An adaptive unstructured grid for HF radar current mapping based on constrained k-means clustering

https://doi.org/10.5194/egusphere-2026-3013

General Assessment

The proposed methodology derives grid nodes directly from the spatial distribution of HF radar radial observations, using k-means, enabling the spatial resolution to adapt to the local density of available radial measurements while maintaining a coherent representation of the entire domain. This data-driven approach naturally increases resolution in well-sampled coastal regions, close to the antennas, and employs a coarser discretization in offshore areas where radial information content is lower. Spatial support is initially defined through Voronoi tessellation, assigning an area of influence to each grid node independently of node placement. Subsequently, Voronoi polygons are replaced by equivalent circular areas, to be supported by radial information, providing a simplified and flexible geometric representation while preserving the underlying spatial coverage associated with each node. Traditional RMS validation analysis demonstrates the well-functioning of the methodology, both near and farther from the antennas.

From the perspective of end users of HF radar products, the proposed framework is particularly attractive because it addresses a long-standing limitation of conventional total current maps: the difficulty of exploiting the full spatial information content available in densely sampled regions. The adaptive redistribution of grid nodes offers the possibility of resolving smaller-scale coastal structures while maintaining sufficient observational support offshore, which has been a persistent objective in the HF radar community. In this sense, the manuscript tackles a relevant and practically important problem for both operational and scientific HF radar applications.

More generally, one of the historical challenges of HF radar current mapping is that the nominal spatial resolution of the radar measurements is often not reflected in the final total vector products. The use of regular grids tends to aggregate a large number of observations in nearshore regions, precisely where the highest observation density occurs. The proposed adaptive discretization framework has the potential to provide a more faithful representation of the information content of the radar observations, to better resolve coastal circulation features, fronts, convergence zones, recirculation patterns, and other spatial structures of interest, among others.

I consider this to be one of the main strengths and novelty of this study. The manuscript is generally well written, the methodology is clearly structured, and the proposed approach is operationally relevant. However, several methodological aspects require further clarification, and some additional analyses would strengthen the demonstration of the actual benefits of the adaptive framework and facilitate its application to other HF radar systems.

Major Comments

1. Justification of the adaptive grid design and selection of the number of centroids

The manuscript introduces an adaptive grid based on balanced K-means clustering and presents results using configurations with 1300 and 2300 centroids (figure 4, lines 315-322). However, the rationale behind the selection of these values is not sufficiently explained. The authors should explain clearly in the text:

- Why the 1300-centroid configuration was determined.
- Whether any optimization or sensitivity analysis was performed.
- The relationship between the number of centroids, the number of radials per cell, GDOP distribution, spatial coverage, and reconstruction skill.
- The practical criteria that would allow another HF radar operator to select an appropriate number of centroids for a different network configuration.

An additional schematic figure illustrating the balanced K-means procedure and the generation of the adaptive grid would significantly improve readability and reproducibility. This could be added in appendix A section.

---

2. Limited quantitative evidence of performance improvement

The manuscript convincingly demonstrates that the adaptive grid provides a different spatial representation and resolution of the radar observations. However, the validation results show only limited differences in RMSE and correlation when compared with drifter observations.

The authors should better justify why the proposed method represents a significant advancement despite the relatively small improvements in traditional validation metrics.

---

3. Spatial representation of validation results

Figure 7 presents the dependence of RMSE on GDOP classes. While useful, it does not show where these differences occur spatially.

I recommend adding a spatial map of reconstruction errors (or differences between adaptive and regular grids) to identify:

- Regions where the adaptive grid performs better.
- Coastal versus offshore behaviour.
- The relationship between error patterns and radar geometry.
- Areas where the adaptive approach provides the largest benefit.

A spatially explicit analysis would considerably strengthen the interpretation of the results.

---

4. Spatial representativeness analysis

The discussion associated with Figure 10 is one of the strongest parts of the manuscript because it directly addresses representativeness errors in radar–drifter comparisons.

To reinforce this result, I suggest adding a spatial map showing the distribution of radar–drifter separation distances (or the reduction achieved by the adaptive grid relative to the regular grid). Such a figure would help the reader understand where the representativeness gains occurs and how they relate to HF radar coverage geometry.

This analysis would also provide additional support for the authors' argument that the adaptive grid improves the spatial consistency of radar-derived current products.

The findings shown in Figure 10 alsobdeserve a stronger discussion. The reduced radar–drifter separation is potentially important for several downstream applications, including, Lagrangian transport analyses, search and rescue modelling, oil-spill forecasting, data assimilation and validation of coastal circulation models. The practical implications of this improvement should be emphasized more clearly.

Minor Comments

Figures

- Several figures appear to have insufficient resolution and are difficult to interpret when zooming into details. Higher-resolution versions are recommended throughout the manuscript.
- Figure 8: panel labels overlap with graphical elements and should be repositioned for clarity.

Data availability and European HF Radar Node

- Lines 95–96: please include an appropriate reference to the European HF Radar Node (https://www.hfrnode.eu/)
- Line 98: it would be useful to indicate that datasets can be accessed through both THREDDS and ERDDAP services and that different output file formats are available through these services.

Vector reconstruction requirements

- Line 214: the manuscript states that nodes supported by radials from at least two distinct radar sites were retained. Please clarify whether there is also a minimum number of radial measurements per site or a minimum total number of radial vectors required for the weighted least-squares solution. Operational HF radar total current generation commonly includes such thresholds, and this information is important for reproducibility.

Overall Assessment

This manuscript presents a technically sound, innovative, and operationally relevant adaptive gridding methodology for HF radar current mapping. The proposed radar-aware framework addresses a long-standing limitation of conventional regular-grid products and has the potential to improve the representation of small-scale coastal circulation features while making more efficient use of the available observational information.

The concept is interesting, clearly relevant to the HF radar community, and particularly valuable from the perspective of end users who have long sought methods capable of exploiting the full spatial information content of HF radar observations.

Overall, I consider this manuscript to have clear scientific value and potential for publication, however, the manuscript would be significantly strengthened by addressing the comments and suggestions outlined above. I therefore recommend publication after minor revisions.