Review for Ocean Science
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<u>A 4D-Var Data Assimilation System for the North-Western Mediterranean Sea and its Impact on the Corsica Channel Transport</u>

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General comment

The research conducted is based on studying the impact of each set of observations, assimilated into a ROMS configuration of the northwestern Mediterranean using the 4D-Var assimilation scheme, on the transport that characterizes the East Corsica Current (ECC) in the Corsica Channel (CC). This study follows on from that of Bendoni et al. (2023) who constructed the configuration and studied the impact of two sets of HFR data plus satellite SST data on the representation of the Northern Current transport. Major improvments enhance the value of the present article. The assimilated observation data has substantially increased (by approximately +40%) thanks to the addition of three new types of data (in situ ADCP mooring in the CC, in situ temperature and salinity profiles and SLA). Although one radar (Toulon) was removed from the assimilated sets, the detection area of the other (Ligurian) was doubled, as it is closer to the CC. The study period was also extended (four times) to cover the entire year 2022, which made it possible to evaluate the correct reproduction of the seasonal variability of ECC transport. In addition, numerous impressive indicators (Tables 1 and 2, Figures 3, 4, 7, 8, 9, 10) yielded robust results in accurately measuring the specific contributions of each observation to the targeted representation of ECC transport. It was demonstrated that the CC mooring was crucial in the DA procedure, while DA of satellite SLA was proved to be almost useless in the ECC representation. Furthermore, the authors showed that observations did not contribute equally across seasons and even show some opposite contributions that refine the vertical distribution of the transport in the CC transect, and that distant observations contribute to the transport refinement.

However, several issues remain to qualify the quality of the article. One-third of the text and half of the figures are grouped together in a single subsection of the results, with multiple references linking the figures in the twenty or so paragraphs of the subsection, to which are added inserted discussions, making it difficult to read. The objective of the study is to « provide insight into dominant dynamic scales » while some major features of the domain and period are not taken in account in the interpretation of the « different observations to transport increments through the CC », such as the upwelling system north of the Gulf of Lion, which is indirectly linked to the Bonifacio Gyre by the same atmospheric driving force (the Mistral and Tramontane winds), and precisely, the involvement of the Bonifacio gyre in modulating the variability of the ECC transport, or the intense and widespread marine heatwave that affected the entire Western Mediterranean from mid-May to the end of September in 2022. The study focuses solely on the western part of the CC, without considering the eastern part of the strait, which is shallower and sometimes features an eddy surrounding the island of Capraia during the summer. I therefore recommend that this article be published only after major revisions have been made.

General remarks

Section 3.2 is substantial ; it must be divided or subdivided. A discussion section is also highly recommended.

Please use the same nomenclature for section and subsection titles (with or without capital letters). Remove acronyms.

In general, figures could be more understandable without having to read their captions or the text (dates in the panels for example).

Please ensure compliance with the author guidelines.

Specific remarks

Please modify the title, it is too close to Bendoni et al. (2023) and does not adequately reflect the quality of your work. You could consider words such as « assessment » or « refinement » or put « 4D-Var DA system » latter in.

1. Introduction

Line 29. as instead of ad.

L 30. « MPA » is not used latter, not necessary.

L 31-32. The WMDW is also present in the Liguro-Provençal basin, as well as the WIW between AW and EIW. And the TIW is comprised in the ECC (Napolitano et al., 2019).

L 32-34. The cyclonic circulation is called the Northern Gyre and Liguro-Provençal basin has more currents than the NC, WCC and ECC, such as the Balearic current for instance. NC, WCC and ECC are focused on the Ligurian Sea.

L 34. LPC is not used after. And the NC also pursue along the Catalan coasts.

L 38-39. The eddy surrounding the island of Capraia is an important process in the CC (e.g. Iacono and Napolitano, 2020 among others). The Bonifacio Gyre is also important in the feeding and shaping of the ECC. The main circulation of the Tyrrhenian basin must also be mentioned.

L 40. « influences Western Mediterranean » … « and the WIW and WMDW formation processes » …

L 41. Could you add also a more recent reference for the importance of the CC in the biological connectivity between the Tyrrhenian and the Ligurian ?

L 45-57. An example of assimilation of mooring data that improved transport in a strait elsewhere ? In order to support your research. As well as for CORA and EMSO.

L 50-54. What kind of observations ?

L 70-72. Rewrite according to the changes.

2. ROMS 4D-Var Da System for the *North-Western Mediterranean*

2.1. Model setup

L 79. There are no explanations concerning Vtransform, Vstretching, ThetaS and ThetaB. A concise reason for changing the values of Nu and KhiT ? And the previous ones, if that is the case ?

L 113-114. It is therefore best to choose one and use it consistently throughout the rest of the text.

L 112. Toulon HFR has not been used. A reason, more than its far location ? You already did in Bendoni et al. (2023) and it was crucial for the NC reproduction.

L 119. « detrended » or smoothed ? A trimestrial smoothing does not remove a seasonal cycle (an annual moving average?). Removing a daily smoothing does not remove the diurnal signal. I think you meant the opposite.

2.2. Assimilated observations

L 130. Is there a reference for JERICO's HFR data such as previously ?

L 134-135. Did you sub-sampled in the space too ?

L 148-149. You could specify the types of data that make up the CORA database. This should also supports your study.

L 151. The website link for Albatross data is not working.

L 155 vs L 158. You have specified all satellites for SLA data, but not for SST data. Please choose one or the other (it seems that SST data is more important than SLA data in this study).

L 163. « signals, such as in Zavala-Garay » ?

L 164-165 Parenthesis around years.

L 171-172. In addition to the mean, could you provide the standard deviation and the extremes along the period ? Figure 3 seem to show lacks in January and July (see the comment about the figure).

2.3. Quantifying impact of observations

L 190. You limited your work in the east to 9.8369°E. Why not 10.5°E? The entire ECC transport would have been calculated accurately, as is generally the case in the literature, and would therefore have allowed for a more accurate comparison with it. You would have been able to detect the presence or absence of the Capraia eddy in the summer and evaluate the DA system's ability to reproduce it. I think you should explore the subject.

<u>3.1. Performance of DA system</u>

L 205. FR is not defined before in the text.

L 215. « are similar (especially for salinity, Figure 3d) »

L 218. Tcora also presents a regime shift in mid-May. This corresponds to the large MHW of 2022 (see McAdam et al. (2023) and Estournel et al. (2025)). This may be the origin of the changes in Fig. 2 (SST+SLA+CORA ~25 % of data). The episode of May is also visible Scora (evaporation) and SLA (thermo-steric evelation), with another episode in late-July (Scora and SLA again), also corresponding to the other maximum of 2022 MHW. SST episode of mid-March : due to a lack of data. What happened in mid-August (Uhfr, Vhfr and Scora) ? A Capraia eddy ? Water from the Arno ? Both ?

L 219. 52.5 % is an important improvement, linked to the MHW ?

L 227. Because of the seasonal varibility of v while u is not predominant in the ECC.

L 229-230. The hydrological characteristics of AW, WIW, and EIW are more sensitive to seasonal surface variability than deeper water masses, which assumes that the seasonal variability is reached thanks to the DA.

L 231. S is less sensitive to seasonal surface variability than T.

L 232. Rho rather means density in oceanography. r is acceptable for Pearson’s correlation coefficient.

L 246-247. W1 is actually located in the Ligurian current, so it cannot be used to measure the WCC.

L 245-247. The general circulation switched from a Western Mediterranean gyre (Algero-Provencal + Tyrrhenian, see Millot and Taupier-Letage, 2005) towards the North-Western Mediterranean gyre (WCC+NC+BC, Northern Gyre or the North Gyre, see Garreau et al., 2018 or Barral et al., 2025) by constructing the ECC’s inner seasonal cycle (Vara et al., 2019). The southeastern closure of the North Gyre has clearly been enhanced along the southern boundary of the domain thanks to the DA.

<u>3.2. Observation Impact on Corsica Channel Transport</u>

L 268. An explanation for the in situ T bias ? Is in situ S doing the opposite ? Is it because of the Bonifacio Gyre assimilation (Fig. 10e) ?

L 270. « CC transport (dI ≥ 0), and vice versa. », isn’t it ?

L 275-276. Or even, what would support the most your point, in a reanalysis with 0.35 ±0.365 Sv in Barral et al. (2025), while they took into acount the eastern part of the Capraia Island. Otherwise,

L 277. Figure 6e) does not exist.

L 276-279. And the fact that you also neglicted the transport in the east of Capraia Island.

L 296-297. Could it be that observation contributes more and more to AD as it is located upstream? Could it then be that observation data for the current located further south than CoCM is relevant? Such as HFR and/or moorings?Could you clarify why TINO/SVIN were not used (Doronzo et al., 2025) ?

L 301-303. Please specify somewhere « Global » and « Datum ».

L 306-307. Is it possible that if Nobs increases then Datum decreases ? And if Nobs increases then Nw increases and consequently Global increases too ? If so, HFR, in situ T & S and SST are approximately following these assumption, whereas CoCM and SLA are not. Consequentely, CoCM can be described as crucial and SLA as of limited impact for ECC transport in this setup, precisely for the ECC transport measurement obviously, whereas they are both of the same order of magnitude for their proportion with respect to the total observations (4.1 vs 2.5 %, Fig. 1d).

L 311-313. The manuscript could note that the northward flow on the western shelf has increased on average ; it is a contrasting result.

L 328-329. If you choose the area-normalized unit (see comment about Figure 9) you could say here that your is an indicator of both at the same time.

L 331. « Furthermore … pattern ». The results appear to show the opposite; please confirm. I think that the WCC enhancement due to the DA could be here better characterized.

L 335. What velocity shows the most surface ADCP from CoCM ? SST data also contributes to the opposite impacts during this period and seem to help CoCM to counteract HFR, the SST being at the surface. Otherwise, plenty of days of summer show that SST counteracts HFR.

L 336. HFR has a shallow impact, such as bathymetry there.

L 338 + 342. These sentences need to be qualified with regard to the circulation : the anticyclonic structure could be interpreted as being the Bonifacio Gyre whereas the northern part of the gyre's dipole is supposed to be cyclonic. A vertically integrated transport over two layers where currents counteracts is difficult to understand. From mid-November to December, IC and AC exert an important influence, in a transition zone between a southward and a strongly northward current. Maybe winds first intensified the Bonifacio gyre and, once the winds calmed down, the gyre weakened, such as the gyre favored the southward flow, while its weakening allowed the northward current to strengthen. If true, this proves that DA generates the ECC modulation by the gyre, without the latter being present in the domain (by a correction of the BC as explained in lines 343-345) and is a valuable result.

L 352-365. The freshwater influence regions (RoFi) of the Rhône and Arno rivers do not correspond to the yellow areas shown in Fig. 10c).

The RoFi of the Rhône does not extend to 6°E; it sometimes reaches 5°E, but less than a quarter of the time during the year (see Fraysse et al., 2014). The large yellow pattern located in the Gulf of Lion corresponds to the upwelling system formed by the Mistral wind and the downwelling system formed by easterly winds in the region (Odic et al., 2022). This coincides with your panels : the locations of upwellings and downwellings (Fig. 10c and e) during the subsurface MHW of 2022 in the Gulf of Lion (see Fig. 5a and 6b in Estournel et al., 2025).

The DA therefore both used the upwelling and downwelling systems, whether this was due to the DA link to the wind that builds the Bonifacio Gyre (that modulates the ECC especially during summer) or the subsurface MHW that may have weaken the ECC even more than a typical summer weakening of the ECC (by an attuation of the geostrophy due to stratification), or both of them at once.

One aspect is particularly interesting here: south-east of Corsica has a high RMSg in Fig. 10e), which does not appear in either Fig. 10c) or Fig. 10f) (or very weakly compared to the Rhône's RoFi importance). This may highlight the importance in situ T data from the intermediate layer there (no SST signal, no coastal signal, no salinity signal) and thus, either signs the MHWs or help to identify which data may have led to the BC improvment for the Bonifacio Gyre, or even both. A time series (such as done for SLA and not shown) may help here.

The RoFi of the Arno river does not extend beyond the north of La Spezia, and sometimes even goes south. It is rather localized, very coastal, on the surface, between Pisa and La Spezia (Vignudelli et al., 2004 ; Lapucci et al., 2012 ; Poulain et al., 2020). In this area, RMSg of SST is lower than offshore, whereas the river's freshwater is colder than the sea on average, even in winter (Vignudelli et al., 2004), and the Rhône issue showed that SST is not the best indicator for a RoFi. This yellow pattern of high SST RMSg that is located between Portofino and La Spezia more corresponds to the HFR RMSg distribution seen in Fig. 10a), which is linked to the ECC circulation in the CC. It seems that SST impact is here linked to HFR impact. Note the circulation of Fig. 9d) and the results of Bendoni et al. (2023) where they concluded that « The impact of the SST is significant and acts to further correct the velocity distribution of the increment induced by the HFRs observations ».

However, the RoFi of the Rhône does indeed have an influence on the DA. This phenomenon is illustrated in Figure 10f) (instead of 10c), which appears to delineate the significance of low salinities in the DA. This signal from low salinities does not reach Marseille, which corresponds to the findings of Fraysse et al. (2014). It should be noted that the aforementioned assistance is not applicable to the RoFi of the Arno river, due to the absence of in situ S data in that particular location. The relative importance of the DA of the Rhône river's RoFi for the ECC transport refinement is a subject of considerable interest, given that the RoFi is located downstream and is separated by the NC as a dynamic barrier. Are precipitations and the substantial discharges of the Rhône river seen as indicators for another process that controls the ECC ? Are the Arno southward extensions linked to the high precipitations ? It appears that in situ S data is also of significance in the western region of the Island of Elba (south of CoCM). Are these two locations of high in situ S RMSg correlated in some episodes alogn the period ? Does the Rhône exert a controlling influence over the BCs in the west ? In consideration of these DA results, which evince a counterintuitive phenomenon, it becomes imperative to propose a hypothesis or explanation for the observed occurrence of remote control.

4. Conclusion

L 429. « Corrections due to »

Figures and Tables

Please remove « 2022 » from times axes in figures 2, 3, 6, 8 and 10, and put all the months.

Fig. 1a. The 2022 surface circulation of the FR is redundant with figure 5a (even if not at the surface). The ‘real’ known average circulation of 2022 should be shown for the reader to have a reference. You could use the 2022 mean surface (or 0-200m, maybe useful for Fig.5) circulation from the reanalysis of Escudier et al., (2021).
Exchange ‘b)’ with ‘c)’, not the panel, only the letter.
Here you provide general information about observations, so another issue here is linked with figure 3 :

Fig. 3. Is the entire number of observation highly variable all along the 2022 year ? With a look at all grey bars, it seems that the lack of data, that is present in a) and b) during January and July, is balanced by panel e) ? Please confirm or show me or in the paper the entire time series of number of data.

Fig. 4. W1 data is lower than 0,0 %. Can you provide a reason ? Overall, W1 data is not mentionned while being close to the ECC.

Fig. 8d. Change FC to AC because you used FC for forecast (and adapt in the text).

Tab. 2. There no column for Nw. Can you provide a reason ? It is linked to Datum.

Fig. 9. Please label panels a-b « CoCM period (01 Jan–09 Apr) », panels c-d « HFR period (22 Apr-11 Aug) », and panels e-f « CoCM-HFR opposing period (18 Nov – 23 Dec) ». Please add in the caption « Periods are choosen with regard to Figure 8c » and adapt L 320-322.
‘Sv*’ is unclear. Please clarify whether it denotes Sverdrups divided by the horizontal area. If yes, use the unit ‘$Sv.m^{-2}$’ and state that it represents depth-integrated transport per horizontal unit area, equivalent to the column-average velocity in the same units. If it is not area-normalized, please specify the denominator explicitly (e.g., ‘per water column’ or ‘per grid point’ instead of ‘per grid cell’). For clarity and consistency, I recommend the area-normalized option or another explicit unit, used consistently across the text and figures. This clarification would strengthen the presentation.

Fig. 12. I think that the caption is linked to an old figure.

References

Please put the DOIs, which is specified in the guide for authors (https://ocean-science.net/submission.html#references)

The references’ section needs data references to be accompanied by the notation [dataset] (author’s guide), such as those in lines 24 to 28, and lines 147 to 156.

LI data from offshore the Gulf of Lion is be cited with Houpert but should be also cited as the way that the website asked at first.

Cited references here in this review that are not in the preprint :

Napolitano et al., 2019, «The Tyrrhenian Intermediate Water...», PiO.
Iacono and Napolitano, 2020, « Aspects of the summer... », DSR P1.
McAdam et al., 2024, « Forecasting the Mediterranean... », SotP.
Estournel et al., 2025, «Extreme sensitivity... », Ocean Science.
Millot and Taupier-Letage, 2005, « Circulation in the Meditteranean Sea », book.
Garreau et al., 2018, « High-resolution Observations... », JGR Oceans.
Barral et al., 2025, « Assessment of the Water Mass Dynamics... », JGR Oceans.
Vara et al., 2019, « Role of atmosperic... », Ocean Modelling.
Doronzo et al., 2025, « Validating HF Radar... », Remote Sensing.
Fraysse et al., 2014, « Intrusion of Rhone River diluted ... », JGR Oceans.
Odic et al., 2022, « Sporadic wind-driven upwellin/downwelling... », CSR.
Vignudelli et al., 2004, « Distributions of dissolved... », ECS.
Lapucci et al., 2012, « Evaluation of empirical... », JARS.
Poulain et al., 2020, « On the dynamics in the ... », CSR.