REVIEWER #2:

General Comments

This paper is an ambitious community work aiming to showcase the current status of the Mediterranean HFR network and the future roadmap for coordinated actions that will allow this to play a major role in the high-level challenges of the ocean observing landscape in the Mediterranean Sea. Significant innovations are described, with interesting multi-site approaches and covering a very wide spectra of fields in the overall value-chain from the HFR systems operations to the transfer of advanced data products. The presented work is also gathering a complete review of the main levers that the community is tackling (BPs, Harmonization, Data Quality, New parameters…) for promoting exchanges between operators, and creating synergies and added value by transforming a set of individual radars into an integrated network. The description of the community status, difficulties, key references and challenges derives to a very useful roadmap for the current actors of the network, also for the potential future contributors, and in general for the ocean observing community.

The established regional roadmap is well linked to the European and Global initiatives. Some regional specificities are well described, in particular in the SWOT analysis. However, it may be clarified which of those challenges for future development is really answering a specific or prioritised issue for the Region, and which are shared with the European or Global community. The manuscript will definitely represent an important step forward for the ocean observing community. Some detailed minor changes and recommendations for improving the manuscript are listed below:

Many thanks to the reviewer for the number of useful comments that will help to significantly improve the quality of the final version of this manuscript. In particular, section 5 of the document has been upgraded to better clarify:

"The Mediterranean HFR network must face a variety of challenges for future development, most of which are shared with the European and Global HFR communities. However, few other aspects are specific to the Mediterranean Sea due to the intrinsic peculiarities of this regional semi-enclosed basin. For instance, the presence of reflections from moving ships or radio frequency interferences from (non)official radio services are more pronounced as the maritime traffic is significantly intense in coastal Mediterranean areas (Bellomo et al., 2015). In this context, obtaining dedicated frequency allocation for HFR technology remains the top priority issue. A network extension to cover a substantial portion of the Mediterranean coastline also constitutes a prime concern, especially in the southern shore countries where the monitoring capabilities are extremely limited. This process is handicapped by the prominent use of medium and short range HFR systems which map smaller spatial domains. Moreover, the Strait of Gibraltar, the Dardanelles and the Suez Canal (Fig. 1) act as physical constraints, leading to slow water renewal cycles and high residence times at basin scale. Consequently, global warming and the chronic degree of pollution related to anthropogenic activities impose higher pressures than in any other sea in the world, turning the Mediterranean Sea into a more vulnerable hot spot for climate change (Tuel and Eltahir, 2020)."

l.138 General capabilities of HFR are explained, but here or elsewhere in the paper, there is no mention to the limitations of using Long Range in semi-enclosed seas like the Mediterranean Sea (difference with the IBIROOS area where there is a significant number of Long-Range systems). This can be also mentioned later in the SWOT Weaknesses or at least as a factor for achieving the full coverage.

In the SWOT diagram (weaknesses section), we have replaced "Still limited coverage in the Mediterranean Sea" by "*Limited coverage in the Mediterranean Sea, exacerbated by the predominant use of medium/short range HFR systems*."

Equally, we have added the following piece of text at the beginning of section 3:

"The Mediterranean HFR network includes 15 different systems, which cover a small portion of the entire coastal domain (Fig. 1). The limited spatial coverage is not only due to the reduced number of HFR deployed but also to the predominant use of medium (13.5 MHz) and short (above 20 MHz) range systems, whose basic technical aspects are gathered in Table 2. While these HFRs present a maximum range of 80 km, long range systems (which operate below 5 MHz and are typically deployed in the Atlantic European waters) can map the surface circulation over broader areas for distances up to 200 km offshore."

Moreover, we have also added a mention to the limitations of using long-range in semi-enclosed seas like the Mediterranean Sea (at the beginning of section 3 of the manuscript):

"Long-range HFR systems are not deployed in the Mediterranean since they present some technical limitations in this semi-enclosed sea. On one hand, they provide surface circulation maps with coarser horizontal grid resolution (above 5 km), which are not convenient to adequately resolve some (sub)mesoscale ocean processes (i.e., eddies, instabilities, etc.) that commonly characterise the Mediterranean dynamics. On the other hand, they cannot accurately monitor the wave field under low sea states as the second-order spectrum is closer to the noise floor (and more likely to be contaminated with spurious contributions) than in the case of short and medium range HFR systems. As the Mediterranean wave climate is not as intense as the Atlantic one, the use of long-range systems would result in limited precision and reduced temporal continuity in wave measurements (Lipa and Nyden, 2005). Finally, it is worth mentioning that a cross-border agreement was signed in 2018 (by in Spain, France and Italy) to establish the 13-16 MHz band as the one to be used for oceanographic radars in the Western Mediterranean Sea (Roarty et al., 2019)".

Fig.2 A Mediterranean HFR Working Group is mentioned. In the text l.184, it is called Mediterranean HFR network. For consistency, this would be named in Fig2 (not to be confused with Observation Working Group, one of the 3 MONGOOS WGs).

Apologies, there was a typo in Figure 2. We wanted to mean "Mediterranean HFR Task Team". Actually we think that there is a subtle but significant difference between both concepts, the Mediterranean HFR Task Team (belonging to the Observing working Group from MONGOOS) and the Mediterranean HFR network. The former is a representation of the latter. While the Mediterranean HFR network comprises all the HFR systems deployed in this regional sea and the respective operators, the Mediterranean HFR Task Team constitutes a smaller entity that represents and coordinates joint actions and research contributions from the

entire network. Indeed, some members of the Mediterranean network are not involved in the task team (for instance, the HFR-Dardanos system operated by our Greek colleagues). Other institutions (like those operating HFR-Israel) are open to collaborate in specific initiatives (like the present paper) but, again, are not active participants of the Mediterranean HFR task team.

l.200 Errata: the EuroGOOS HFR Task Team (word order and upper case for Task)

Corrected!

l.237: It may be more precise to say 0.5-5m in "operating at specific frequencies within the 3-30 MHz band and providing radial measurements which are representative of current velocities in the upper 0.5–2 m of the water column. See Rubio et al. 2017

OK! As indicated in Rubio et al. (2017), the maximum integration depth is 420 cm so we have rounded and simplified to: 0.5-4 m. A reference to Rubio et al. (2017) has been also added.

In 2.1 Fundamentals of HFR technology, it could have been mentioned how the common sea states of a semi-enclosed sea like Med may impact the performance of longer range HFR, with possible consequences to be taken into account in the plan for achieving a full coverage of the Mediterranean coastline.

Fully agree. As previously indicated, we have mentioned the limitations of using long-range in semi-enclosed seas like the Mediterranean Sea at the beginning of section 3 of the manuscript (instead of section 2.1):

"Long-range HFR systems are not deployed in the Mediterranean since they present some technical limitations in this semi-enclosed. On one hand, they provide surface circulation maps with coarser horizontal grid resolution (above 5 km), which are not convenient to adequately resolve some (sub)mesoscale ocean processes (i.e., eddies, instabilities, etc.) that commonly characterise the Mediterranean dynamics. On the other hand, they cannot accurately monitor the wave field under low sea states as the second-order spectrum is closer to the noise floor (and more likely to be contaminated with spurious contributions) than in the case of short and medium range HFR systems. Since the Mediterranean wave climate is not as intense as the Atlantic one, the use of long-range systems would result in limited precision and reduced temporal continuity in wave measurements (Lipa and Nyden, 2005). Finally, it is worth mentioning that a cross-border agreement was signed in 2018 (by in Spain, France and Italy) to establish the 13-16 MHz band as the one to be used for oceanographic radars in the Western Mediterranean Sea (Roarty et al., 2019)"

l.426. The abbreviation GoN is used before the full version that appears l.456.

Corrected in line 426 and also in Table 1.

Table 1. For consistency, I would recommend to use "Gulf of Naples" in Table 1.

Done.

l.448: Long et al 2011 (Central California) should not be included in references on European waters.

True! Deleted from the list of references.

l.459: using two "alternative data sources" rather than "different platforms"

Done!

l.465 errata: against

Corrected.

Figure 5a. Quality of graphs should be improved (size of labels, same limits for Axes Y, same type of lines, general image sharpness).

Improved.

l.569: Add a comma: In the Ligurian Sea experiment,

Added.

l.571: adda comma: During the experiment,

Added.

Section 2.4: the beginning of Section 2.4 appears too general for this section and may better fit in section 1.5. Only aspects dealing with data flow may be kept in the historical review of the roles of the different initiatives.

Fully agree. The first paragraph has been shortened and reformulated, following the reviewer's suggestion. The piece of text eliminated has not been integrated into 1.5 since it is a little bit redundant with other paragraphs along the manuscript.

L636-642: The text may be simplified here as it is a bit redundant with what is explained later in 2.5 and 2.6.

Fully agree. The following paragraph has been deleted from L636-L642 and integrated into sections 2.5 and 2.6 to avoid any redundancy:

"The European standard format for HFR data and metadata model has been defined and implemented, compliant with Climate and Forecast Metadata Convention version 1.6 (CF-1.6), OceanSITES convention, CMEMS-INSTAC and SDC requirements and INSPIRE directive. Furthermore, a battery of the QC tests to be mandatorily applied to HFR data has been defined 640 according to the EuroGOOS Data Management, Exchange and Quality Work Group (DATAMEQ) working recommendations on real-time QC and building on the Quality Assurance/Quality Control of Real-Time Oceanographic Data (QARTOD) manual produced by the US Integrated Ocean Observing System (IOOS)"

l.651 Figures by mid-2021 should be presented as a result, not as an objective. Or the date and corresponding objective should be updated.

Right. The sentence has been modified:

"Within the European framework, the EU HFR Node is currently managing data from 16 systems (http://150.145.136.27:8080/thredds/HF_RADAR/HFradar_CMEMS_INSTAC_catalog.html) . In particular, 5 of these 16 systems (31%) are deployed in the Mediterranean coastline and belong to the MONGOOS network: HFR-Gibraltar, HFR-Ibiza, HFR-DeltaEbro, HFR-TirLig and HFR-NAdr (Fig. 1)."

4. Multi-institutional collaborative projects with HFRs in the Mediterranean Sea: I would suggest to mention the ongoing JERICO-S3 and JERICO-DS projects, part of the JERICO-RI initiative. Their impact could be significant in terms of integration of HFR among key coastal observing technologies.

Done! We have added the following paragraph:

"In this context, it is worth mentioning the ongoing JERICO-S3 and JERICO Design Study (DS) projects (2020-2023), as part of the JERICO Research Infrastructure (RI) initiative. JERICO-RI, which is a long-term integrated framework providing high-quality marine data, expertise and multi-platform infrastructures for Europe's coastal seas, might have a significant impact in terms of integration of HFR among key coastal observing technologies."

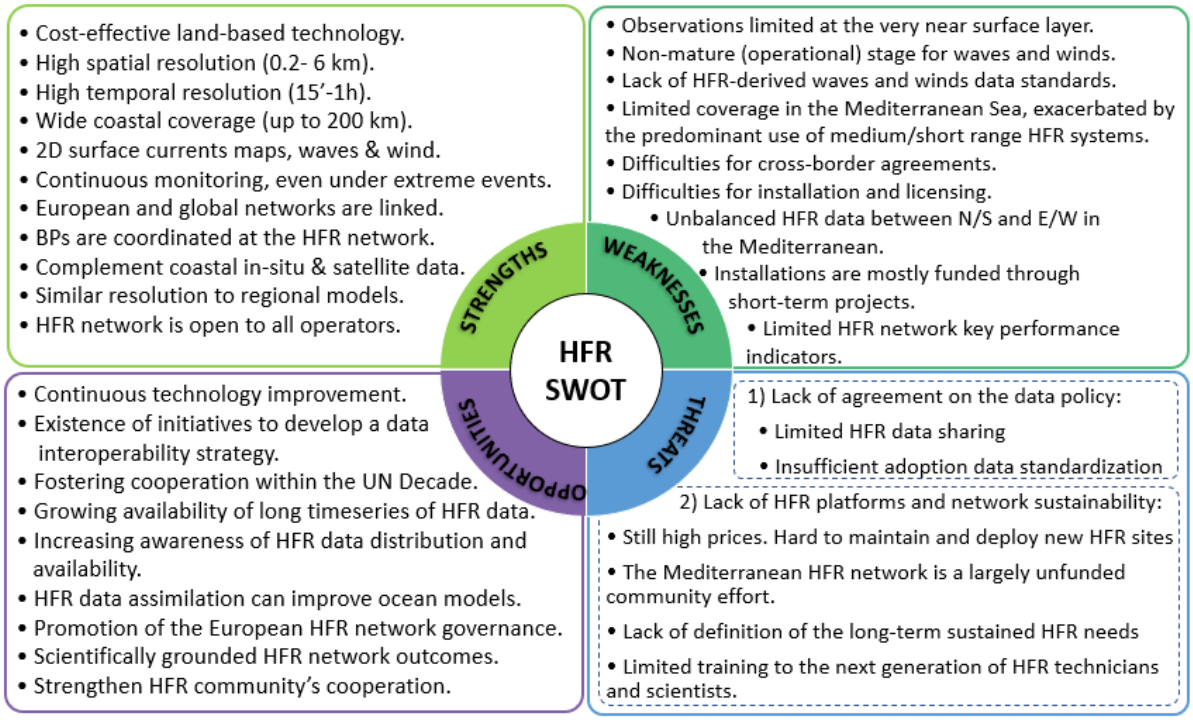
l.923: I would suggest expressing differently the reason for a clear north-south unbalance in the Mediterranean region. The MOONGOOS community knows better than me the regional variability. More than the Political systems themselves, the factors may lie in the differences between environmental policies, resources dedicated to marine monitoring and research programs, socioeconomical and political priorities, etc.

Fully agree. The sentence has been expanded to better clarify the reasons:

"Furthermore, the monitoring capabilities are variable, with a clear north-south unbalance in the Mediterranean region due to a variety of reasons. In addition to the existence of fragile and volatile political systems in southern shore countries that seriously handicap sustained research programs (Fig. 11), precarious socio-economic conditions also impact on the political priorities. Intermittent and uncoordinated initiatives might result in underdeveloped marine policies (at both national and regional level), significant resources dispersion and the inefficient management of the coastal environment. In this context, the implementation of lower-cost HFRs would greatly enhance developing countries' capability to monitor coastal waters and to establish new alliances and regional partnerships. The link between MONGOOS and GOOS Africa must be strengthened in order to define common roles and shared activities in the Mediterranean Sea."

Figure 10. the different Threats may be organized with "Insufficient adoption of HFR currents standardization" after other linked issues like "Lack of agreement on the data policy".

The section "Threads" of the SWOT diagram (Fig. 11) has been reorganised and grouped into 2 different categories to better clarify the risks associated with the Mediterranean HFR network.



In 5. Future challenges and prospects:

As part of the roadmap to transform individual radars into an integrated network, a phased approach is proposed. The different steps aim to optimize and consolidate the network of existing systems. However, the network is currently covering "a small portion of the entire coastal domain". As part of this roadmap, authors could add plans for:

- Defining a quantitative objective (number of systems, surface covered…) as a long-term target

Considering that only 2% of the world's coastline is currently monitored with HFRs (Moltmann et al., 2019) and the 46000 km of coastline length in the Mediterranean, is would be recommended to progressively increase the number of HFR sites, keeping the European rate of 6 new HFR sites installed per year (Rubio et al., 2017), particularly in critical data-sparse areas that prove challenging for other observation platforms, with a clear focus on outcomes and societal benefit.

In particular, we have added the following paragraph in section 5.1.:

"As a quantitative long-term objective, it would be recommended to maintain the rate reported in Rubio et al. (2017) of 6 new HFR sites installed per year in Europe. That might imply the installation of 2-3 new HFR sites per year in geostrategic coastal regions of the Mediterranean Sea such as marine protected areas, straits or port-approach areas."

Reference

Moltmann, T., Turton, J., Zhang, H.-M., Nolan, G., Gouldman, C., Griesbauer, L., Willis, Z., Piniella, Á. M., Barrell, S., Andersson, E., Gallage, C., Charpentier, E., Belbeoch, M., Poli, P., Rea, A., Burger, E. F., Legler, D. M., Lumpkin, R., Meinig, C., … Zhang, Y. (2019). A Global Ocean Observing System (GOOS), Delivered Through Enhanced Collaboration Across Regions, Communities, and New Technologies . In Frontiers in Marine Science (Vol. 6). https://www.frontiersin.org/article/10.3389/fmars.2019.00291

- Agreeing a joint methodology to define priority areas at regional level in the development of the network (for example as introduced in JERICO-NEXT Deliverable D3.4)

Following the methodological guidelines to define the joint strategy to design an integrated HFR network at regional scale developed in the context of Jerico Next project (Griffa et al., 2019), a combination of societal needs and HFR technology limitations should be considered within this purpose. Regarding the former and taking into account the importance of the HFR data and applications for Maritime Safety, the joint analysis of the marine traffic density maps (by using AIS data), historical SAR incidents (reported by all the coastal countries), location of bunkering operation areas and the location of migratory routes in the Mediterranean Sea can help to design the geographical distribution of the future installations.

Moreover, the study of the environmental sensitivity of the coastline, categorised based on the geomorphological classification of the coast, the biological resources (coastal protected areas, fish recruitment, areas of dispersion and retention of larvae, etc) and the human use (i.e. infrastructures, services, cultural and historic resources), as defined by NOAA (2002), is also recommended for the mapping of monitoring needs.

The improvement of models through HFRr data assimilation in potential locations can also be assessed based on OSE/OSSEs methods, thus contributing to better design the network expansion.

In addition, the wave climate must be considered for selecting the HFRs central operating frequency (i.e. limiting the use of long-range in the Mediterranean), the shape of the coastline will impact the GDOP error and should be contemplated, and the site locations must comply with the separation distances as advised by the ITU (Mantovani et al., 2020) and with the recommendations to mitigate wind turbine interference impacts on HFR (Kirincich et al., 2019)

References:

1) Petersen, J., et al. 2019. Environmental Sensitivity Index Guidelines, Version 4.0. NOAA Technical Memorandum NOS OR&R 52.
2) Griffa, A.; Horstmann, J. and Mader, J. et al (2019) Report on final assessment of methodological improvements and testing. JERICO-NEXT WP3 Innovations in Technology and Methodology, Deliverable D3.4, Version 2. Brest, France, IFREMER, 56pp. (JERICO-NEXT-WP3-D3.4-180719-V2). DOI:http://dx.doi.org/10.25607/OBP-948

Finally, the following paragraph has been added to section 5.1:

"To better define priority installation areas at regional level, methodological guidelines were developed in the context of JERICO-NEXT project (Griffa et al., 2019), where a combination of societal needs (maritime traffic density, historical SAR incidents, location of bunkering areas, biological resources, etc.) and HFR technology limitations were jointly considered. Similarly, the Mediterranean HFR network should be further implemented following these shared guidelines."

- Performing coordinated actions towards stakeholders (for example towards National GOOS Focal points who are serving in EOOS Operation Committee)

The following paragraph has been added to section 5.1.:

"Potential stakeholders should be clearly identified and promptly informed to boost their engagement. Coordinated actions to involve the national focal points (which are the appropriate contact points in each member state for affairs regarding the implementation of the GOOS at national and global levels) should be also performed within the European Ocean Observing System (EOOS) framework".

Additionally, all the general, technical and Research aspects are relevant for the Med and beyond at European and Global level. But it would be interesting to mention a bit more explicitly how will be tackled some regional specificities exposed in the SWOT analysis.

Done!

Regarding the "north-south unbalance" in the monitoring capabilities (Figure 11):

"Furthermore, the monitoring capabilities are variable, with a clear north-south unbalance in the Mediterranean region due to a variety of reasons. In addition to the existence of fragile and volatile political systems in southern shore countries that severely handicap sustained research programs (Fig. 11), precarious socio-economic conditions also impact on the political priorities. Intermittent and uncoordinated initiatives might result in underdeveloped

marine policies (at both national and regional level), significant resources dispersion and the inefficient management of the coastal environment. In this context, the implementation of lower-cost HFRs would greatly enhance developing countries' capability to monitor coastal waters and to establish new alliances and regional partnerships. The link between MONGOOS and GOOS Africa must be strengthened in order to define common roles and shared activities in the Mediterranean Sea".

Regarding the "limited training of technicians" (Figure 11):

"training of new technicians to operate the network, which would include the dissemination of the latest available methodologies to ensure that the most up-to-date best practices are followed [..] holding open-house conferences and workshops, not only focused on HFR operator community and permitting agencies but also on a more general non-instructed audience, might be an effective way of promoting public awareness and ensuring the network's survival.

Regarding the "difficulties for cross-border-agreements:"

"In spite of the fruitful collaborations between the HFR national networks, the coordination and long-term integration at regional scale are sometimes handicapped by poor data policy and restricted data access (Fig. 11). There is still a recognized necessity for the unification of standards, the centralization of methodologies and best practices documentation to increase not only the interoperability of the coastal HFRs network design, operation and maintenance tasks but also the efficient data discovery (Mantovani et al., 2020). In this context, new cross-border agreements should be reached to consolidate the observing infrastructure, following the example of that one signed in 2018 by Spain, France and Italy in the Western Mediterranean Sea (Roarty et al., 2019). For instance, the surface circulation monitoring in the Strait of Gibraltar could be significantly enhanced thanks to a cross-border agreement between Spain and Morocco to integrate their respective HFR sites into one single network".