Response to Reviewer 1

We sincerely thank Reviewer 1 for her/his constructive and valuable comments. These insightful suggestions have undoubtedly helped enhance the overall quality of this manuscript and the rigor of the study. After we carefully studied the comments one by one, we have revised the manuscript and addressed each comment point by point below. For clarity, the original comments from the reviewer are presented in blue, followed by our responses in black.

Majors:

1. Definition issue. In the abstract, the manuscript states that, "Atmospheric rivers (ARs) are long, narrow corridors in the atmosphere that transport immense amounts of water vapor poleward across the mid-latitudes." Several keywords are embedded in the definition: (1) elongated geometry (long, narrow), (2) poleward transport, and (3) occurrence in the mid-latitudes. The elongated geometry is enforced by the first two criteria (Lines 184–185), while the curvature criteria (Lines 185–187) are related to the poleward requirement. However, it is unclear how the "mid-latitude" aspect is enforced in the algorithm. The manuscript discussed filtering certain tropical AR candidates (Lines 222–224: grids located in tropics must not exceed 95%), but I did not see an equivalent consideration for high latitudes. Please clarify whether the algorithm intends to apply the mid-latitude criterion. If so, please justify the 95% threshold for the tropics, which seems relatively permissive, and explain how the algorithm distinguishes or filters features at high latitudes.

Reply： We sincerely appreciate the reviewer's thoughtful comment on the AR definition. We agree that the wording in the Abstract is inaccurate. It is true that ARs mainly occur in the mid-latitudes. In our algorithm, the "mid-latitude occurrence" is not a mandatory diagnostic criterion. Namely, the algorithm is designed for global AR identification rather than for ARs within a prescribed latitude band. After global AR candidates are extracted in Step 1, the quantification of their main characteristics in Step 2 and the subsequent diagnosis in Step 3 are designed around two fundamental aspects: elongated morphology (Step2: **Lines 187–196**; Step3: **Lines 204–220** in the revised manuscript) and poleward moisture transport (Step2: **Lines 197–202**; Step3: **Lines 243–265** in the revised manuscript). No additional diagnostic criterion is introduced to confine AR candidates only to the mid-latitudes. For clarity, the curvature-related criteria are put in the section introducing the morphological diagnostics, whereas the tropical-specific criterion is in the section introducing the poleward moisture transport diagnostics.

To avoid this ambiguity, we have revised the sentence in the Abstract as follows: "Atmospheric rivers (ARs) are long, narrow corridors of enhanced water vapor transport that play an important role in transporting moisture from lower latitudes toward the extratropical and polar regions." (**Lines 11–12**)

We also reorganized the presentation of the metric definitions in Step 2 (**Lines 180–202**) to clarify that the main characteristics of AR candidates are considered in terms of these two aspects. This structural revision also improves the correspondence between the metric definitions in Step 2 and the respective diagnostic criteria in Step 3.

As a global AR identification algorithm, our method is intended to account for the distinct characteristics of moisture transport in different latitude bands and enable identification of ARs outside the conventional mid-latitude belt, such as subtropical East Asian summer ARs and Antarctic ARs. The moisture transport systems that satisfy the essential AR characteristics can be identified in different latitudes under different climatological backgrounds.

In the tropics (20°S–20°N) where the water vapor is rich, AR candidates may include numerous tropical moisture filaments associated with trade wind transport (e.g., Fig. 3d in the revised manuscript). These candidates often exhibit elongated shapes but are dominated by zonal rather than poleward water vapor transport. To reduce such false identifications, an additional diagnostic criterion is applied to candidates with a large tropical fraction in the poleward moisture transport diagnosis (**Lines 248–250** in the revised manuscript). First, candidates with more than 95% of the grids in the tropics are directly excluded. We agree with the reviewer that this threshold, if considered alone, may appear permissive. This requirement is aimed to exclude candidates almost entirely confined in the tropics, but to keep candidates originating from the tropics extending into the extratropics. Those candidates are genuine AR events. Further, for candidates with more than 50% of their grids located in the tropics, the algorithm also requires that more than 50% of the total grids have a vertically integrated water vapor transport (IVT) direction angle greater than 15° with the latitude circle. This requirement considers the dominance of zonal moisture transport in tropical moisture filaments and helps retain candidates with a sufficient poleward transport component. Therefore, the tropical diagnostic criterion is more than what the 95% threshold alone may suggest, because it also imposes an explicit condition for the poleward moisture transport in tropical candidates.

To evaluate the effect of this tropical diagnostic criterion, we compared the number of ARs identified in low-latitude regions during 1980–2016 with and without this criterion (Table R1). After applying the tropical diagnostic criterion, the number of ARs identified in these regions decreased by 36.3% in the Northern Hemisphere and by 29.2% in the Southern Hemisphere. This result indicates that the criterion effectively reduces potential false identifications associated with tropical moisture filaments, while still retaining candidates with a sufficiently strong poleward transport component.

Table R1. Number of ARs identified in low-latitude regions during 1980–2016 with and without the tropical diagnostic criterion. Low-latitude regions are defined as 0°–30°N/S.

Region	Without tropical criterion	With tropical criterion	Reduction
30°N–0°	83580	53209	36.34%
0°–30°S	76630	54258	29.19%
Low latitudes	160210	107467	32.92%

The additional exclusion criterion used in tropics is not applied for high latitudes. High-latitude AR identification is accommodated primarily through the reasonable setup of IVT threshold. The atmospheric moisture content and the IVT magnitude are generally lower at high latitudes, so a fixed global IVT threshold would lead to large biases of AR identifications. To address this issue, the algorithm introduces an adaptive hemispheric lower limit for the IVT threshold, which considers seasonal variations of the moisture transport in the two hemispheres. The IVT thresholds in our algorithm are generally consistent with studies focusing specifically on high-latitude and polar ARs (**Lines 131–133** in the revised manuscript). That is, high-latitude AR candidates are not excluded simply due to their relatively low absolute IVT values. However, the elongated morphology and poleward moisture transport are still necessary conditions as in other latitude bands.

To well address the reviewer's concerns, we have revised the final paragraph of the Introduction (**Lines 73–76**) to more clearly summarize the considerations and improvements in AR identification.

2. Poleward transport requirement. Using the provided dataset, I plotted ARs for the monsoon case in a domain larger than that used in the manuscript. Attached are results at 06Z and 12Z 27 Jun 2018 (blue shading for ARs). Several features appear to deviate from the definition of an AR:

- At 06Z, a detected feature near 90°N appears almost entirely zonal. Please clarify how this feature close to the North Pole adheres to the poleward transport requirement.
- At 12Z, an AR segment extending over Russia, Mongolia, and northern China shows IVT vectors pointing toward the tropics (Fig. 7c). Please justify its inclusion as an AR when the moisture transport is directed equatorward.
- At 12Z, the connection between the Northern European and Russian segments appears to rely on only one or two grid points. Are such tenuous connections physically meaningful?

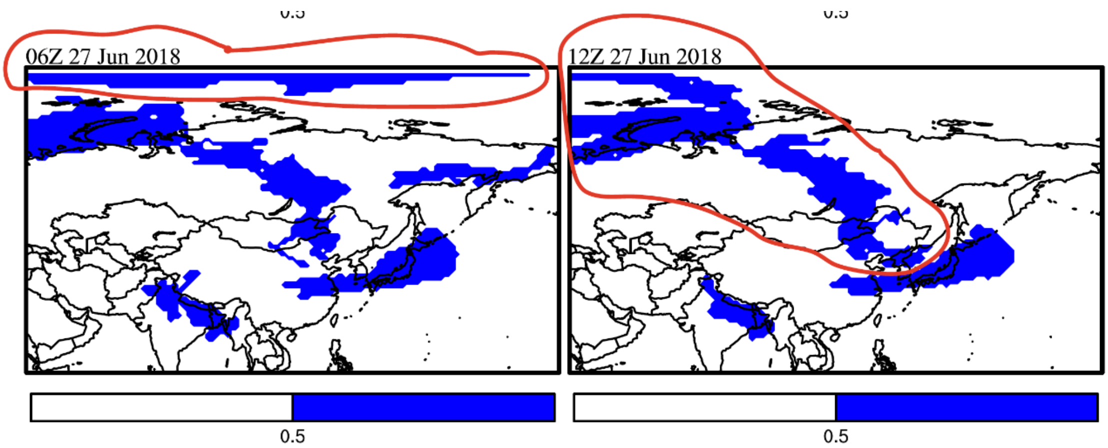

Figure R1. Figure included in the reviewer's comment.

Reply: We are sincerely grateful to the reviewer for examining the provided dataset in details. The reviewer's comments focused on this case and found AR identification uncertainties. She/He further clarified the rationale behind the quantitative metrics in Step 2 and the diagnostic criteria in Step 3 of the algorithm, as well as the appropriate interpretation and use of the resulting dataset.

To better address these issues, we also replotted this AR case at 06Z and 12Z on 27 June 2018 using our dataset (Fig. R2). We used a North Polar stereographic projection to show the complete structure of the identified AR. For clarity, the continuous AR over the Arctic and neighboring areas is divided into three parts: Part 1 denotes the high-latitude portion over the Arctic, Part 2 denotes the main body with typical AR characteristics (the major axis), and Part 3 denotes the elongated moisture transport band located to the east of Part 2 and extending toward lower latitudes.

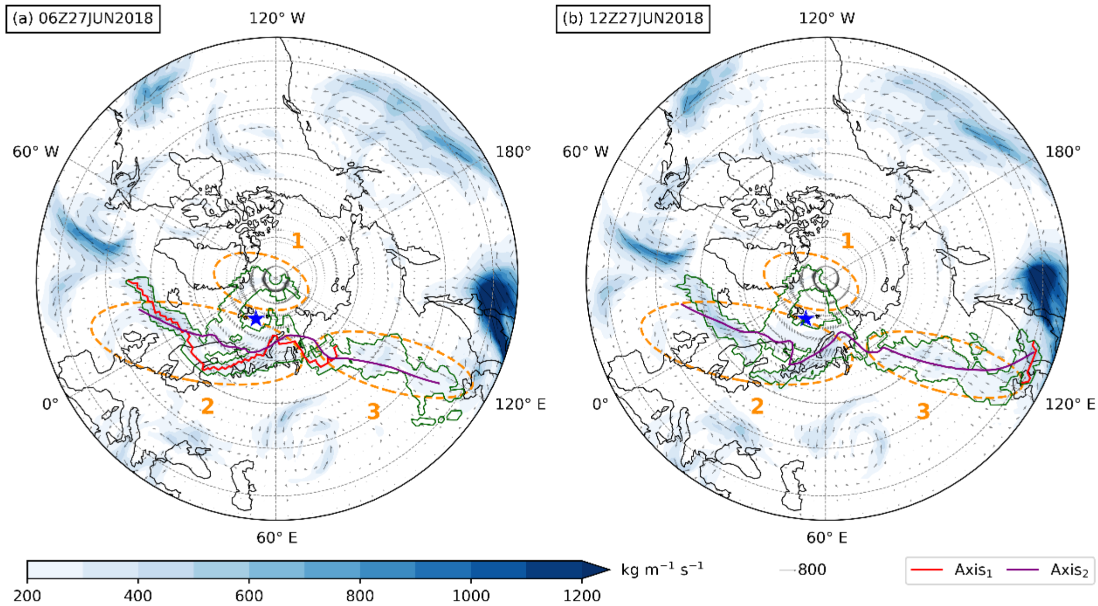

Figure R2. Snapshots of the identified AR object at 06Z (a) and 12Z (b) on 27 June 2018. The green curve denotes the shape boundary of the AR object. The three regions discussed in the response are highlighted by thick orange dashed ellipses and labeled with numbers 1–3. The blue star marks the cyclonic weather system center. The red and purple solid lines represent $Axis_1$ and $Axis_2$, respectively. Shading denotes the IVT magnitude (units: kg m^{-1} s^{-1}), and vectors indicate the IVT direction.

- *Regarding the first question:*

The cylindrical equidistant (like Mercator) projections can lead to enlarged transformation of the area and lead to unrealistic sense of the true world. We showed the ARs using the polar stereographic projection with little transformation for polar areas. As shown in Fig. R2 above, Part 1 is only part of an independent AR object, very close to the pole. Part 1 exhibits a clear meridionally elongated structure and a pronounced meridional component of moisture transport.

The moisture content and the moisture transport are relatively small in the polar region. In this case, the cyclonic weather system located to the east of Part 1 and northeast of Part 2 acts to drive a strong moisture transport associated with Part 1. The moisture transport from Part 1 converges with that from Part 2 along the southern flank of the cyclonic system, helping to maintain the strong moisture transport in the northeastern portion of Part 2. Therefore, retaining Part 1 as part of the complete AR object also helps explain the dynamical linkage between the identified AR object and the adjacent cyclonic weather system.

- *Regarding the second question:*

The AR segment with equatorward moisture transport as mentioned by our reviewer in Fig. R1 at 12Z corresponds to Part 3 in Fig. R2b. We agree with the reviewer that this segment itself does not exhibit the poleward moisture transport typically expected for the main body of an AR. However, in our algorithm, Part 3 is not the main body of the AR object. Rather, it is only an elongated extension segment of the enhanced moisture transport that remains geometrically connected to Part 2.

According to our algorithm, the poleward moisture transport is not required for all grids. This diagnostic step is aimed to provide a flexible structure for poleward moisture transport (**Lines 250–251** in the revised manuscript), rather than a uniform directional constraint on the entire candidate. Namely, an AR candidate contains organized poleward transport that still allows water vapor transport directions to vary along the major axis of the same candidate. Most of the major axis shows poleward moisture transport.

The reasons that allow the water vapor transport directions to vary along the major axis are as follows. First, a continuous region with strong IVT is affected by multiple weather systems simultaneously. As a result, moisture transport directions may vary substantially among different parts of the same IVT band. Second, pointwise poleward transport requirement would be too restrictive for complex mid- and high-latitude cases. If such a strict requirement were imposed on every local portion of an AR candidate, or if a fixed threshold were applied to the area-mean poleward IVT component of the entire object, some physically continuous moisture transport regions could be erroneously removed.

Our algorithm uses the total length of axis segments satisfying the poleward moisture flux condition as a quantitative metric to determine whether an AR candidate contains organized poleward moisture transport structures (**Lines 197–199** in the revised manuscript). This metric was also used in Guan and Waliser (2024).

By contrast, strong moisture transport bands in the tropics are primarily influenced by the trade winds and exhibit a more coherent zonal transport structure. To reduce the likelihood of misidentifying such tropical moisture filaments as ARs, we apply the tropical-specific criterion of the poleward moisture transport requirement as an additional and stringent criterion. The tropical criterion is a supplementary filtering step.

Understanding this, Part 2 is the main part of the continuous typical AR, whereas Part 3 is an adjacent elongated band of strong moisture transport. In this particular case, the AR object satisfies both the morphological and structural diagnostic criteria for poleward moisture transport. Part 3 remains connected to the main body of the IVT threshold, it is retained as part of the identified AR object in our algorithmic framework.

We would like to thank the reviewer once again for noticing this, as it prompted us to further evaluate whether this diagnostic algorithm could introduce potential false identifications of AR cases of which only a limited portion satisfy the required length of poleward moisture transport along the major axis. To assess the possible influence of this issue, we further counted ARs for which at least one of $Axis_1$ or $Axis_2$ is longer than 2000 km and for which more than half the total length of axis segments satisfies an equatorward moisture flux (Table R2). This metric is designed to flag objects that are dominated by equatorward moisture transport as a whole. The results show that, even if all such flagged objects are regarded as potential false identifications, their proportion remains low.

Table R2. Total number of identified ARs, number of potentially misidentified ARs, and their percentage in different latitude bands during 1980–2016. Potentially misidentified ARs are defined as AR objects for which at least one axis is longer than 2000 km and more than half the total length of the axis segments satisfies the equatorward-flux condition. The equatorward-flux condition is defined as the ratio of the equatorward component of IVT to the total IVT magnitude being greater than 0.25.

Regions	Total identified ARs	Potentially misidentified ARs	Percentage
90° N–60° N	61090	1181	1.93%
60° N–30° N	196067	2202	1.12%
30° N–0°	53209	260	0.49%
0°–30° S	54258	75	0.14%
30° S–60° S	239178	1039	0.43%
60° S–90° S	56569	255	0.45%
Global	660371	5012	0.76%

We also note that many existing AR identification algorithms primarily focus on morphological criteria and do not explicitly include a poleward transport constraint. By incorporating poleward moisture transport as a diagnostic component of the AR identification procedure, the present algorithm is kept consistent with the general AR definition. To clarify this, we have revised the relevant descriptions in Steps 2 and 3 of the revised manuscript (**Lines 199–202 and 257–261**). These revisions further clarify the structural role of the axis-based poleward moisture transport metric and the rationale for applying a flexible directional diagnosis to candidates under complex circulation conditions.

- *Regarding the third question:*

We agree that spatial connectivity maintained by only one or a few grid prints (such as the connection between Parts 2 and 3) should not be overinterpreted as evidence of a strict or strong physical connection. Most AR identification algorithms first isolate regions of strong moisture transport from the background using IVT or vertically integrated water vapor (IWV) thresholds, and then merge adjacent grid points satisfying the threshold into AR candidates. Under this framework, an AR candidate is first an objectively defined connected region determined by thresholds and spatial connectivity, rather than a region bounded by a strict physical interface. A physically continuous AR region may contain small holes if a few grid points fall below the threshold. Physically related enhanced moisture transport regions may be separated if a few intervening grid points fail to meet the threshold. Conversely, strong IVT regions physically unrelated may be merged into a single AR candidate if a few intervening grid points exceed the threshold (e.g., Fig. 4 in the revised manuscript).

We agree that the narrow connection between Parts 2 and 3 should not be interpreted as definitive evidence of strong physical continuity. However, similar cases are very rare. From the perspective of dataset usage and especially for AR climatological studies, the influence of this uncertainty is usually obscured by large sample sizes. For case studies, however, we recommend that users interpret the identified AR objects in combination with the actual moisture transport background and synoptic conditions.

To reflect this conceptual clarification in the manuscript, we have revised the text in **Lines 97–99**. In summary, an AR candidate should be understood as a diagnostic representation of the spatial extent of enhanced moisture transport, with its delineation depending on the selected detection variable, threshold field, and spatial connectivity rule.

Minors:

1. Line 185: what do the authors mean by "the standard deviation of the two sums"?

Reply: "The two sums" refers to the two sums of turning angles calculated separately along $Axis_1$ and $Axis_2$ of AR candidates. This quantity is used as a diagnostic measure of the consistency between the curvature-related characteristics of the two axes. We have revised the sentence as follows:

"3) For each axis, the absolute value of the sum of turning angles is less than $300° - i \times 30°$, and the standard deviation of the two numbers (i.e., sums of turning angles for $Axis_1$ and $Axis_2$, respectively) is less than 60°, where $i \in \{0, 1, 2, 3, 4\}$ and denotes the current threshold-level index within the threshold adjustment step, as detailed in the next step." (**Lines 207–209**)

2. In Table 1, it may be clearer to present values in parentheses as percentage ratios rather than raw numbers, which would more directly illustrate the consistency between the proposed algorithm and the other two methods.

Reply: We thank the reviewer for this helpful suggestion. We have added the percentage rations. Please refer to the revised Table 1.

3. Figs. 5g–i: There appear to be discontinuities near the dateline. Is this a plotting artifact, or is it related to how DB3 handles data crossing the dateline?

Reply: We appreciate the reviewer's comment regarding the discontinuities near the dateline. The discontinuities in Figs. 5g–i do not arise from the plotting procedure. The DB3 is constructed by merging multiple independently developed AR datasets through a data fusion algorithm. Some regional constituent datasets are artificially truncated near this boundary, resulting in a few similarly truncated cases in the fused DB3. We changed the figure display with the zero longitude in the center.

4. Figs. 6 and 7 are swapped: the caption is not matched with figures.

Reply: Thank you for your careful review. This superficial error has been corrected.

5. DB1/DB2/DB3 are used subsection 3.1, while DS1/DS2 are used in subsection 3.2. It would be better to use consistent abbreviations throughout the manuscript.

Reply: We have carefully checked the revised manuscript and corrected the inconsistent abbreviations. All are corrected.

References

Guan, B. and Waliser, D. E.: A regionally refined quarter-degree global atmospheric rivers database based on ERA5, Sci. Data, 11, 440, https://doi.org/10.1038/s41597-024-03258-4, 2024.