

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

3 Laura Gómez-Navarro^{1,2}, Maxime Ballarotta³, Diego Cortés-Morales¹, Marie-Isabelle Pujol³, Laura
4 Fortunato⁴, Baptiste Mourre¹, Ananda Pascual¹

5 ¹ IMEDEA (UIB-CSIC), Esporles, 07190, Spain

6 ² ICM (CSIC), Barcelona, 08003, Spain

7 ³ CLS, Ramonville-Saint-Agne, 31520, France

8 ⁴ Università degli studi di Napoli Parthenope, Dipartimento di Scienze e tecnologie, 80143, Naples, Italy

9 *Correspondence to:* Laura Gómez-Navarro (laura.gomez@icm.csic.es)

10

11

12

13

14

15

16

17

18

19

20

21

22

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.

42

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 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, EU Copernicus Marine Service Product, 2024). 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 (EU Copernicus Marine Service Product, 2024). More details can be found in Ballarotta et al.,
118 (2025c). These products were processed by SSALTO/DUACS and distributed by AVISO (<https://www.aviso.altimetry.fr>)
119 supported by CNES.

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

124 3 Methods

125 3.1 Py-eddy tracker

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

135 in the MDT. A pre-processing and set of parameterizations are necessary to implement the py-eddy tracker (see Mason et al.,
136 2014; Pegliasco et al., 2022 for further details):

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

147 3.2 Particle simulations and eddy retention calculation

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

160

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

$$163 \text{ ERP} = \frac{N_T - N_0}{N_0} \times 100, \quad (1)$$

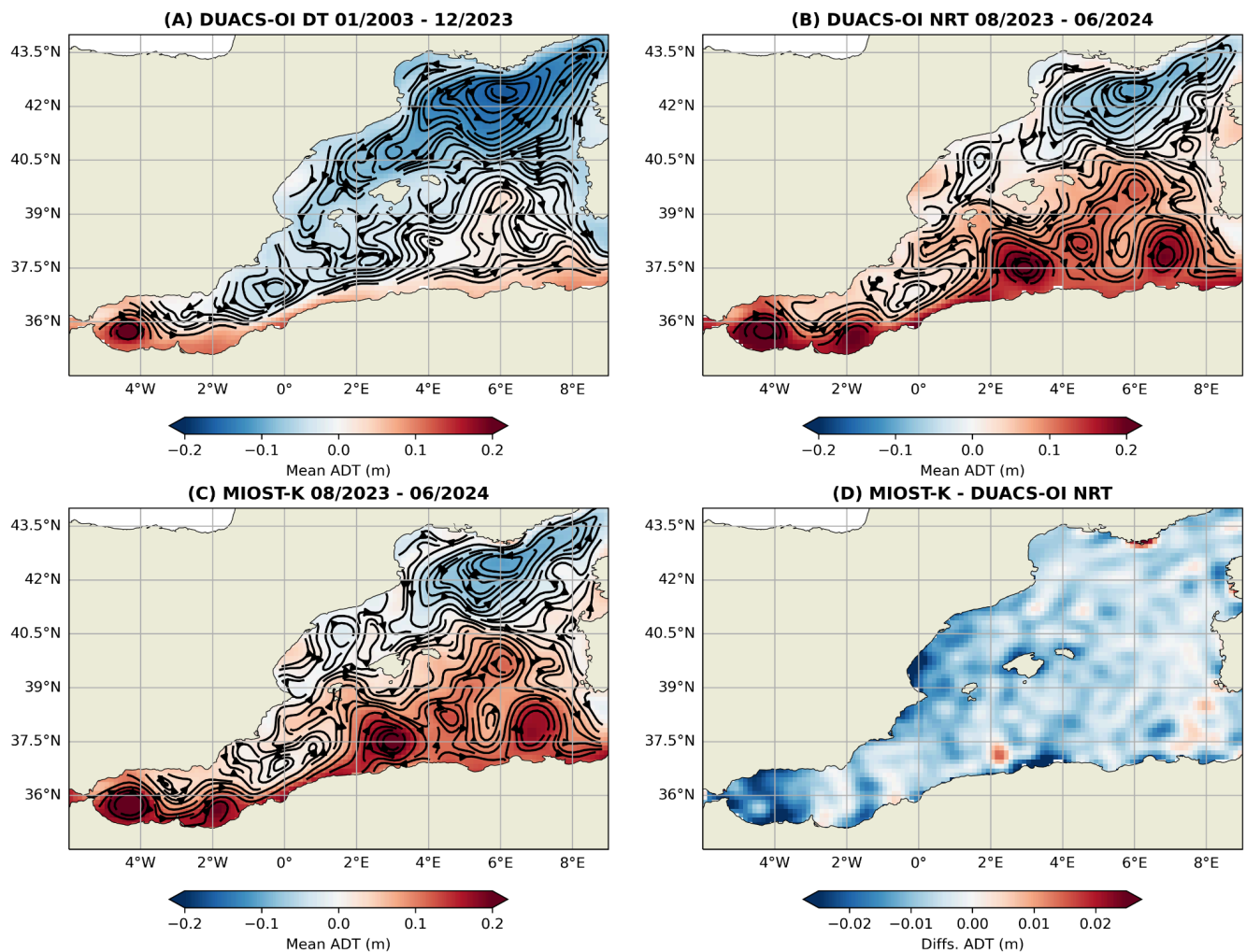
164 where N_T and N_0 are the number of particles at the final and the release days, respectively.

165 4 Results

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

188

189



190

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

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

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

212

213

214

215

216

217

218

219

220

221

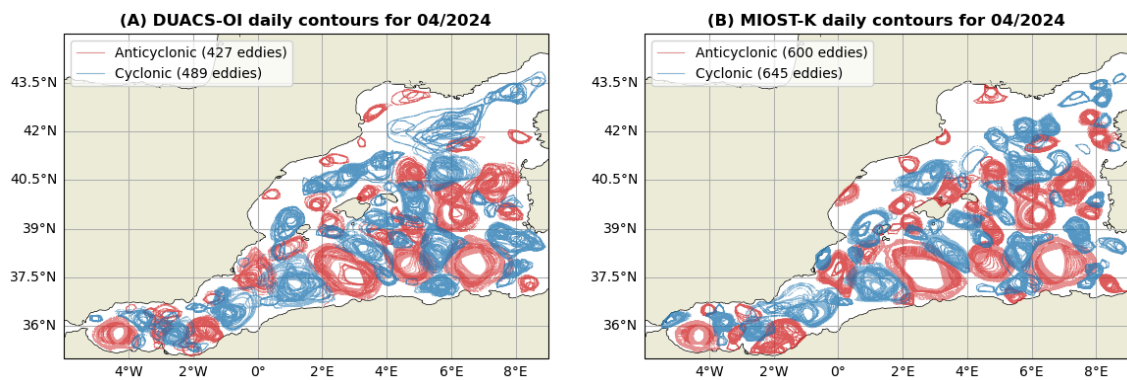
222

223

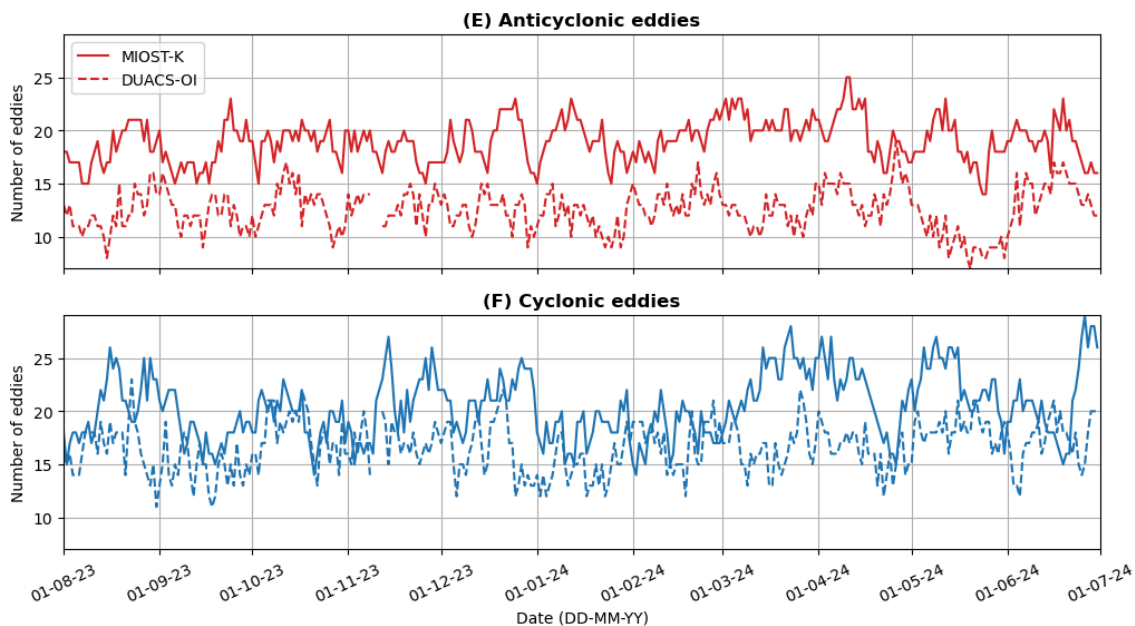
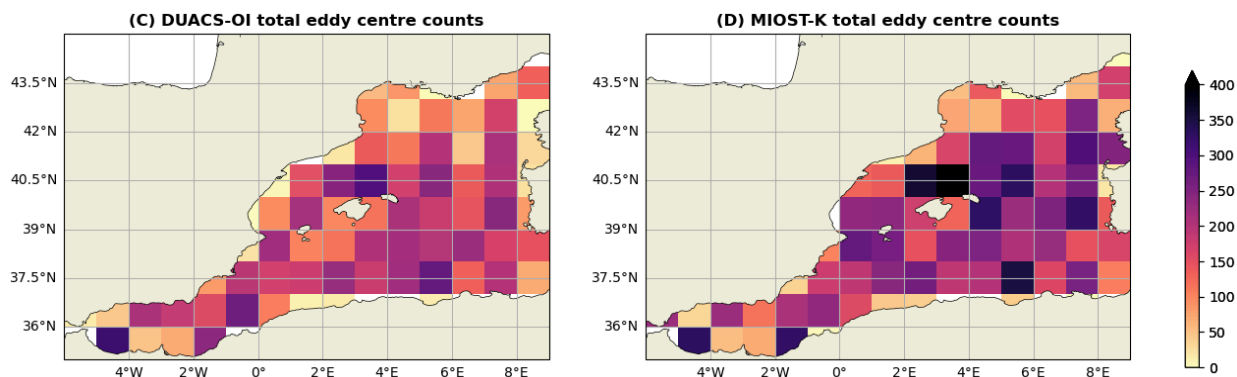
224

225

226



227

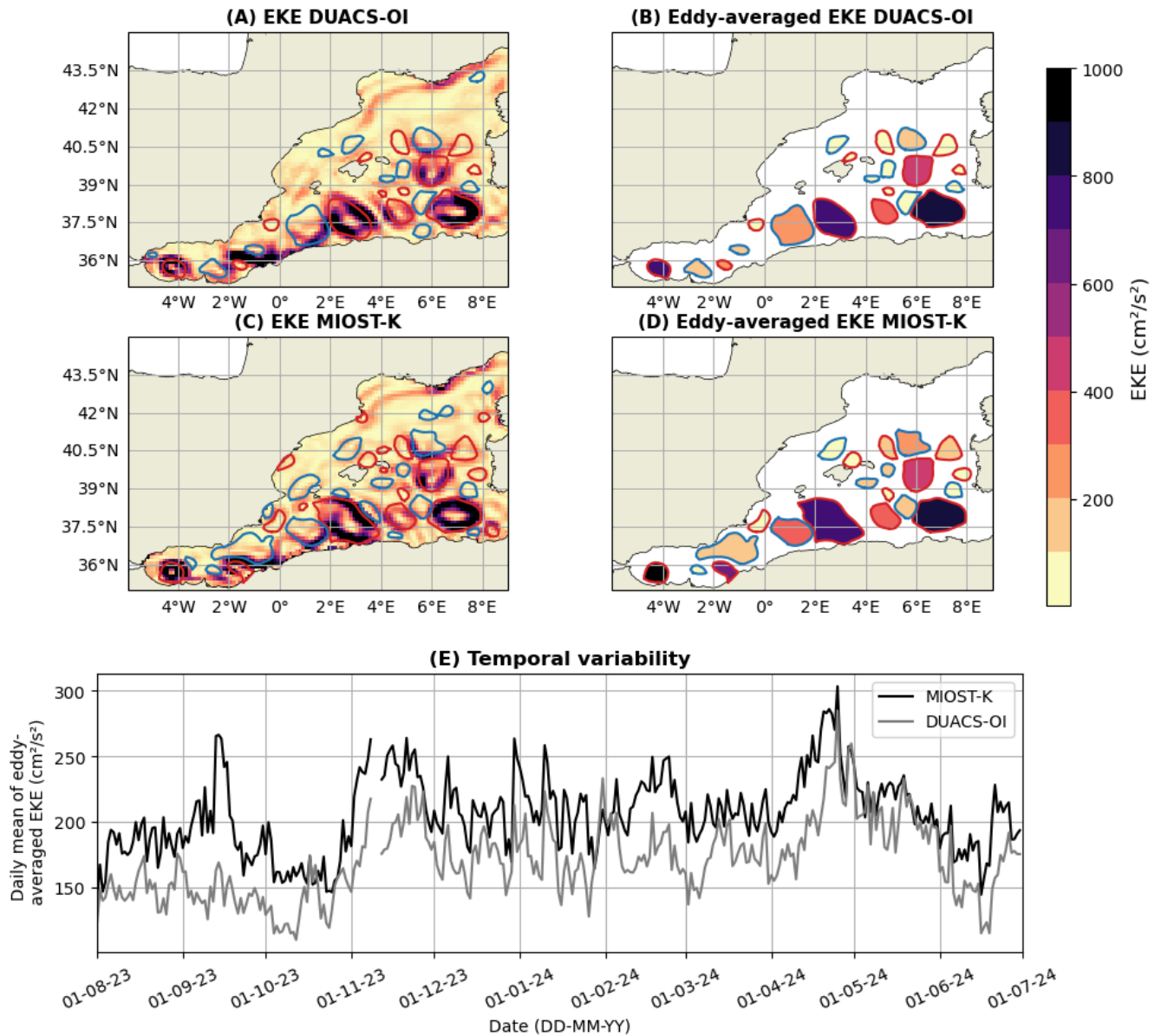


228

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 1x1° 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
236 calculate the mean EKE associated to these eddies. i.e., the eddy-averaged EKE (Figs. 3B and 3D). Fig. 3E shows the
237 temporal variability of the daily mean of eddy-averaged EKE (daily mean EKE) of all the matching eddies identified.
238 MIOST-K shows a higher daily mean throughout the majority of the study's time period. Both datasets reach their maximum
239 during the same energetic event on 25/04/2024, although the MIOST-K value is approximately 6% higher than in
240 DUACS-OI. More importantly, specific daily differences between the products can be substantially larger, with MIOST-K
241 exhibiting increases of up to 78% relative to DUACS-OI during certain energetic mesoscale events, such as on 16/09/23. On
242 96% of the days, the daily mean in MIOST-K is higher than in DUACS-OI (we also checked the differences in the daily
243 maximum of eddy-averaged EKE, and these are higher 93% of the time). This enhanced EKE representation is likely
244 associated with the improved spatial sampling, two-dimensional swath geometry, and enhanced representation of
245 higher-wavenumber variability enabled by SWOT observations. Furthermore, SWOT observations are expected to exhibit
246 substantially lower noise levels than conventional nadir altimeters (Vergara et al., 2023), which may also contribute to the
247 differences observed. This has important implications for KE trend studies (e.g. Martínez-Moreno et al., 2019; Barcelo-Llull
248 et al., 2025), which in turn also can mean a challenge for current climate model projections (Barcelo-Llull et al., 2025). For
249 example, Hogg et al. (2015) mention the significant impact EKE trend variations have on the ocean's carbon and heat sinks
250 in regions like the Southern Ocean, where increasing EKE has been associated with changes in the efficacy of these sinks
251 and the consequent global climatic implications. In the western Mediterranean Sea, where mesoscale eddies strongly
252 influence transport and exchanges between subbasins, the enhanced EKE representation identified in MIOST-K may
253 similarly have important implications for regional heat, salt, and carbon-related transport processes. For example, the higher
254 EKE observed in the energetic Alboran Sea eddies shown in Fig. 3 could affect the representation of heat and salt exchanges
255 through the Strait of Gibraltar (e.g. Bryden et al., 1994; Tsimplis and Bryden, 2000; Sánchez-Román et al., 2009; Hargous et
256 al., 2026). Such differences in EKE and mesoscale structure representation may also influence particle transport and
257 retention estimates, with implications for marine pollution management and offshore spatial planning, as explored in the
258 Algerian eddy case study presented in the following section.

259

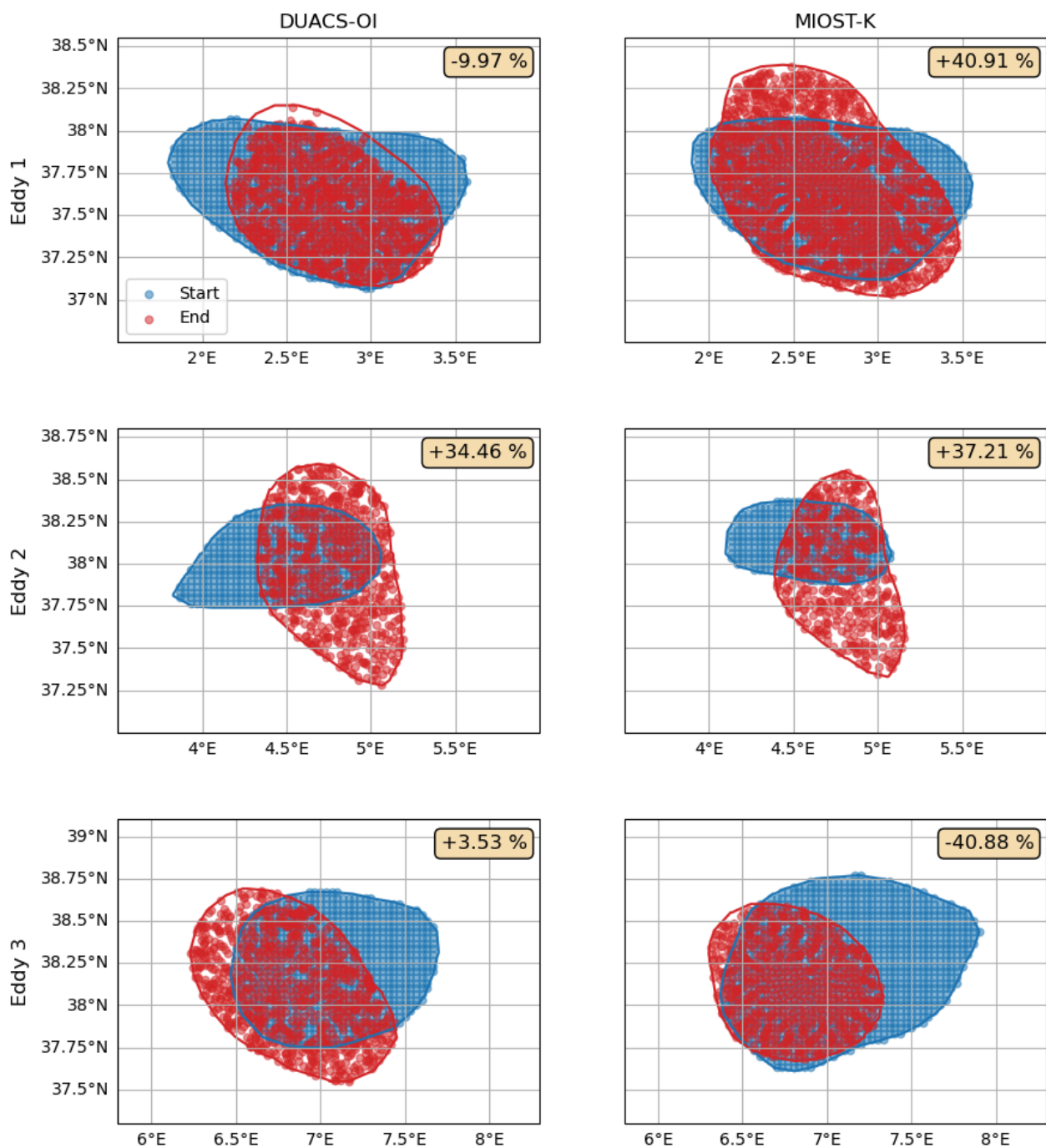


260

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.



286

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). To further validate the robustness of our retention findings, future work could extend the Lagrangian
323 analysis to a larger ensemble of eddies. Statistical comparison across datasets would help quantify whether observed

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

330

331 It is worth mentioning that, by design, conventional interpolation methods tend to filter out small-scale features detected by
332 SWOT, leading to an underrepresentation of fine-scale eddies (typically around 50 km in diameter, or <100 km in
333 wavelength) in Level-4 products such as DUACS and MIOST. Moreover, SWOT captures a broader range of high-resolution
334 ocean dynamics, including nonlinear eddies and internal waves, that are beyond the reach of nadir altimeters and not
335 resolved by current mapping techniques. Recent studies have shown that mesoscale eddies can be identified directly from
336 SWOT wide-swath SSH observations (e.g. Verger-Miralles et al., 2025; de Marez et al., 2026; Han et al., 2026; Fu et al.,
337 2026). This direct approach is less suited to larger eddies that extend beyond the swath, but preserves the fine-scale
338 information contained in SWOT observations and avoids the smoothing introduced by Level-4 mapping. However, a key
339 limitation lies in the coarse temporal sampling imposed by the 21-day repeat cycle of the science phase, which hinders the
340 analysis of rapidly evolving fine-scale dynamics (Archer et al., 2025). To fully exploit SWOT's potential, especially at
341 submesoscales, new frameworks are needed. Promising advances in this direction are emerging from data- and model-driven
342 mapping approaches (e.g., Fablet et al., 2021; Le Guillou et al., 2023, 2024) and in the development of robust validation
343 strategies tailored to SWOT observations (Coadou-Chaventon et al, 2025; Verger-Miralles et al, 2025).

344 6 Conclusions

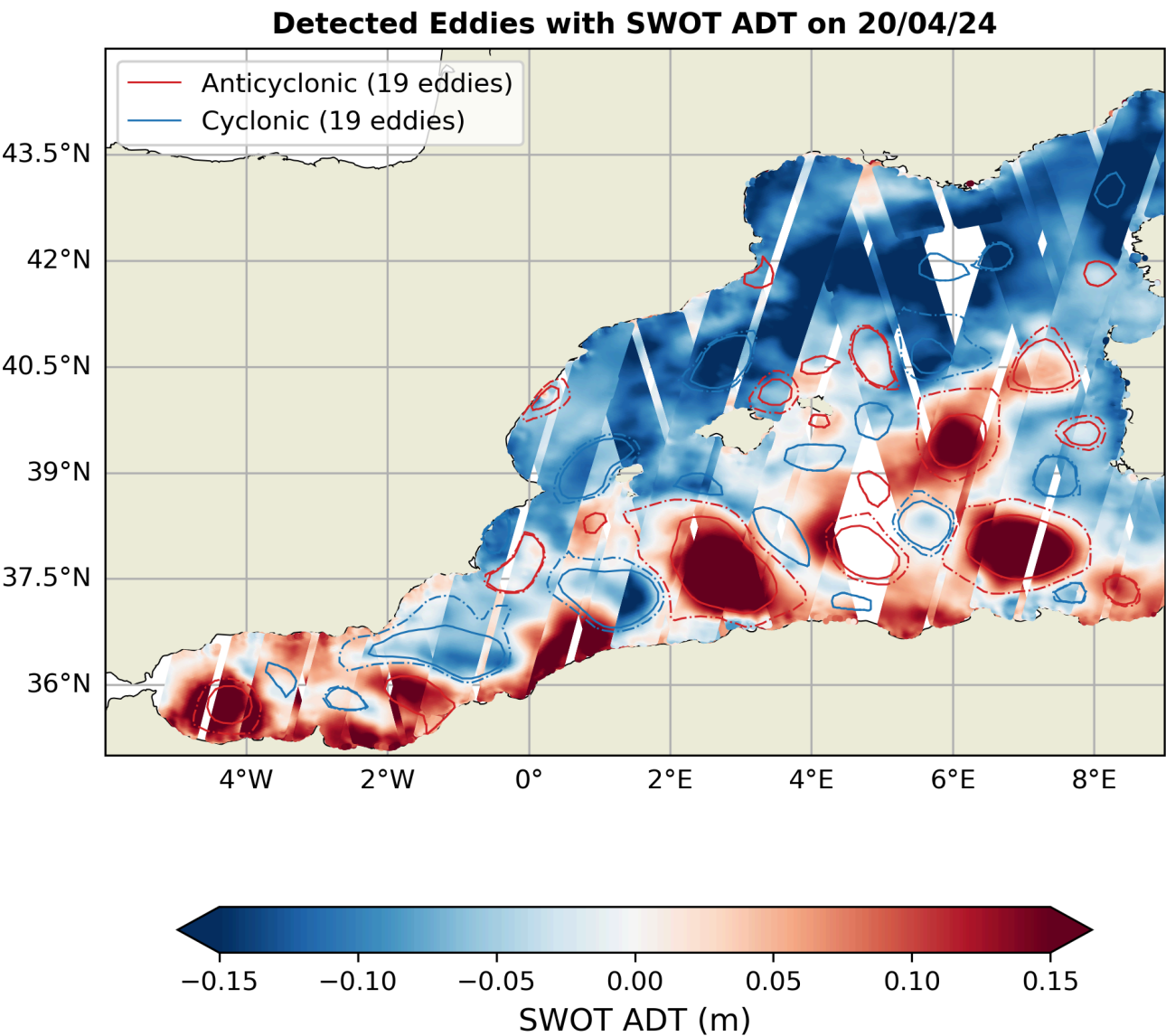
345 This study provides new insights on how the monitoring capabilities of surface circulation, namely mesoscale activity, will
346 improve with the new wide-swath satellites such as SWOT. This is relevant to improve operational oceanography services,
347 for example in managing and forecasting marine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

352

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

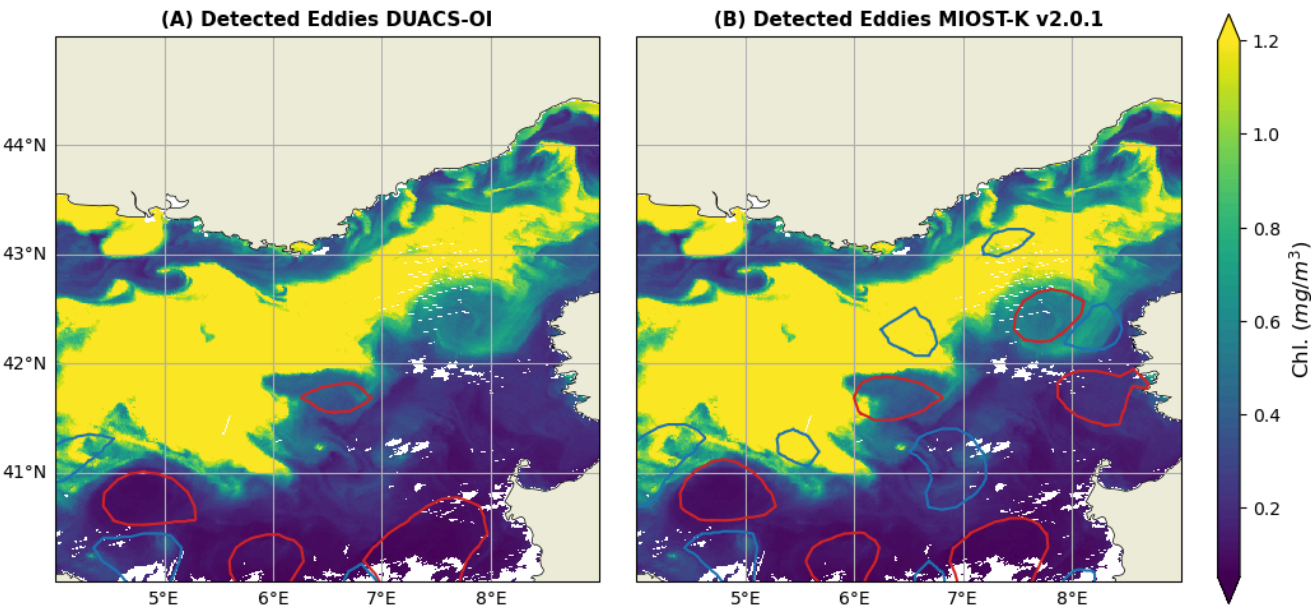
new products including SWOT (MIOST-K). An increase in Eddy Kinetic Energy (EKE) is found, which plays a vital role in the Mediterranean Sea by driving the variability of ocean circulation, redistributing heat, salt, and nutrients, and supporting marine productivity in this climatically sensitive region. 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 (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

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, and the version used for the manuscript
397 is published on Zenodo: <https://doi.org/10.5281/zenodo.22725565> (Gómez-Navarro, 2026).

398 **Data availability**

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

401 **Author contributions**

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

405 **Competing interests.**

406 The contact author has declared that none of the authors has any competing interests.

407 **Acknowledgements**

408 The authors gratefully acknowledge the helpful comments of the OSR coordination team, Karina von Schuckmann, Lorena
409 Moreira and Alvaro de Pascual during the definition, implementation and writing of this study, and the feedback of the two
410 anonymous reviewers. Additionally, the Copernicus Marine Service and AVISO are acknowledged for access to the datasets
411 used for this work.

412 **Financial support**

413 This study is funded by the Copernicus Marine Service (Sea-Level Thematic Center 24251L02-COP-TAC SL-2100). We
414 also acknowledge funding from the Spanish Ministry of Science, Innovation, and Universities, the Spanish Research Agency,
415 the European Regional Development Fund (MCIN/AEI/10.13039/501100011033/FUE) under Grant
416 PID2021-122417NB-I00 (FaSt-SWOT project). LGN is also grateful for current funding under the Marie Skłodowska-Curie
417 Actions programme, funded by the European Union (HORIZON-MSCA-2023-PF RELACS, grant agreement no.

101155713), and funding from the Spanish government through the “Severo Ochoa Centre of Excellence” accreditation (CEX2019-000928-S).

References

20minutos: El GOB denuncia la presencia de numerosos residuos plásticos en aguas del parque Nacional de Cabrera. <https://www.20minutos.es/noticia/2517637/0/gob-denuncia-presencia-numerosos-residuos-plasticos-aguas-parque-nacional-cabrera/>, last access: 9 July 2025, 2015.

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

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

AVISO/DUACS. SWOT level-3 KaRIn low rate SSH expert (v2.0.1) dataset. CNES. <https://doi.org/10.24400/527896/A01-2023.018>, 2024.

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

Ballarotta, M., Pujol, M.-I. and SL-TAC team: EU Copernicus Marine Service Quality Information Document for the European Seas Gridded L4 Sea Surface Heights And Derived Variables NRT, , SEALEVEL_EUR_PHY_L4_NRT_008_060, Issue 13.0, Mercator Ocean International, <https://documentation.marine.copernicus.eu/QUID/CMEMS-SL-QUID-008-032-068.pdf>, last access: 16 July 2025, 2025a.

Ballarotta, M., Pujol, M.-I. and SL-TAC team: EU Copernicus Marine Service Quality Information Document for the European Seas Gridded L4 Sea Surface Heights And Derived Variables Reprocessed 1993 Ongoing, SEALEVEL_EUR_PHY_L4_MY_008_068, Issue 13.0, Mercator Ocean International, <https://documentation.marine.copernicus.eu/QUID/CMEMS-SL-QUID-008-032-068.pdf>, last access: 16 July 2025, 2025b.

449 Ballarotta, M., Ubelmann, C., Bellemin-Laponnaz, V., Le Guillou, F., Meda, G., Anadon, C., Laloue, A., Delepoulle, A.,
 450 Faugère, Y., Pujol, M.-I., Fablet, R., and Dibarboure, G.: Integrating wide-swath altimetry data into Level-4 multi-mission
 451 maps, *Ocean Science*, 21, 63–80, <https://doi.org/10.5194/os-21-63-2025>, 2025c.
 452

453 Ballarotta, M.: SSALTO/DUACS Experimental Product Handbook: Gridded Sea Level Heights and geostrophic velocities
 454 computed with SWOT Level-3 products (using both KaRIn and nadir instruments) with MIOST Version 2.0.1., Issue 2.1.,
 455 AVISO, https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_duacs_experimental_miost_swot_v2.1.pdf, last
 456 access: 22 April 2026, 2025.
 457

458 Barceló-Llull, B., Rosselló, P., Combes, V., Sánchez-Román, A., Pujol, M. I., and Pascual, A.: Kuroshio Extension and Gulf
 459 Stream dominate the Eddy Kinetic Energy intensification observed in the global ocean, *Sci Rep*, 15,
 460 <https://doi.org/10.1038/s41598-025-06149-9>, 2025.
 461

462 Beron-Vera, F. J., Wang, Y., Olascoaga, M. J., Goni, G. J., and Haller, G.: Objective Detection of Oceanic Eddies and the
 463 Agulhas Leakage, *Journal of Physical Oceanography*, 43, <https://doi.org/10.1175/JPO-D-12-0171.1>, 2013.
 464

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

467 Compa, M., Alomar, C., Mourre, B., March, D., Tintoré, J., and Deudero, S.: Nearshore spatio-temporal sea surface trawls of
 468 plastic debris in the Balearic Islands, *Marine Environmental Research*, 158, 104945,
 469 <https://doi.org/10.1016/j.marenvres.2020.104945>, 2020.
 470

471 Coadou-Chaventon, S., Swart, S., Novelli, G., and Speich, S.: Resolving Sharper Fronts of the Agulhas Current Retroflection
 472 Using SWOT Altimetry, *Geophysical Research Letters*, 52, <https://doi.org/10.1029/2025gl115203>, 2025.
 473

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

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

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

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

486

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

490

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

495

496 Escudier, R., Mourre, B., Juza, M., and Tintoré, J.: Subsurface circulation and mesoscale variability in the Algerian subbasin
 497 from altimeter-derived eddy trajectories, Journal of Geophysical Research: Oceans, 121, 6310–6322,
 498 <https://doi.org/10.1002/2016JC011760>, 2016.

499

500 EU Copernicus Marine Service Product: Mediterranean Sea Mean Dynamic Topography, Mercator Ocean International [data
 501 set], <https://doi.org/10.48670/moi-00151>, 2024.

502

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

505

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

508

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

511

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

514

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

519

520 Gómez-Navarro, L.: LauraGomezNavarro/paper-OSR10_Gomez-Navarro_etal_2026: First release update (Version v1.0.2).
521 Zenodo [code]. <https://doi.org/10.5281/zenodo.22725565>, 2026.

522

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

525

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

528

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

532

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

536

537 Le Traon, P. Y., Nadal, F., and Ducet, N.: An Improved Mapping Method of Multisatellite Altimeter Data, *Journal of*
538 *Atmospheric and Oceanic Technology*, 15, 522–534,
539 [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.

540

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

545

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

548

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

551

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

555

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

559

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

564

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

568

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

572

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

576

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

580

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

583

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

587

588 Pujol, M.-I.: EU Copernicus Marine Service Product User Manual for the European Seas Gridded L4 Sea Surface Heights
 589 And Derived Variables Reprocessed 1993 Ongoing, SEALEVEL_EUR_PHY_L4_MY_008_068, Issue 10.0, Mercator
 590 Ocean International, <https://documentation.marine.copernicus.eu/PUM/CMEMS-SL-PUM-008-032-068.pdf>, last access: 16
 591 July 2025, 2025b.
 592
 593 py-eddy-tracker: Welcome to py-eddy-tracker's documentation!, <https://py-eddy-tracker.readthedocs.io/en/v3.3.1/>, last
 594 access: 8 July 2025.
 595
 596 Ruiz-Orejón, L. F., Mourre, B., Sardá, R., Tintoré, J., and Ramis-Pujol, J.: Quarterly variability of floating plastic debris in
 597 the marine protected area of the Menorca Channel (Spain), *Environmental Pollution*, 252, 1742–1754,
 598 <https://doi.org/10.1016/j.envpol.2019.06.063>, 2019.
 599
 600 Sánchez-Román, A., Pujol, M. I., Faugère, Y., and Pascual, A.: DUACS DT2021 reprocessed altimetry improves sea level
 601 retrieval in the coastal band of the European Seas, *EGU sphere*, 1–22, <https://doi.org/10.5194/egusphere-2023-63>, 2023.
 602
 603 Stegner, A., Vu, B. L., Dumas, F., Ghannami, M. A., Nicolle, A., Durand, C., and Faugere, Y.: Cyclone-Anticyclone
 604 asymmetry of eddy detection on gridded altimetry product in the Mediterranean Sea, *Journal of Geophysical Research:*
 605 *Oceans*, 126, e2021JC017475, <https://doi.org/10.1029/2021JC017475>, 2021.
 606
 607 Suaria, G. and Aliani, S.: Floating debris in the Mediterranean Sea, *Marine Pollution Bulletin*, 86, 494–504,
 608 <https://doi.org/10.1016/j.marpolbul.2014.06.025>, 2014.
 609
 610 Taburet, G., Sanchez-Roman, A., Ballarotta, M., Pujol, M.-I., Legeais, J.-F., Fournier, F., Faugere, Y., and Dibarbouré, G.:
 611 DUACS DT-2018: 25 years of reprocessed sea level altimeter products, *Ocean Sci.* 15, 1207-1224. 675 680 685 690 695 700
 612 <https://doi.org/10.5194/os-15-1207-2019>, 2019.
 613
 614 Taupier-Letage, I., Puillat, I., Millot, C., and Raimbault, P.: Biological response to mesoscale eddies in the Algerian Basin, *J.*
 615 *Geophys. Res.*, 108, <https://doi.org/10.1029/1999JC000117>, 2003.
 616
 617 Ubelmann, C., Dibarbouré, G., Gaultier, L., Ponte, A., Arduin, F., Ballarotta, M., and Faugère, Y.: Reconstructing Ocean
 618 Surface Current Combining Altimetry and Future Spaceborne Doppler Data, *Journal of Geophysical Research: Oceans*, 126,
 619 e2020JC016560, <https://doi.org/10.1029/2020JC016560>, 2021.
 620

621 Ubelmann, C., Carrere, L., Durand, C., Dibarboure, G., Faugère, Y., Ballarotta, M., Briol, F., and Lyard, F.: Simultaneous
 622 estimation of ocean mesoscale and coherent internal tide sea surface height signatures from the global altimetry record,
 623 Ocean Science, 18, 469–481, <https://doi.org/10.5194/os-18-469-2022>, 2022.
 624
 625 Última Hora: Un mar de plásticos. <https://www.ultimahora.es/noticias/local/2015/07/23/157489/mar-plasticos.html>, last
 626 access: 22 July 2025, 2015.
 627
 628 Verbrugghe, N., Greiner E., Augot, J., Sammartino, M., Colella, S., Buongiorno-Nardelli, B., Hernandez-Carrasco, I., Falcini,
 629 F., Rossi, V. and Lacorata, G.: Algorithm Theoretical Baseline Document for 4DMED-SEA Project, version 2, ESA,
 630 http://ricerca.ismar.cnr.it/4DMED/docs/4DMED-SEA-D2_ATBD_v2.0-signed.pdf, last access: 15 June 2026, 2024.
 631
 632 Verger-Miralles, E., Moure, B., Gómez-Navarro, L., Barceló-Llull, B., Casas, B., Cutolo, E., Díaz-Barroso, L., d’Ovidio, F.,
 633 Tarry, D. R., Zarokanellos, N. D., and Pascual, A.: SWOT Enhances Small-Scale Eddy Detection in the Mediterranean Sea,
 634 Geophysical Research Letters, 52, e2025GL116480, <https://doi.org/10.1029/2025GL116480>, 2025.
 635
 636 Volpe, G., Colella, S., Brando, V. E., Forneris, V., La Padula, F., Di Ciccio, A., Sammartino, M., Bracaglia, M., Artuso, F.,
 637 and Santoleri, R.: Mediterranean ocean colour Level 3 operational multi-sensor processing, Ocean Sci., 15, 127–146,
 638 <https://doi.org/10.5194/os-15-127-2019>, 2019.
 639
 640 Wang, H., Liu, Y., Yang, Y., Yan, R., and Wang, S.: Optimal Shipping Route under the Designation of the Mediterranean
 641 Sulfur Emission Control Area: Mathematical Models and Applications, Mathematics, 11, 4897,
 642 <https://doi.org/10.3390/math11244897>, 2023.