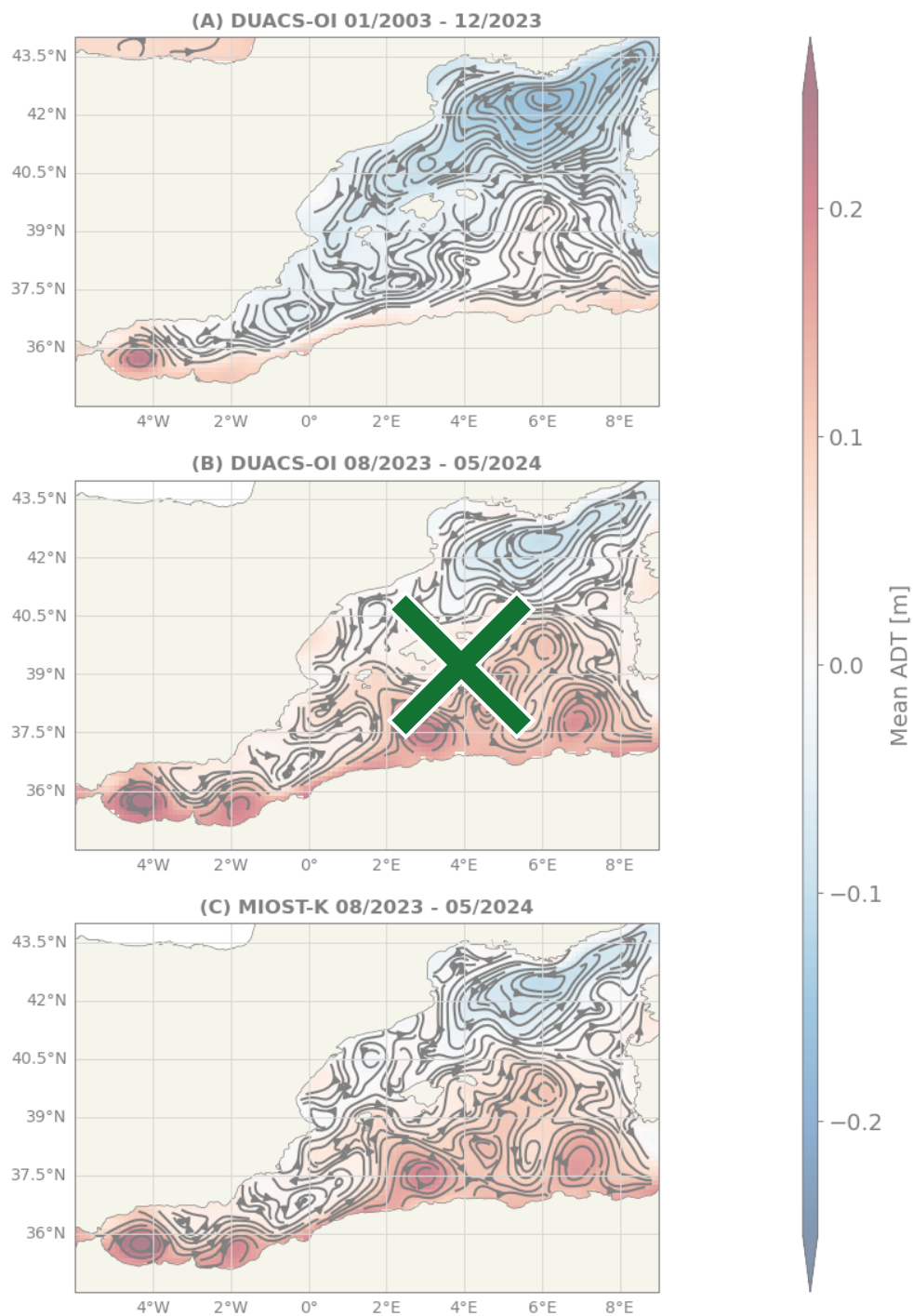
$$176 \text{ ERP} = \frac{N_T - N_0}{N_0} \times 100, \quad (1)$$

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

178 ~~4.3~~ Results

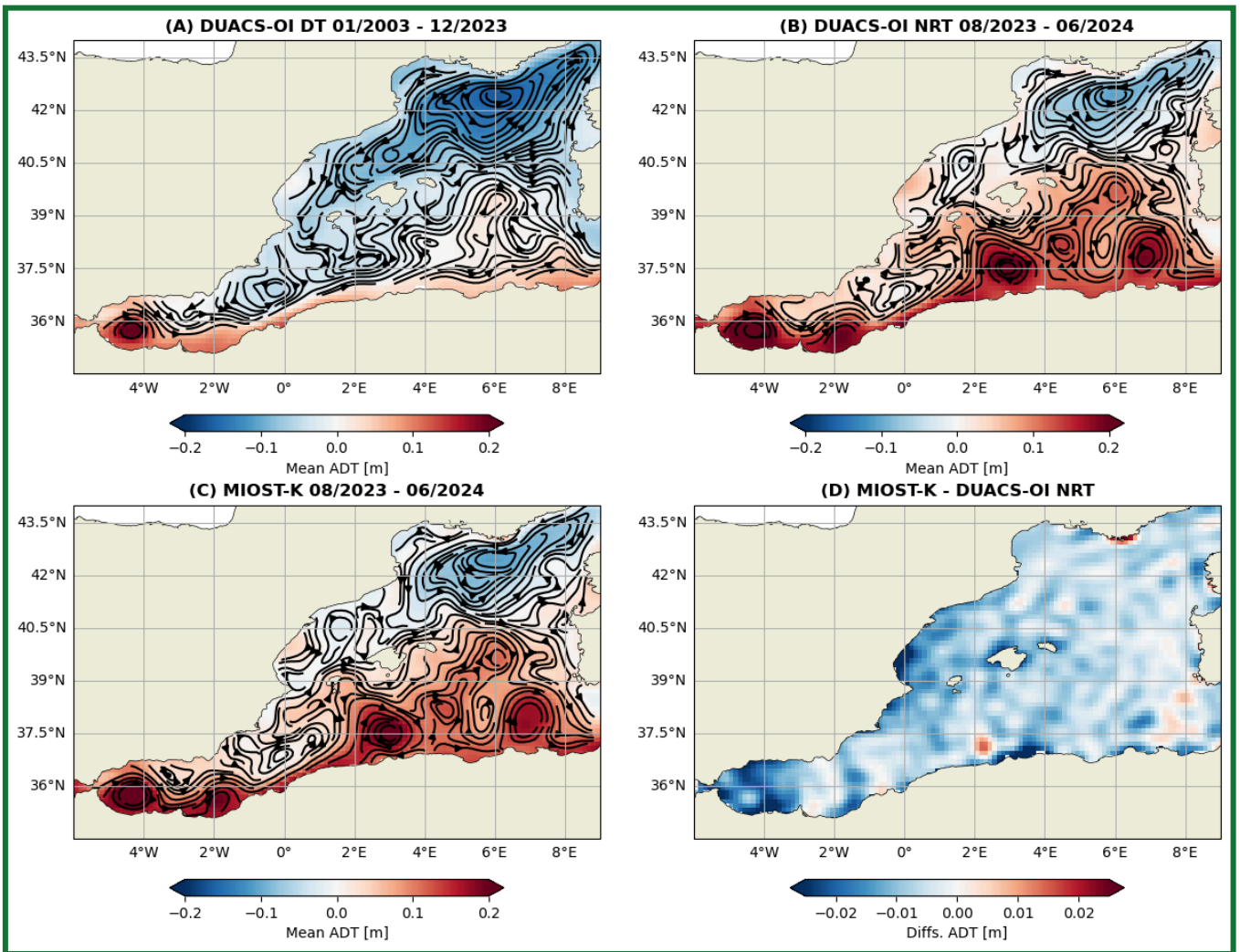
179 The general circulation of the western Mediterranean has been thoroughly studied in the past. The new SWOT data is
 180 unveiling smaller oceanic scales and partially or even unobserved dynamics, but the impact of this on the general circulation
 181 patterns will be better understood when we have more years of SWOT data. Currently, with ~~more than one~~ the nearly 1.5
 182 years of SWOT data during the science phase, we can already infer a first estimate of how and if these general circulation
 183 patterns are affected by this new dataset, and thus the consequences this could have for different monitoring efforts (Fig. 1).
 184 ~~The main circulation features shown in Fig. 1A are also observed in the other 2 panels, showing that these are represented in~~
 185 ~~both datasets.~~ Fig. 1A is included as a reference representation of the mean circulation over 20 years in the western
 186 Mediterranean. The main circulation features shown in Fig. 1A are also observed in the shorter-term averages shown in
 187 panels B and C, indicating that the large-scale circulation is consistently represented in both datasets. Differences ~~We can~~
 188 ~~observe that~~ between Figs. 1B and C, differences arise ~~mainly at~~ on the smaller-scale features; and in the characteristics of
 189 the mesoscale structures, already ~~suggesting~~ giving us a first insight that ~~at the mesoscale the circulation will be impacted by~~
 190 ~~the inclusion of the new SWOT observations.~~ the inclusion of SWOT observations impacts the representation of mesoscale
 191 circulation. Although part of these differences may also arise from intrinsic methodological differences between the
 192 DUACS-OI and MIOST reconstruction approaches, previous comparisons based solely on nadir altimetry showed relatively
 193 small differences between the two products in the Mediterranean (Ballarotta et al., 2023; Verbrugge et al., 2024). This
 194 suggests that the higher differences observed here are strongly influenced by the inclusion of SWOT wide-swath

195 observations in MIOST-K. These differences are further highlighted in the mean ADT difference field shown in Fig. 1D,
196 particularly in coastal regions and along energetic circulation pathways (e.g. Alboran Sea and Algerian Current). However,
197 the magnitude of these differences is about an order of magnitude smaller than the values in the ADT field (note the limits of
198 colorbar in Figures 1B, 1C and 1D). This is expected from the enhanced spatial sampling provided by SWOT wide-swath
199 observations compared to conventional nadir altimetry (e.g. Lopez-Radcenco et al., 2019; Ballarotta et al., 2025),
200 particularly for mesoscale and coastal structures (e.g. Dibarboure et al., 2024). In contrast to the effectively one-dimensional
201 along-track sampling of nadir altimeters, SWOT provides two-dimensional swath measurements, and the implications of
202 these differences are further explored through the analysis of daily eddy variability in the following sections.



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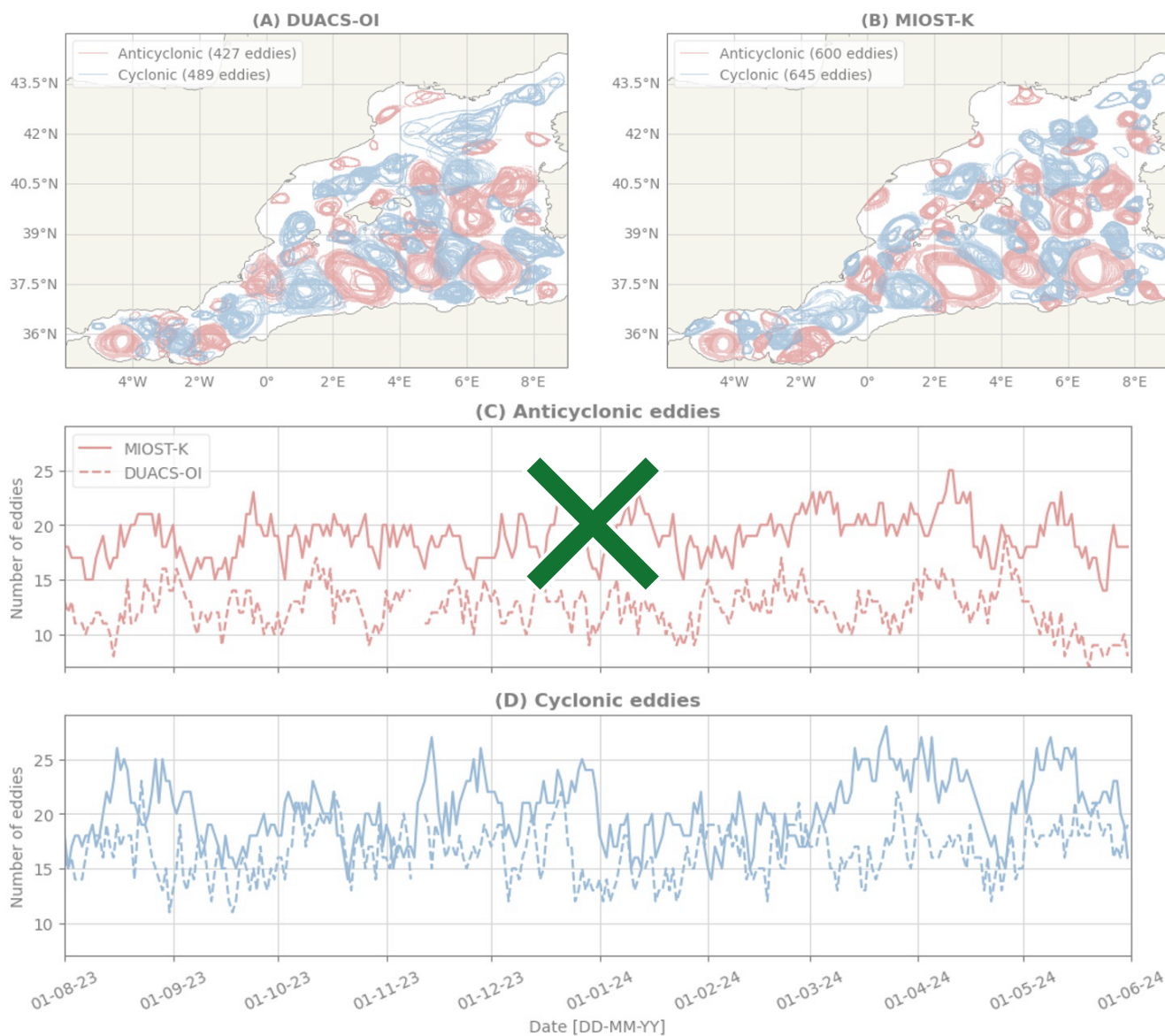


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206 Figure 1: General circulation represented by the mean Absolute Dynamic Topography (ADT) and the mean velocity field
 207 (streamlines) calculated from the different altimetric products: (A) 20 years mean from DUACS-DTM (product reference 2), (B)
 208 117 months mean of DUACS-NRT (product reference 1), and (C) 117 months mean of MIOST-K (product reference 3) and (D)
 209 mean ADT difference between MIOST-K and DUACS-OI ((C) - (B)).

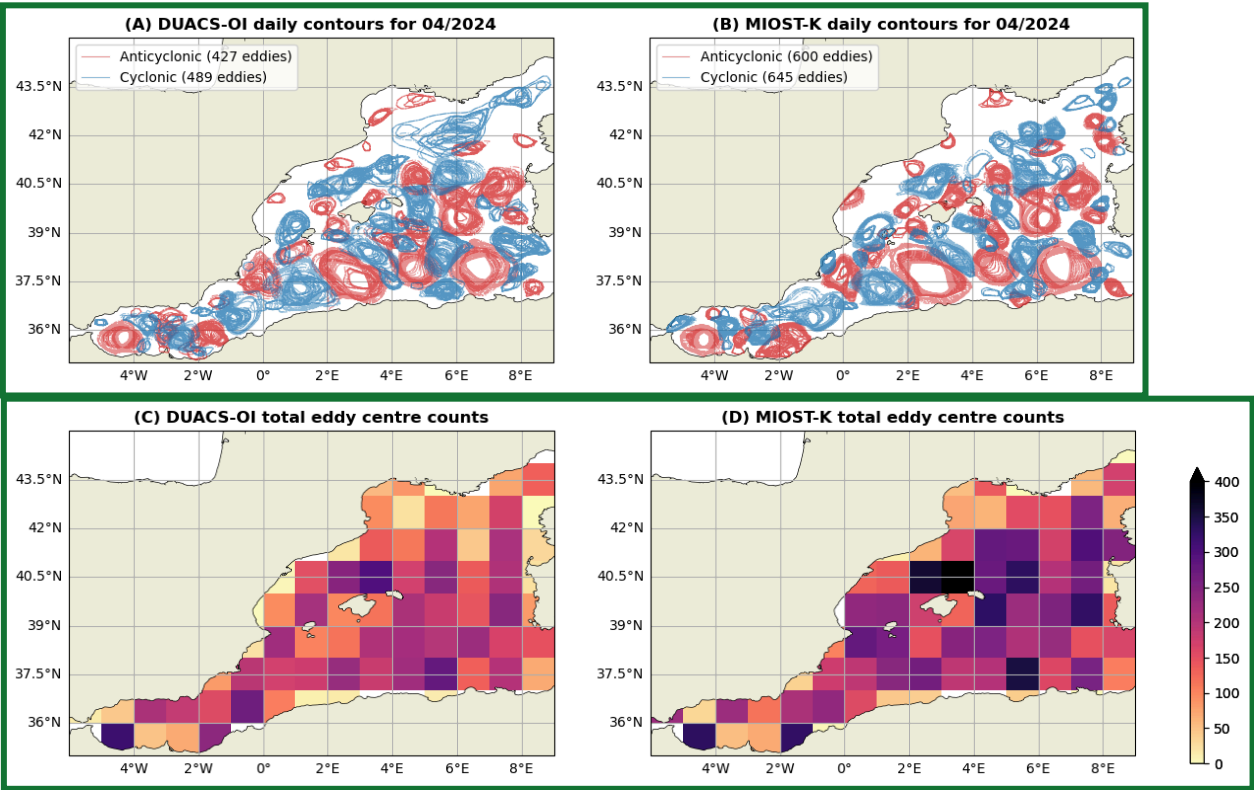
210 We obtain the daily fields of eddy identification fields for both datasets from August 2023 to June 2024
 211 (inclusive), and we calculate the total number of cyclonic (blue) and anticyclonic (red) eddies. An example of all the eddies
 212 identified daily during April 2024 is shown in panels (A)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

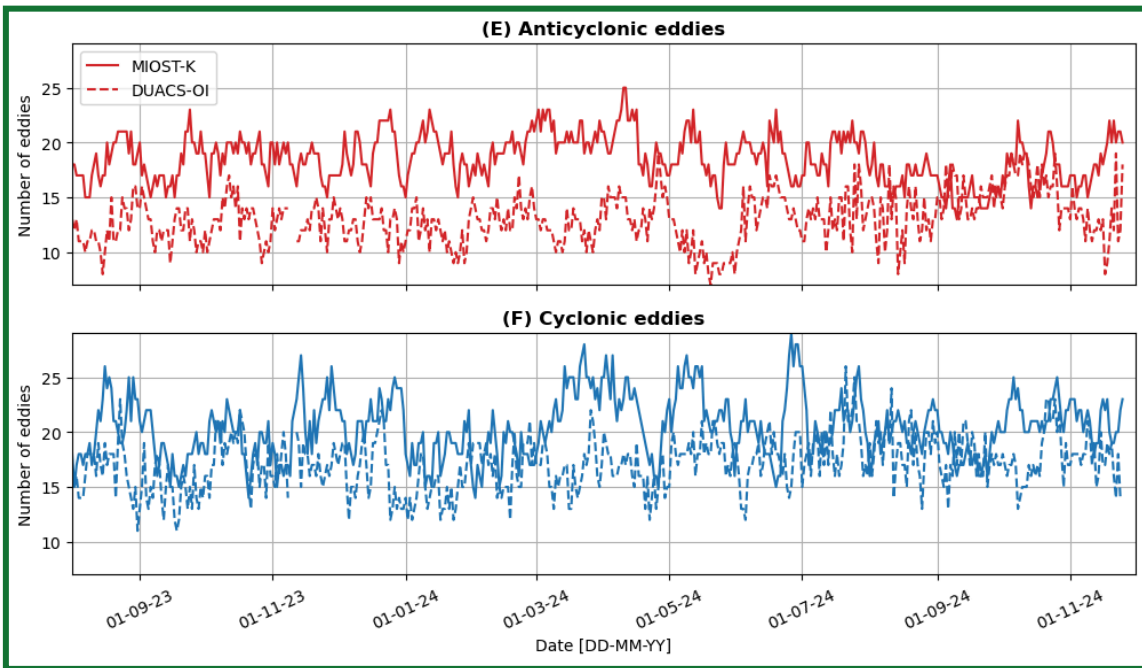
218 eddies into one larger structure, particularly in areas such as the Gulf of Lion, thereby reducing the number of identified
219 eddies. The daily temporal variability of anticyclonic and cyclonic eddy counts is shown in panels (E) and (F), respectively.
220 Despite high temporal variability, MIOST-K consistently identifies a larger number of eddies than DUACS-OI throughout
221 most of the analysis period. For anticyclonic eddies, MIOST-K detects on average 19.0 ± 2.0 eddies per day (mean $\pm$ standard deviation), compared to 12.5 ± 2.0 for DUACS-OI. For cyclonic eddies, the mean daily counts are 20.4 ± 3.1
222 and 16.6 ± 2.4 for MIOST-K and DUACS-OI, respectively. The temporal correlation between the two daily eddy-count
223 time series is low for both anticyclonic ($r = 0.253$) and cyclonic eddies ($r = 0.165$). This likely reflects the sensitivity of daily
224 eddy counts to product-dependent differences not only in eddy detection, but also splitting, merging, and lifetime, rather than
225 fundamental differences in the temporal variability of mesoscale activity. ~~The daily variability of the eddy number for
226 anticyclones and cyclones is shown in panels C and D in Fig. 2. Although there is high temporal variability in the eddy
227 number, in general we observe a greater number of eddies with the MIOST-K than the DUACS-OI product. This is
228 particularly noticeable in coastal areas, such as off the western coast of Corsica (Fig. 2A and B). Complementary
229 observations such as satellite chlorophyll data, show the presence of coastal eddies in this region (Fig. A1, Fortunato et al.,
230 2025). Moreover, the DUACS-OI product seems to merge multiple cyclonic eddies into one, affecting notably the mesoscale
231 field in areas such as the Gulf of Lions. Therefore, throughout most of the analysis period we can observe an increase in the
232 number of daily identified eddies with MIOST-K.~~



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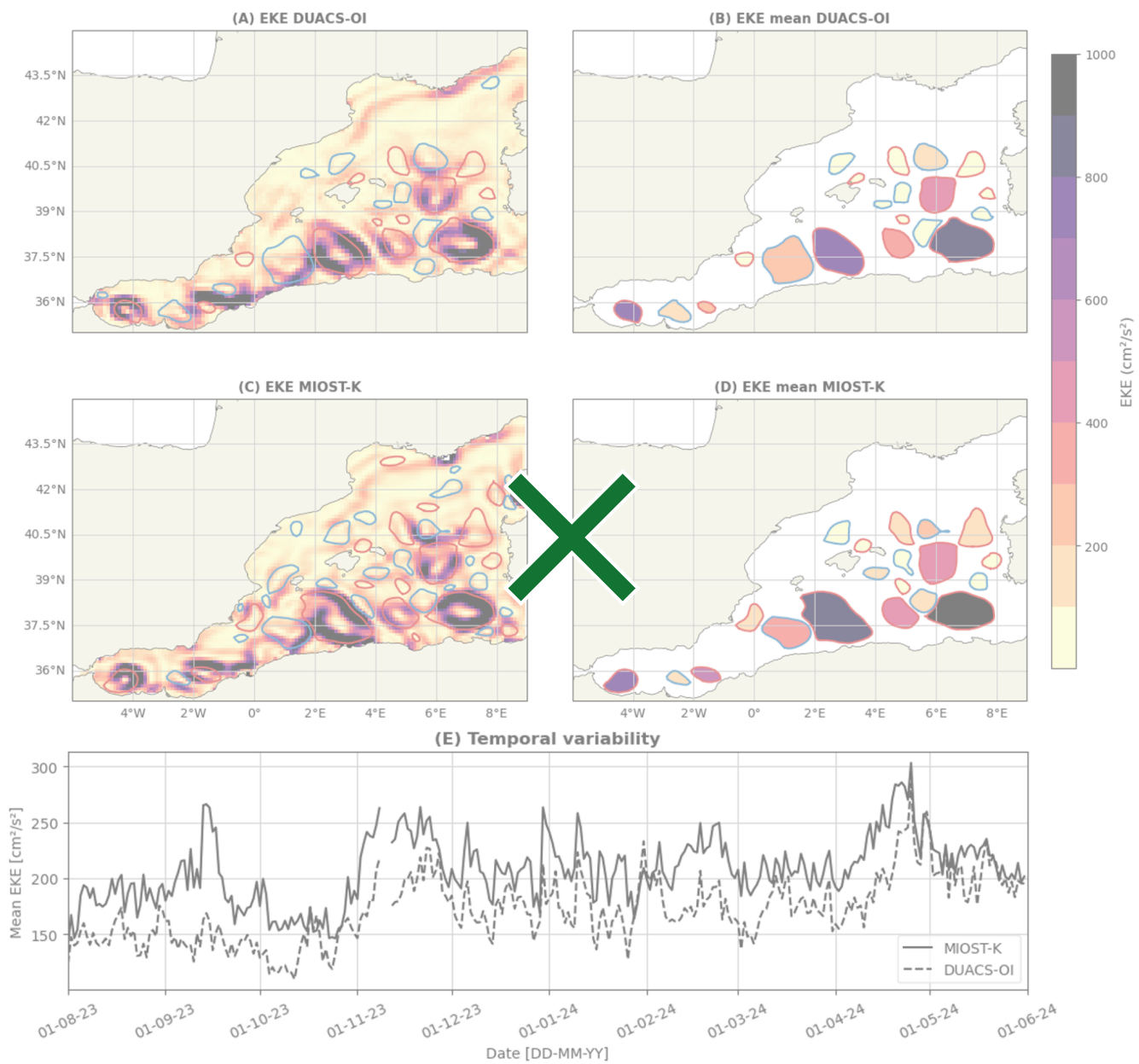




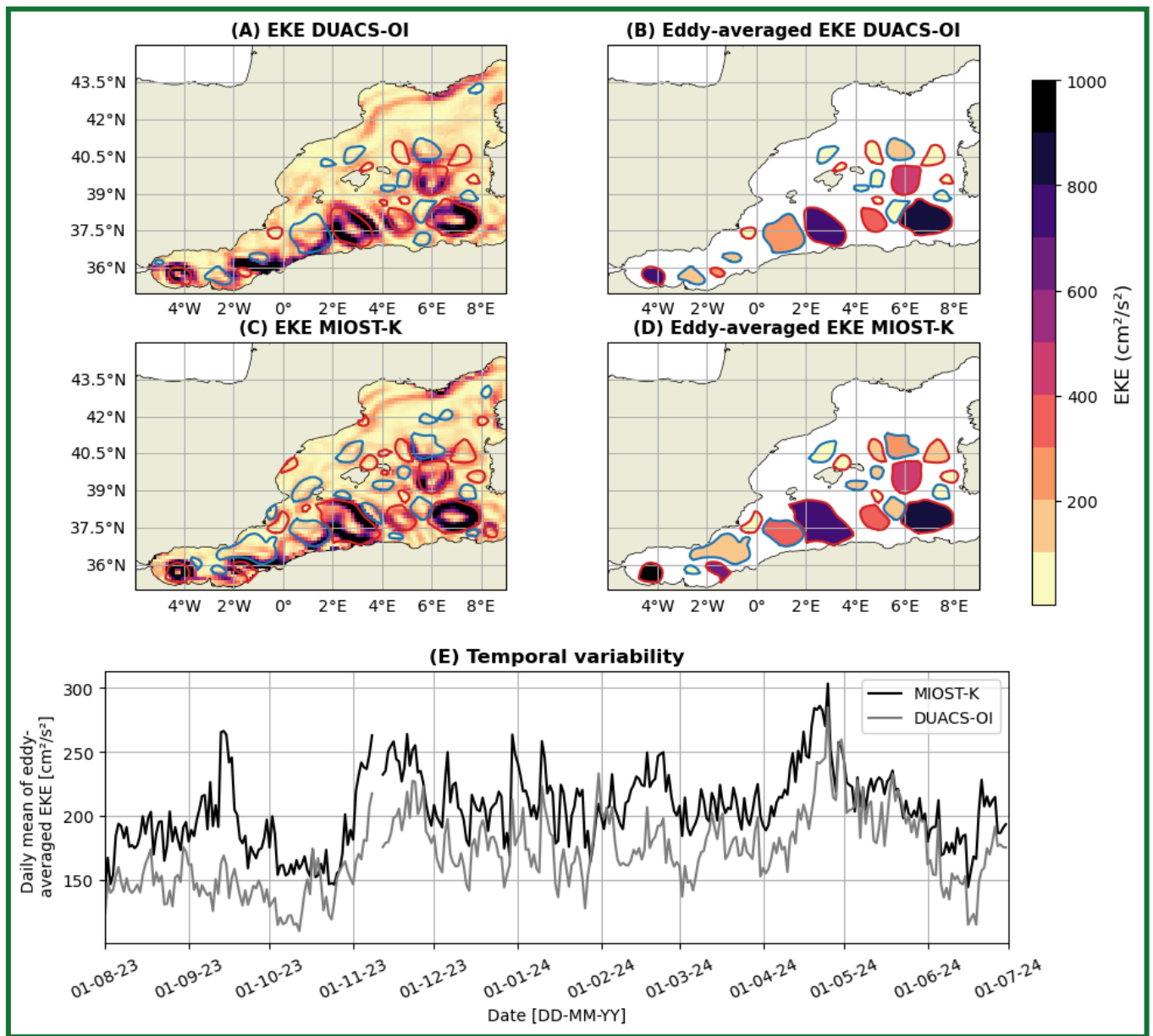
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 251 **Figure 2: Number of daily eddy identifications.** Panels (A) and (B) show all the daily eddies (outer contours) identified during
 252 April 2024 for DUACS-OI (product reference 1) and MIOST-K (product reference 3), respectively. Panels (C) and (D) show the
 253 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
 254 the anticyclones and cyclones, respectively, identified throughout the study period.

255 With the inclusion of the SWOT data, we also observe changes in the already observed big mesoscale eddies of the
 256 DUACS-OI product. An important change is in the EKE associated with these eddies. Firstly, the EKE field is retrieved
 257 (Delepoulle et al., 2022) for each daily field (Figs. 3Aa and 3Ce). Then we find the eddies that match for both datasets and
 258 calculate the mean EKE associated to these eddies. i.e., the eddy-averaged EKE (Figs. 3Bb and 3Dd). Fig. 3Ee shows the
 259 temporal variability of the daily mean of eddy-averaged EKE (daily mean EKE) of all the matching eddies identified.
 260 MIOST-K shows a higher daily mean EKE throughout the majority of the study's time period. Both datasets reach their
 261 maximum during the same energetic event on 25/04/2024, although the MIOST-K value is approximately 6% higher than in
 262 DUACS-OI. More importantly, specific daily differences between the products can be substantially larger, with MIOST-K
 263 exhibiting increases of up to 78% relative to DUACS-OI during certain energetic mesoscale events, such as on 16/09/23. On
 264 96% of the days, the daily mean EKE in MIOST-K is higher than in DUACS-OI (we also checked the differences in the
 265 daily maximum daily of eddy-averaged EKE, and these are higher 93% of the time). This may be due to enhanced signal
 266 capture by the altimetric constellation, made possible by SWOT's wide swath. enhanced EKE representation is likely
 267 associated with the improved spatial sampling, two-dimensional swath geometry, and enhanced representation of
 268 higher-wavenumber variability enabled by SWOT observations. Furthermore, SWOT observations are expected to exhibit
 269 substantially lower noise levels than conventional nadir altimeters (Vergara et al., 2023), which may also contribute to the
 270 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.



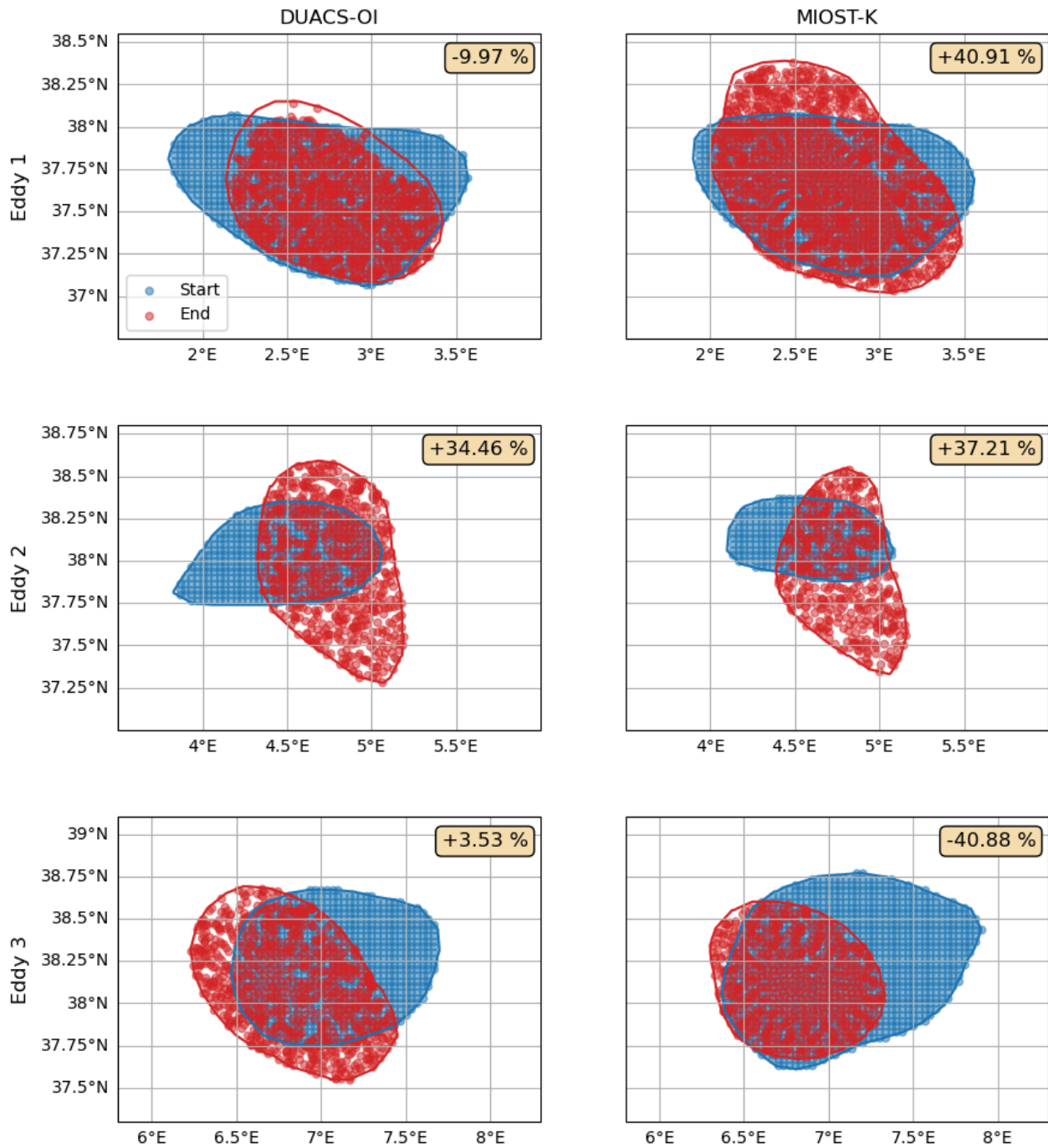
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284 Figure 3: Temporal variability of the mean Eddy Kinetic Energy (EKE) associated with the detected eddies. Panels (A) and (C)
 285 show the EKE field on 20/04/2024 and all the identified (outer eddy contours) anticyclones (red) and cyclones (blue) outer eddy
 286 contours, for DUACS-OI (product reference 1) and MIOST-K (product reference 3), respectively. Panels (B) and (D) show the
 287 individual eddy-averaged associated mean EKE of only the eddies identified on both datasets on that date. (E) shows the mean
 288 EKE temporal variability of the spatially averaged EKE within detected, matching eddy contours and averaged across all eddies
 289 for each day for DUACS-OI (dashed) and MIOST-K (solid).

290 Figure 4 illustrates three examples of Algerian Eddies, and their retention capacity. All three eddies were observed in
 291 different regions of the Algerian Basin during multiple SWOT KaRIn overpasses throughout their respective 20-day

292 advection periods (approximately five overpasses for each case), supporting the use of these examples to assess the influence
293 of SWOT-enhanced reconstruction on particle retention estimates. After 20 days, the eddies retain substantially different
294 percentages of particles, reflecting the strong variability in mesoscale transport and retention processes across the subbasin.
295 Such differences are expected between Algerian eddies, as their retention capacity can depend on their dynamical state,
296 including eddy intensity, coherence, deformation, interaction with the surrounding circulation, and eddy lifetime stage. We
297 therefore consider three different eddy examples to illustrate how differences in mesoscale representation between
298 DUACS-OI and MIOST-K can impact transport and retention estimates under different dynamical conditions. ~~We observe~~
299 ~~that after 20 days, they have retained different percentages of particles.~~ In Eddy 1, the DUACS-OI eddy shows leakage,
300 while the MIOST-K eddy retains and even increases the number of particles inside the eddy contour. In Eddy 2, both
301 products retain more particles, although ~~with slightly higher retention is slightly higher~~ in MIOST-K. In contrast, Eddy 3
302 exhibits stronger leakage in MIOST-K, while DUACS-OI retains slightly more particles; ~~DUACS-OI retains more particles,~~
303 ~~while MIOST-K shows high leakage.~~ This demonstrates an important impact of the differences in eddy properties
304 ~~identified/observed between these far with operational datasets such as~~ DUACS-OI and the new dataset, MIOST-K. Despite
305 only subtle qualitative differences in eddy contours (Fig. 2), the particle retention over just 20 days shows a high variability,
306 likely linked to the higher EKE structures observed in the SWOT-enhanced product (Fig. 3). These differences are not only
307 scientifically relevant but may also have practical implications for environmental monitoring and marine spatial planning.
308 The same eddy can exhibit opposite retention and leakage behaviours depending on the product used. If applied
309 operationally, such contrasting representations could lead to substantially different estimates of the transport and
310 accumulation of pollutants, marine litter, nutrients, fish larvae, or aquaculture-derived waste, potentially influencing
311 pollutant dispersion assessments, aquaculture site suitability, or ecosystem management strategies.



312

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

317 54 Discussion

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

325

326 The increase in eddy detections with MIOST-K is more pronounced for anticyclonic eddies than for cyclonic eddies.
327 Although the origin of this eddy asymmetry was not specifically investigated here, it may be related to the improved
328 detection of smaller-scale and coastal eddies, where the differences between the products are strongest. In the western
329 Mediterranean, anticyclonic eddies tend to be more persistent, coherent, and longer-lived than cyclonic eddies (Stegner et al.,
330 2021), potentially increasing their detectability in SWOT products. Similar asymmetries have also been observed by SWOT
331 in other regions, and are generally explained by the greater stability and propagation capacity of anticyclonic eddies,
332 allowing them to persist longer and propagate farther (de Marez et al., 2026). This enhanced detection of anticyclonic eddies
333 may also be relevant for the monitoring of long-lasting surface temperature anomalies associated with these structures, which
334 could contribute to the development of local marine heatwaves (Aguilar et al., 2022).

335

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

341

342 The eddy identification algorithm used to identify eddies is quite sensitive to pre-processing choices and parameterizations
343 (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
344 the conclusions obtained should be minimal. The Eulerian method used here is commonly implemented in the community,
345 namely in altimetry. Many other eddy identification and tracking techniques exist which use an Eulerian framework (e.g.
346 Ioannou et al., 2024), but also Lagrangian ones, which could help to better capture retention capabilities, as Lagrangian
347 structures could assess material coherence in space and time simultaneously (Cortes-Morales et al., in prep.). To further
348 validate the robustness of our retention findings, future work could extend the Lagrangian analysis to a larger ensemble of
349 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. 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).

65 Conclusions

This study provides new insights on how the monitoring capabilities of surface circulation, namely mesoscale activity, will improve with the new ~~SWOT~~ wide-swath satellites such as SWOT. ~~This is and its relevance to~~ ^{for improving} 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~~ ^{does not aim to compare the datasets}, 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.

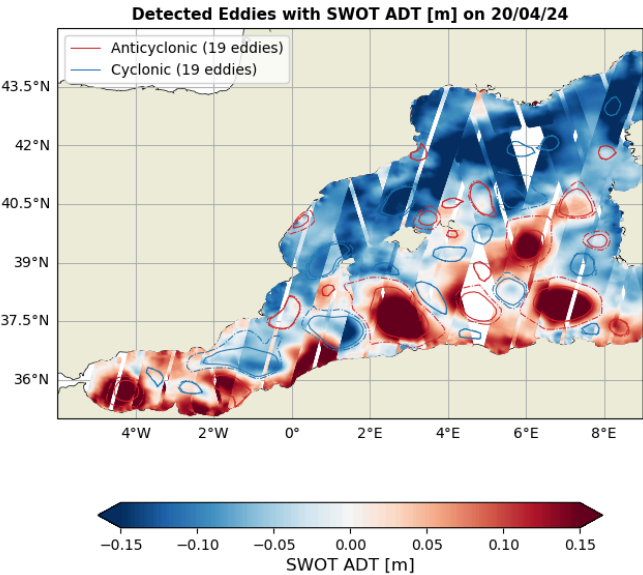
The results show the promising potential of new wide-swath products to better understand the eddy field, achieving specific capacities, particularly for observing small mesoscale eddies and resolving features in coastal areas. We also find that the already observed mesoscale eddy field by conventional 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 ~~marine heatwaves and~~ 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.

Appendices

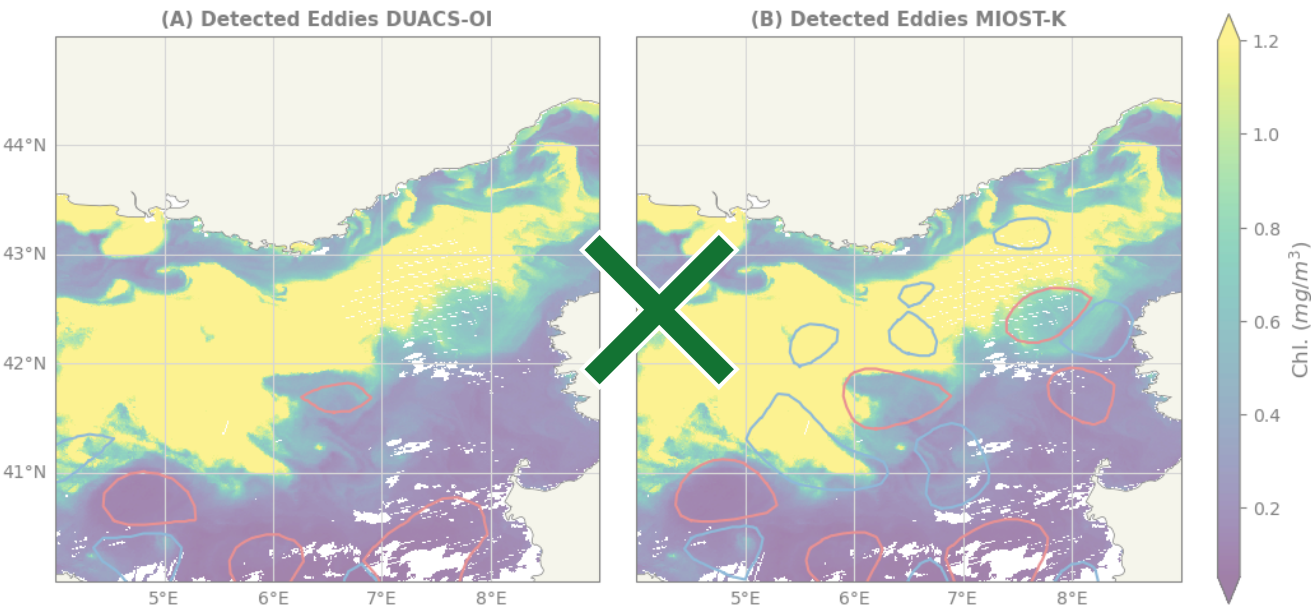
Appendix A



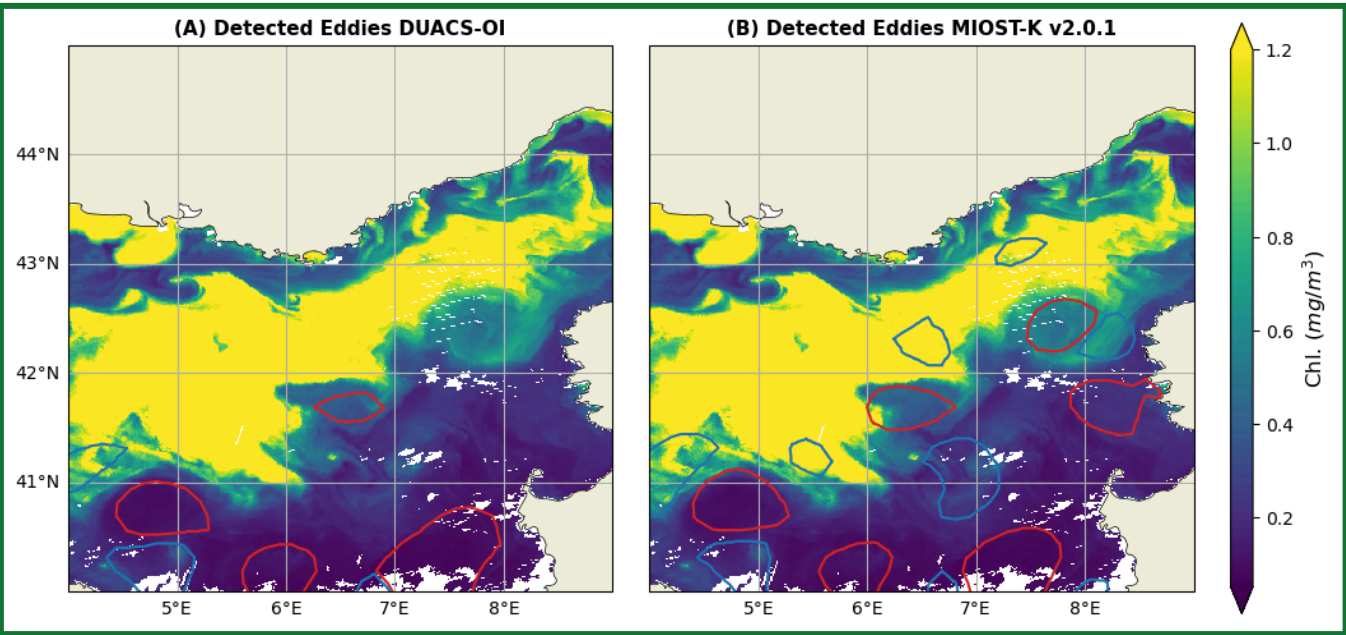
401 Figure A1: Outer eddy contours identified with MIOST-K on 20/04/24. The background field are all the SWOT L3 ADT [m]
402 observations on 20/04/24 +/- 10 days.

403 Appendix B

404



405



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

408 Daily level-3 chlorophyll-*a* concentrations at 1 km spatial resolution were obtained from the multi-sensor dataset
409 cmems_obs-oc_med_bgc-plankton_my_l3-multi-1km_PID, distributed within the Copernicus Marine product
410 *Mediterranean Sea, Bio-Geo-Chemical, L3, daily Satellite Observations (1997–ongoing)* (product ID:
411 OCEANCOLOUR_MED_BGC_L3_MY_009_143; DOI: 10.48670/moi-00299). Last accessed on: 17/05/2026. (Berthon
412 and Zibordi, 2004; Volpe et al., 2019)

413 **Appendix CB**

414 **Table CB1. Eddy retention information.**

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

415

416 **Code availability**

417 The codes used in this study are available on GitHub:
418 https://github.com/LauraGomezNavarro/paper-OSR10_Gomez-Navarro_etal_2026, and the version used for the manuscript
419 is published on Zenodo: <https://doi.org/10.5281/zenodo.16940147> (Gomez-Navarro_2025).

420 **Data availability**

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

423 **Author contribution**

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

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439 (CEX2019-000928-S).

440 References

441 20minutos: El GOB denuncia la presencia de numerosos residuos plásticos en aguas del parque Nacional de Cabrera.
442 [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/)
443 [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.

444

445 Aguiar, E., Mourre, B., Alvera-Azcárate, A., Pascual, A., Mason, E., and Tintoré, J.: Strong Long-Lived Anticyclonic
446 Mesoscale Eddies in the Balearic Sea: Formation, Intensification, and Thermal Impact, *Journal of Geophysical Research:*
447 *Oceans*, 127, e2021JC017589, <https://doi.org/10.1029/2021JC017589>, 2022.

448

449 Archer, M., Wang, J., Klein, P., Dibarboure, G., and Fu, L.-L.: Wide-swath satellite altimetry unveils global submesoscale
450 ocean dynamics, *Nature*, 640, 691–696, <https://doi.org/10.1038/s41586-025-08722-8>, 2025.

451

452 Ballarotta, M., Ubelmann, C., Pujol, M., Taburet, G., Fournier, F., Legeais, J., Faugère, Y., Delepouille, A., Chelton, D.,
453 Dibarboure, G., and Picot, N.: On the resolutions of ocean altimetry maps, 2018, 1091–1109,
454 <https://doi.org/10.5194/os-15-1091-2019>, 2019.

455

456 Ballarotta, M., Pujol, M.-I. and SL-TAC team: EU Copernicus Marine Service Quality Information Document for the
457 European Seas Gridded L4 Sea Surface Heights And Derived Variables NRT, , SEALEVEL_EUR_PHY_L4_NRT_008_060,

458 Issue 13.0, Mercator Ocean International,
 459 <https://documentation.marine.copernicus.eu/QUID/CMEMS-SL-QUID-008-032-068.pdf>, last access: 16 July 2025, 2025a.
 460
 461 Ballarotta, M., Pujol, M.-I. and SL-TAC team: EU Copernicus Marine Service Quality Information Document for the
 462 European Seas Gridded L4 Sea Surface Heights And Derived Variables Reprocessed 1993 Ongoing,
 463 SEALEVEL_EUR_PHY_L4_MY_008_068, Issue 13.0, Mercator Ocean International,
 464 <https://documentation.marine.copernicus.eu/QUID/CMEMS-SL-QUID-008-032-068.pdf>, last access: 16 July 2025, 2025b.
 465
 466 Ballarotta, M., Ubelmann, C., Bellemin-Laponnaz, V., Le Guillou, F., Meda, G., Anadon, C., Laloue, A., Delepouille, A.,
 467 Faugère, Y., Pujol, M.-I., Fablet, R., and Dibarboure, G.: Integrating wide-swath altimetry data into Level-4 multi-mission
 468 maps, Ocean Science, 21, 63–80, <https://doi.org/10.5194/os-21-63-2025>, 2025c.
 469
 470 Ballarotta, M.: SSALTO/DUACS Experimental Product Handbook: Gridded Sea Level Heights and geostrophic velocities
 471 computed with SWOT Level-3 products (using both KaRIn and nadir instruments) with MIOST Version 2.0.1., Issue 2.1.0,
 472 AVISO,
 473 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_SLA_MIOST.pdf~~, last access: 22 AprilJuly
 474 ~~2025~~, 2025.
 475
 476
 477 Barceló-Llull, B., Rosselló, P., Combes, V., Sánchez-Román, A., Pujol, M. I., and Pascual, A.: Kuroshio Extension and Gulf
 478 Stream dominate the Eddy Kinetic Energy intensification observed in the global ocean, Sci Rep, 15,
 479 <https://doi.org/10.1038/s41598-025-06149-9>, 2025.
 480 Berthon, J.-F. and Zibordi, G.: Bio-optical relationships for the northern Adriatic Sea, International Journal of Remote
 481 Sensing, 25, 1527–1532, <https://doi.org/10.1080/01431160310001592544>, 2004.
 482 Compa, M., Alomar, C., Mourre, B., March, D., Tintoré, J., and Deudero, S.: Nearshore spatio-temporal sea surface trawls of
 483 plastic debris in the Balearic Islands, Marine Environmental Research, 158, 104945,
 484 <https://doi.org/10.1016/j.marenvres.2020.104945>, 2020.
 485
 486 Coadou-Chaventon, S., Swart, S., Novelli, G., and Speich, S.: Resolving Sharper Fronts of the Agulhas Current Retroflection
 487 Using SWOT Altimetry, Geophysical Research Letters, 52, <https://doi.org/10.1029/2025gl115203>, 2025.
 488
 489 Cortés-Morales, D. and Hernández-Carrasco, I.: Lagrangian coherent rate as an indicator of transport properties associated
 490 with eddies in the Mediterranean sea~~Polarity Asymmetry in Lagrangian Coherent Vortices in the Mediterranean Sea~~ (in
 491 preparation).
 492

493 Cotroneo, Y., Celentano, P., Aulicino, G., Perilli, A., Olita, A., Falco, P., Sorgente, R., Ribotti, A., Budillon, G., Fusco, G.,
 494 and Pessini, F.: Connectivity Analysis Applied to Mesoscale Eddies in the Western Mediterranean Basin, Remote Sensing,
 495 13, 4228, <https://doi.org/10.3390/rs13214228>, 2021.

496

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

499

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

502

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

505

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

509

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

514

515 Escudier, R., Mourre, B., Juza, M., and Tintoré, J.: Subsurface circulation and mesoscale variability in the Algerian subbasin
 516 from altimeter-derived eddy trajectories, Journal of Geophysical Research: Oceans, <https://doi.org/10.1002/2016JC011760>,
 517 2016.

518

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

521

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

524

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

527

528 Fu, L., Pavelsky, T., Cretaux, J., Morrow, R., Farrar, J. T., Vaze, P., Sengenès, P., Vinogradova-Shiffer, N., Sylvestre-Baron,
 529 A., Picot, N., and Dibarboure, G.: The Surface Water and Ocean Topography Mission: A Breakthrough in Radar Remote
 530 Sensing of the Ocean and Land Surface Water, *Geophysical Research Letters*, 51, e2023GL107652,
 531 <https://doi.org/10.1029/2023GL107652>, 2024.
 532
 533 Gomez-Navarro, L.: LauraGomezNavarro/paper-OSR10_Gomez-Navarro_etal_2026: First pre-release update. Zenodo.
 534 Retrieved from doi: [10.5281/zenodo.16940147](https://doi.org/10.5281/zenodo.16940147), 2025.
 535
 536 Hogg, A. McC., Meredith, M. P., Chambers, D. P., Abrahamsen, E. P., Hughes, C. W., and Morrison, A. K.: Recent trends in
 537 the Southern Ocean eddy field, *JGR Oceans*, 120, 257–267, <https://doi.org/10.1002/2014JC010470>, 2015.
 538
 539 Ioannou, A., Guez, L., Laxenaire, R., and Speich, S.: Global Assessment of Mesoscale Eddies with TOEddies: Comparison
 540 Between Multiple Datasets and Colocation with In Situ Measurements, *Remote Sensing*, 16, 4336,
 541 <https://doi.org/10.3390/rs16224336>, 2024.
 542
 543 Jousset, S., Aydogdu, A., Ciliberti, S., Clementi, E., Escudier, R., Jansen, E., Lima, L., Menna, M., Mulet, S., Nigam, T.,
 544 Sanchez-Roman, A., Tarry, D. R., Pascual, A., Peneva, E., Poulain, P.-M., and TaupierLetage, I.: New Mean Dynamic
 545 Topography of the Mediterranean Sea from altimetry, gravity and in-situ data, *Prep*, 2022.
 546
 547 Le Traon, P. Y., Nadal, F., and Ducet, N.: An Improved Mapping Method of Multisatellite Altimeter Data, *Journal of*
 548 *Atmospheric and Oceanic Technology*, 15, 522–534,
 549 [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.
 550
 551 Lopez-Radcenco, M., Pascual, A., Gomez-Navarro, L., Aissa-El-Bey, A., Chapron, B., and Fablet, R.: Analog Data
 552 Assimilation of Along-Track Nadir and Wide-Swath SWOT Altimetry Observations in the Western Mediterranean Sea,
 553 *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 12, 2530–2540,
 554 <https://doi.org/10.1109/JSTARS.2019.2903941>, 2019.
 555
 556 Marcos, M., Pascual, A., and Pujol, I.: Improved satellite altimeter mapped sea level anomalies in the Mediterranean Sea: A
 557 comparison with tide gauges, *Adv. Space Res.*, 56, 596–604, <https://doi.org/10.1016/j.asr.2015.04.027>, 2015.
 558
 559 Martínez-Moreno, J., Hogg, A. McC., Kiss, A. E., Constantinou, N. C., and Morrison, A. K.: Kinetic Energy of Eddy-Like
 560 Features From Sea Surface Altimetry, *Journal of Advances in Modeling Earth Systems*, 11, 3090–3105,
 561 <https://doi.org/10.1029/2019MS001769>, 2019.
 562

563 Mason, E., Pascual, A., and McWilliams, J. C.: A New Sea Surface Height–Based Code for Oceanic Mesoscale Eddy
 564 Tracking, *Journal of Atmospheric and Oceanic Technology*, 31, 1181–1188, <https://doi.org/10.1175/JTECH-D-14-00019.1>,
 565 2014.

566

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

571

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

575

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

579

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

583

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

587

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

590

591 Pujol, M.-I.: EU Copernicus Marine Service Product User Manual for the European Seas Gridded L 4 Sea Surface Heights
 592 And Derived Variables NRT, SEALEVEL_EUR_PHY_L4_NRT_008_060, Issue 10.0, Mercator Ocean International,
 593 <https://documentation.marine.copernicus.eu/PUM/CMEMS-SL-PUM-008-032-068.pdf>, last access: 16 July 2025, 2025a.

594

595 Pujol, M.-I.: EU Copernicus Marine Service Product User Manual for the European Seas Gridded L 4 Sea Surface Heights
 596 And Derived Variables Reprocessed 1993 Ongoing, SEALEVEL_EUR_PHY_L4_MY_008_068, Issue 10.0, Mercator

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

599

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

602

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

606

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

609

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

613

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

616

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

620

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

623

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

627

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

631

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

634

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

638

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

642

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

646

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