

We would like to thank the Reviewer for the careful reading of the manuscript and for the valuable comments and suggestions. We found them very constructive, and we will certainly do our best effort to address all of them, as detailed below.

Comment 1: Choice of AR detection algorithm and novelty

In the introduction, the authors acknowledge the wide range of AR detection algorithms currently available at both regional and global scales, based on a variety of methodological approaches. They state that existing state-of-the-art algorithms, including tARget by Guan & Waliser, may not be well suited to identifying Mediterranean ARs, which motivates their decision to develop a regional AR catalog based on modifications to tARget. The manuscript builds on tARget v1, originally developed in 2015. However, tARget has since undergone several substantial developments and is currently available in version 4, released in May 2024 (Guan & Waliser, 2024). My main concern is that several of the modifications introduced by the authors to tARget v1 appear to already be implemented in tARget v4. It is therefore unclear why the first version of the algorithm was chosen instead of the most updated one. This issue is illustrated by the case studies of storms Vaia and Alex. The authors motivate their methodological choices by stating that tARget fails to detect the AR associated with storm Alex (Figure 2 of the manuscript). However, tARget v4 detects the ARs associated with both Alex and Vaia. To support this statement, I provide Figure 1 of this review, which shows the ARs detected by tARget v4 during these two events (panels a and c). Given the rapid evolution of AR detection methodologies, I encourage the authors to more clearly position their approach relative to recent developments in the field. In particular, it would be important to clarify which methodological gaps remain unaddressed by current state-of-the-art algorithms and how the proposed modifications advance beyond existing implementations.

At the time we started our research about AR in the Mediterranean, target v1 was still the current version of the algorithm that the authors kindly shared with us. The following releases V2 and V3 few years ago included improvements in terms of capability of the algorithm to track ARs from genesis to termination, but without solving the issues we found in the Med. Therefore, we decided to proceed with the algorithm and, after the “tuning” described in the paper, we applied it to obtain our dataset of ARs.

Our primary goal was to apply a well-tested and robust algorithm to our specific area to develop a Mediterranean AR climatology, not specifically to address gaps in AR detection. On the other hand, the updated V4 algorithm was released in late 2024 when our dataset was nearly complete. Upon carefully reading Guan & Waliser (2024), we realized that some of the developments were aimed to address the issues we encountered (e.g. zonal or southward ARs). Implementing the new algorithm would have required considerable effort due to both technical factors—such as the different interface with input data already downloaded—and practical considerations, including the need to repeat the detection process for the whole 64 year period. Therefore, we concluded that it was not reasonable to proceed with the new algorithm. However, we mentioned in the paper the release of the V4 algorithm and of its improvement, since it represents a confirmation of the way we adapted the old algorithm to our specific use. However, it is not our intention to dig further into possible detection gaps or to develop a new algorithm. We will try to make this point clearer.

Comment 2: AR tracking methodology and event selection

Beyond AR detection, it appears that the authors have implemented an AR tracking algorithm to connect individual AR contours into trajectories. However, the description of this tracking methodology is not sufficiently detailed to allow proper evaluation or reproducibility. From the manuscript, I infer that an overlap-based approach was used, but it is unclear how mergers and separations are handled. These choices directly affect key AR properties such as lifetime, spatial extent, and persistence. Related to this point, the authors based their analysis on ARs that simultaneously intersect the Atlantic Ocean and Italy, based on the overlap between the AR footprint and a circular sector (Figure 3 of the manuscript). It is unclear how sensitive the results are to the location and geometry of this circular sector. Moreover, this criterion may exclude ARs that originate over the Atlantic and reach the study region without fulfilling this condition at a given time. Several modern AR detection and tracking algorithms, including tARget v4, explicitly track ARs from origin to termination. Exploiting these advancements could reduce the need for additional parametrization and provide a more physically grounded selection of ARs based on the evolution of their trajectories rather than on instantaneous spatial intersections.

The aim of this study is to detect and investigate ARs that affect northern-central Italy. Most of the intense precipitation events in this area are associated with low-level jets over the Mediterranean Sea, transporting moisture toward the orography. Thus, the first issue was to distinguish between this intense but local transport within the Mediterranean basin and the vapour really coming from remote sources, since our definition of AR requires moisture transport from outside the Mediterranean (we will try to make this clearer). Therefore, we decided to define our AR objects as those whose shape covers the target area (where precipitation occurs) and are characterized by vapour transport from outside the Mediterranean, requiring that this transport last at least 12 hours. This is an arbitrary choice, and we are aware it is conservative, in the sense that we may lose AR objects that initiate in the Mediterranean, overlap with the target area and extend further east or north-east (but in these cases, there's no transport from outside the Med). The distance of the circular sector imposes a length of the AR of at least 2000 km. We checked slightly different positions of the sector and also, we checked all the selected ARs of the database, and we did find that it was very useful and effective to discard objects related to "local" transport of WV.

Basically, we followed the approach of Lorente-Plazas et al (JGR, 2019) or Lavers and Villarini (GRL, 2013): the identification of the ARs started from a specific location (a specific coastal area or a latitude), and looked backward for gridpoints with IVT over a threshold, until a geometrical requirement was fulfilled. In our case, the geometrical requirement concerns the length, and it is satisfied as soon as the shape overlaps with the circular remote area.

Mergers and separators are not an issue, since each object is assigned a number and we require that the overlapping is due to a specific object. Moreover, ARs from the (north) Atlantic that does not fulfil the requirements are directed or to the northern slopes of the Alps (as in Rossler et al., HESS, 2014) or to the southern Mediterranean, thus in both cases do not affect the target area.

We believe it will be absolutely worth to apply a recently developed tracking methodology as soon as we extend our study to a larger area (such as all the western Mediterranean). But as long as we deal with a specific and relatively small target area, as northern-central Italy, this methodology works correctly.

Comment 3: Uncertainty associated with AR detection and tracking

The authors thoughtfully acknowledge that AR detection and tracking represent one of the main sources of uncertainty in AR science, as underscored by the ARTMIP project and related studies. Despite this, the results presented in the manuscript rely on a single algorithm. Consequently, the manuscript does not provide an assessment of the uncertainty associated with methodological choices in AR detection and tracking. Given that the key conclusions rely on the identified AR climatology and its linkage to extreme precipitation, an evaluation of methodological uncertainty is essential to support the robustness of the findings. Reproducing the main results with at least one additional AR detection algorithm would allow the authors to assess the sensitivity of their conclusions to the detection methodology. If the AR signal over northern–central Italy is physically robust, its main climatological features and impacts should be relatively insensitive to the specific detection algorithm employed.

Several ARTMIP studies have shown that results can vary depending on both the tracking algorithm and reanalysis dataset. Authors presenting findings consistently highlight this issue to make readers aware of the primary source of uncertainty. Thus, we did the same. The usual approach that can be found in many other papers, as the present one, is to select a methodology (i.e., algorithm and dataset) and build a dataset of ARs or analyse case studies without the need of provide an intercomparison with other algorithms or datasets. Although this would make the conclusions more robust, it would require to duplicate the efforts, and it has never been done at least in all the studies we took as “reference” (just to mention some of them in different parts of the globe: Lavers et al. GRL 2011; Lavers & Villarini GRL 2013 and J Hydrol 2015; Lorente-Plazas et al. JGR 2019; Dettinger et al J. Hydrom. 2018; Doiteau et al. Atmos. 2021; Eiras-Barca et al. JGR 2016; Francis et al. GRL 2024; Ramos et al. J. Hydrom. 2015; Rutz et al. MWR 2014; Porhemmat et al. J. Hydrom. 2021).

Therefore, we cannot satisfy this request for the present paper. Since in our plan we aim at studying ARs over a larger area of the Mediterranean, adopting a different and more up-to-date algorithm, a comparison will be done in future for sure. We will mention this in the conclusions.

Comment 4: AR landfall and recent methodological advances

In the introduction (lines 62–64), the authors emphasize the complexity of Mediterranean morphology and orography as a key challenge for AR detection and for defining AR landfall. Later (lines 217–219), they note that their algorithm cannot provide an exact landfall location over the Italian peninsula because it assumes a single sea–land transition along the AR path. This is indeed a fundamental challenge in the Mediterranean context. It has also motivated the development of alternative AR detection approaches. For instance, the PIKART algorithm (published in August 2025) adopts a fundamentally different detection strategy than tARget and is able to identify AR landfall locations even in complex regions such as the Mediterranean. I verified that PIKART successfully detects the ARs associated with storms Vaia and Alex, including their landfall locations, as shown in Figure 1b,d of this review. The PIKART catalog and code are publicly available. I fully acknowledge that the results presented in this manuscript were produced prior to the publication of PIKART, and I do not demand reprocessing the analysis using this algorithm. However, I recommend updating the introduction to reflect recent developments in AR detection for complex regions and considering

whether aspects of the PIKART approach could inform future refinements of the proposed regional catalog, particularly regarding landfall identification.

We are absolutely grateful for this suggestion, and we will likely adopt PIKART for our future analysis. As the Reviewer said, this paper was released under discussion last summer and unfortunately has been undergoing a pretty long revision phase, while PIKART results were published right after the submission of the paper. We will mention this important point in our discussion. We must say that taking the max IVT close to the coastline (as we did) was a bit tricky but revealed interesting connection between ARs intensity and impacts.

Comment 5: Use of the AR strength scale

The manuscript applies the AR strength scale proposed by Ralph et al. (2019) to characterize the intensity and persistence of ARs. Based on the description in lines 219–221 and 239–241, it appears that the scale is applied to individual AR objects identified by the detection algorithm, assigning a rank to each AR. This approach raises concerns regarding the interpretation of the AR strength scale. The scale is designed to rank AR conditions at fixed locations using a Eulerian framework, rather than to classify ARs themselves from a Lagrangian perspective. In other words, it evaluates atmospheric conditions experienced at a given location during AR passage, not the intrinsic strength of a detected AR object. This nuance is critical and has been discussed in previous studies (e.g. Guan et al., 2023; see also <https://cw3e.ucsd.edu/arscale/>). To align with the intended use of the AR strength scale, the authors should revise their methodology, for example by evaluating AR conditions at each grid cell within the study region or at selected reference locations, as currently implemented in operational forecasting systems such as the one by the CW3E along transects of the west coast of the United States.

We thank the Reviewer for spotting this inconsistency. We will revise the results presenting only the AR classification based on IVT max close to the coast, since we have found it is well correlated with impacts. Although also the AR duration is an important parameter (and we have stored in the dataset also this information), the IVT max is a good proxy for the total transport of moisture of an AR.

Recommendations

1) Focus on AR climatology and impacts over northern-central Italy: Rather than developing a new AR detection algorithm, I suggest that the authors consider using two or more of the freely available, state-of-the-art AR catalogs as the basis for their study. This would allow the manuscript to focus on the climatology, impacts, and associated uncertainties of ARs affecting northern–central Italy, while avoiding the additional complexity of developing a new detection method.

As we said before, our aim was not to develop a new algorithm, neither to dig into gaps of these procedures. We started from a well-known algorithm, and we tried to fix some issues that emerged during its application to our specific area. Since our modifications have been substantially confirmed by the last release of the algorithm (that, by the way, includes many other applications and

developments that we do not need here), we feel comfortable to exploit our detection results to focus on AR climatology on our target area. The latter is our primary aim.

Use of the most updated version of tARget: If the authors consider that a new regional catalog is still needed for this study, I recommend using tARget v4 as the baseline, rather than version 1. Modifications should focus on aspects not already implemented in version 4, for example, adjusting the lower limit of IVT magnitude to $250 \text{ kg m}^{-1} \text{ s}^{-1}$. This would require updating the corresponding results and, in particular, Figure 2 of the manuscript.

As said above, we believe it is not reasonable to proceed with the new algorithm, since it would mean to restart everything from the very beginning. We are confident that our AR selection reflects our aim to capture organized moisture transport from remote sources. Fig. 2, as well as most of Section 3, devoted to the description of the algorithm, could be shortened, but we believe it is important, not for proposing development for the algorithm, but to clearly document our detection procedure.

Documentation of differences: The manuscript should provide a thorough comparison between the original tARget algorithm and the new regional catalog. Beyond showing AR contours for two case studies, the authors should quantify differences in key aspects that affect uncertainty, such as the number of events, frequency, intensity, and persistence of AR conditions over the study region (see, for example, Figure 7 of Vallejo-Bernal & Braun et al., 2025).

We cannot satisfy this request, since it would mean to throw away all the work done so far and redo everything from the beginning. Our aim is not to propose a new algorithm (as in Vallejo-Bernal et al 2025) that would require such a validation. We have just adapted an existing algorithm and although we are aware it is outdated, we are confident that it is robust enough and we trust the results since we carefully checked all the detected AR of the catalogue. An intercomparison as required would be beyond the scope of the present study.

Assessment of methodological uncertainty: To evaluate the robustness of the results, I suggest applying at least one additional AR detection algorithm to reproduce the main findings. If the AR signal in northern–central Italy is physically robust, the main climatology and associated impacts should remain consistent across detection methods.

As said before, this request, which is almost the same as the last two above, is not realistically feasible: it would take months. Moreover, all the papers presenting studies adopting a similar approach were based on a single detection algorithm only. No one was required to confirm the results by applying an alternative algorithm. We believe our study provides the first AR climatology for Italy. This is relevant and worth of publication and it may be further refined and updated in future research.

AR strength scale methodology: The authors should clarify how they apply the AR strength scale of Ralph et al. (2019). If the current approach assigns ranks to individual AR objects, it should be

revised, as the scale is intended to rank AR conditions at specific locations (Eulerian approach), rather than ARs themselves (Lagrangian approach).

For sure this will be fixed since it was clearly our mistake and misinterpretation.

Minor comments

We will revise the figures as suggested.

Line-by-line comments

We will carefully follow the indications provided, many thanks.