Response to the comments from Anonymous Referee 1 for the submitted ACP paper: ´Dorff, H. et al. 2023: Observability of Moisture Transport Divergence in Arctic Atmospheric Rivers by Dropsondes

Superior Erratum:

With the aid of the reviewer’s remarks concerning the frontal gradients in moisture transport divergence and the emerging revision of our manuscript, we identified erroneous results in our divergence calculation. In specific, we accidently did not calculate the wind divergence from using both u, v components but considered the absolute values of wind speed. By that our divergence results were direction-independent. In order to conduct a component-wise divergence calculation, we now had to rotate the u, v components in CARRA, as they are oriented along the local grid rotation and not the zonal/meridional direction. In doing so, the results in chapter 5 and chapter 6 (Figure 12-15) have changed moderately. In the response sections that refer to the respective manuscript sections, you will find the updated figures, alongside a specification of differences to the preprint results. In the remainder of this response, our updated results are already included when we present corresponding snippets of the updated manuscript paragraphs.

Prefaces:

We thank the ACP associating editor, Geraint Vaughan, as well as the Anonymous Referee #1, for this enlightening review. Please find our responses (in standard font) to the remarks from the Anonymous Referee #1 (in *italics*) below. We structured this response in such a way that comments on the most relevant text blocks being improved (e.g. introduction and discussion of results) are distinguishable from each other.

We reserve the right to apply minor changes to the here modified text snippets for the final revised manuscript in order to achieve even more concise phrasing and to guarantee grammatical correctness.

Responses to Reviewer 1:

The article is a comprehensive piece of work and presents nice and illustrative figures. I think the presented approach is valid and the content is certainly worth for publication. However, in its current form, the study is not sufficiently motivated and the results are not properly discussed in view of related work. Hence, the novelty in terms of applied methods and results and the added knowledge about Arctic ARs and their observation strategy remains unclear. The presentation quality suffers from a confusing writing style. I recommend major revisions and encourage the authors to carefully rewrite their work to improve the readability of the manuscript.

Response: First of all, we want to expressly thank you for the very detailed and well-specified feedback. We are certainly confident that the consideration of your remarks enables a significant improvement of the manuscript. The remarks help to transfer our scientific content and knowledge, that is considered as worth publishing, to the reader in a more logical and precise way. Accordingly, in our revision, we focus on improving the readability by more elaborated clarity and structure.

Writing/Grammar

The grammar is a bit awkward and the article misses coherence and logical order within the paragraphs and sentences. The writing of this paper would benefit from a grammatical editing and language check.

Response: We will invest more focus on coherence and the logical order for the paragraphs (individually and in its entirety). We will confirm additional cross-reading of the revised manuscript by either well-experienced or native English speakers.

Terminologies

- *the authors skim over many aspects simultaneously and it is up to the reader to guess potential relationships. Terms like "significant impacts", "pathway of ARs" (in a Lagrangian sense or AR displacement?), "moisture transformation processes", "moisture budget", "precipitation efficiency", "divergence of IVT", "IVT variability", "horizontal corridors", "dynamical and thermodynamical processes", "AR moisture budget components", "AR evolution" (many more examples in the other sections) are not defined or described, which makes it hard to understand the context of this work.*
- *Formulations like "are widely assessed over the mid-latitudes" (L33) or "manifold understanding" (L35) are without substance and should be avoided.*

Response:

- We agree that the introduction in particular was overloaded with terms defined/ described little or even not at all. You will find more details in our responses concerning the introduction (see below):
  "significant impacts" → The impact of ARs in the Arctic is now the key topic of the first paragraph and thus not unspecified.
  "pathway of ARs" → the ambiguous formulation has been modified to specify the long-distance displacement where air mass transformations occur.
  "moisture transformation processes" → here we decided to keep them more or less unspecified. Transformation processes, such as airmasses starting to precipitate, are described above (although indeed not linked to the term "transformation process"). Now we refer to according literature (You et al., 2022) and more clearly highlight the relevance of moisture transport to understand air mass transformation processes. We see a risk of distracting the reader more from our major research focus, the moisture transport and its observability (which the following paragraph is about) if we specify the air mass transformation much more at this early stage.
  "moisture budget", "precipitation efficiency", "divergence of IVT" → In order to not confuse the reader by too much details, we will erase the term "moisture budget" and focus on the fact that Seager and Henderson et al. (2013) finds the link between moisture transport divergence/convergence to local tendencies of moisture amount and how efficiently precipitation is induced. We are confident that this reformulation achieves more clarity. Nonetheless, in our opinion, defining each of the terms once again can be neglected in some cases. In particular, we consider the conceptional definition of divergence (convergence) to be known. A concise definition of the moisture budget follows in Section 2 using Eq. 1.
  "IVT variability"
  We agree that this wording was imprecise. We will specify that we mean the spatial variability and add respective findings from Guan et al (2015) describing how spatial IVT variability is composed in atmospheric rivers.
  "horizontal corridors"
  We rephrased this to "horizontally extended areas". Later, the term "AR corridor" will be defined using Figure 3.
  "dynamical and thermodynamic processes",
  We carefully checked the respective phrase, but argued that too much specification here might distract from the key message of this phrase and paragraph, namely the frontal gradients in moisture transport divergence.
  "AR moisture budget components"

we will reformulate the sentence without explicitly mentioning the moisture budget components and solely refer to IVT divergence. By that, the term “AR moisture budget component” is not needed before it is introduced in Sec 2.3.
“AR evolution”
We will specify that we mean the evolution in a temporal sense, meaning the life cycle of an AR and the AR displacement, that cause Eulerian differences over time.
We are confident that stronger interconnection between the above-mentioned terms delivers a substantial improvement for the clarity and logical order of the terms. This is explained in more detail in the answers to the introduction.
- We will delete any formulations like “widely assessed” (L33) or “manifold understanding” (L35) that impair the argumentation in the introduction.

Introduction:

The motivation […] remains unclear. I understand that a limited number of dropsondes might affect IVT estimates and […] that Arctic ARs may be not well characterized, but is that all? The authors remain very vague about related work. Although references are given, only rarely a relevant result is described. […] this is needed to understand the motivation of the study.
Response: We suppose that this results from an interplay between insufficient clear structuring in specifying the motivation and identifying the research gaps that emerge from so far broadly studied airborne observations of ARs (at least in the mid-latitudes). When referring to literature, we mostly miss to pinpoint clear findings relevant for our motivation.
Therefore, we carefully rewrite the introduction to clearly identify research gaps and include the following modifications, addressing several reviewer remarks:

- We rephrase the first sentence of the manuscript that actually intended to highlight the presence of ARs. Following Referee 2, a *“clear and concise description (definition, shape, evolution, region of occurrence) “*of ARs is now added.
- The purpose of the first paragraph which is about the importance of the presence of ARs in the Arctic, is described in more detail.
- We conduct a more thorough literature review regarding arctic ARs. We will describe findings from the literature precisely, in particular, in the first paragraph that focusses on the importance of ARs in the Arctic on short-term scale, but also at many other places throughout the manuscript.
- The research focus and overarching motivation of our feasibility study are introduced earlier (4th paragraph). This facilitates the understanding of our conceptual perspective (assess the observability of AR to improve flight campaigns) in the following.
- Built on this, our four research questions will not anymore be introduced at the end of the introduction. They are motivated with a respective paragraph one after another. Each paragraph faces a relevant problem/requirement of airborne moisture transport sounding and refers to knowledge gained from ARs in mid-latitudes. By this, we aim to more thoroughly cover the questions arising for the reviewer:
Why should ARs and their observation strategy be different in the Arctic? What is known about Arctic ARs in general and dropsonde-based IVT estimates? Current studies so far mainly focused on IVT variability within mid-latitude AR centers. For the Arctic, where we do expect less IVT, the sea-ice region is more affected by the outflow region of long-elongated ARs residing over the North Atlantic than by the center of an AR overpassing this region. One may argue, that if IVT and its variability are supposed to be weaker in the Arctic, then the mid-latitude AR based requirements will, or even more so, hold for arctic ARs. However, the deployment of dropsondes is cost-intensive and should be always optimized in a cost-loss ratio. This should be quantified in such a way: *How few dropsondes are sufficient to characterize IVT in Arctic ARs and what is their uncertainty?*
Regarding the frontal-specific characteristics of divergence in arctic AR, Guan et al. (2020) and Norris et al. (2020) determined AR frontal differences of moisture transport

divergence for mid-latitude ARs. However, we do not know how the divergence/convergence of moisture transport takes place in arctic AR regions. Guan et al. (2023) found that the Arctic is more affected by mature ARs that commonly start to dissipate and by the outflow regions of ARs. Correspondingly, such facts are elaborated more thoroughly in the introduction to better motivate Q3.
"How has the problem been addressed (methods)?". We understand this interest. We give more relevant information from the literature (e.g in how the sensitivity to sonde spacing has been assessed already). In our opinion, too many details on specific methods to derive IVT divergence should be postponed for the sake of readability. When picturing the remainder of the manuscript (last paragraph of the introduction), we try to more explicitly mention that an entire section introduces how divergence can be calculated from airborne sonde profiles and how, in detail, it is done in this study.

- *How and why were the particular nine cases selected (unclear: L68 "predefined in ERA5", L119ff "picking (…) from catalogue") and why was only the Atlantic region considered? Please explain the purpose of placing the legs at the sea ice edge (L105ff is unclear). Why is only spring considered?* The selection is related to the AR impact on the sea-ice melting when sea-ice reached its maximum extent in spring (paragraph 1). We specify the Arctic ocean as our region of interest due to the fact that the North Atlantic represents one of the most prominent pathways for ARs (Guan et al., 2023) into the Arctic as the moisture transport is undisturbed by any orographic barriers.
  We revisit the explanation of the case selection are revisited in the respective section introducing the AR cases (Sec 2.2). We there add more details as given above. We remove the distracting and unprecise information about ERA5.
- ***Observation strategy:*** *How was the simulated observation strategy defined? How do aircraft limitations (flight duration, number of dropsondes) affect the strategy?* **Response:** In the introduction, we now highlight that long-range research aircrafts are in any case needed for a strategy to derive IVT divergence in ARs. The different characteristics across the embedded AR front require a large area of interest and the flight duration consists of a couple of hours, in contrast to single circles (being performed to derive divergence in trade-wind regions, Bony and Stevens, 2019). We add more information of the width of ARs responsible for the final flight duration and the importance of two cross-section legs. In turn, such detailed specifications will be given in Section 2.3 that deals entirely with the reason for our envisioned flight strategy.

Specific remarks in the introduction:

Unusual language:
L31:
Response: as mentioned above we rephrased the sentence: "Seager and Henderson (2013) point to the divergence (convergence) of IVT as the link of the temporal evolution of moisture amount to its efficiency to induce precipitation."

L51 (deteriorate … representation?):
Response: We rephrased the sentence to clarify that too few sondes affect the airborne representation of IVT negatively: "A limited number of dropsondes may deteriorate the airborne representation of AR moisture transport variability if the sounding frequency is too low to reproduce the spatial variability of IVT."

L57 (monitors transport (…) seen from research aircraft?):
Response: As a consequence of our restructuring we deleted this sentence.

In the introduction the reader is distracted by details about CARRA regional reanalyses. I suggest adding more details about CARRA, but in the methods section.
Response: We delete the corresponding sentence and extended the specifications of CARRA in the respective data section

Q2 addresses correlations of wind and moisture, which has not been motivated by the introduction. What is (un)known? For understanding Q3, the relevance of IVT divergence needs to be explained more carefully.

Response: The restructuring of the introduction considers these remarks in the paragraphs. Q2 now has an individual motivation like all other research questions. We motivate more thoroughly the correlations of wind and moisture and their potential interest for the measurement strategies and also for different spatial patterns along the AR cross-section. This is done after highlighting the sensitivity to sounding frequency.

For Q3, we describe the relevance of IVT divergence more thoroughly with respect to steering the local amount of moisture or to precipitation triggering.

Section 2 and 3 (structure of the article):

The structure of the method sections is confusing and I suggest that sections 2 and 3 are merged. Section 2.1 (description of dropsonde data that is actually not used) can be deleted. Sections 2.2-2.4 can be summarized in a data and methods section. The TIVT definition (now in Sec. 4) should be moved to the Sec. 2-3.

Response: We agree that a merging of both sections improves the structure of the manuscript. Furthermore, we deleted Section 2.1 which is indeed redundant. Hence, we come up with a modified structure of Section 2, which now consists of:

2 Airborne derivation of moisture transport divergence in arctic ARs
2.1 Reanalysis framework
2.2 Selection of Atmospheric River cases
2.3 Flight pattern and emulated observations
2.3.1 Zig-zag flight tracks observing AR corridors
2.3.2 Synthetic dropsondes
2.4 Sonde-based divergence derivation
2.5 Decomposition in AR frontal sectors

Since this section becomes rather long, we will provide some guidance for the reader at the beginning of Section 2, before then coming to the subsections.

In the following, the responses relevant to the modified Section 2 are specified. All section numbers refer to the modified outline. From Section 2.3 on, this means that the first number of each original major section decreases by one.

Section 2.2

L105ff is unclear. How and why were the particular nine cases selected (unclear: L68 "predefined in ERA5 […] and why was only the Atlantic region considered? Please explain the purpose of placing the legs at the sea ice edge (L105ff is unclear). Why is only spring considered?

Response: We will carefully rewrite the first paragraphs of the original Sect 2.2. We will move the definition of IVT to Sect. 2 as it is a basic concept to define ARs. Before, it distracted in Sect. 2.2 when giving details about our individual AR selection criteria. To better explain our selection, we orientate to your question and recapture information given in the introduction as: "The transformation of arctic airmasses moving over changing surface types (open ocean and sea-ice) along large-scale meridional circulations is part of current research and investigated by research aircraft over the Arctic ocean (Wendisch et al., 2021). In this context, our study selects ARs causing air masses to overshoot the sea ice edge in the Arctic ocean. The principle identification of relevant arctic AR events is based on the IVT-based AR detection catalogue by Guan et al. (2022). Among these ARs, we focus on spring season, when maximum sea-ice extent in the Arctic ocean starts to break-up and reacts very prone to the intrusion of warm and moist air (Mattingly et al., 2018). We remain to conditions and AR events only from last decade, as the arctic climate has been changed rapidly and intensively over the last decades (Wendisch et al., 2023). Our selection constrains on ARs, whose lateral width is purely situated over open-ocean or sea-ice. This ensures that we do not encounter additional land effects on IVT (e.g. orographic-induced convergence) which are out of the scope of this study. Moreover, airborne observations and sonde releases over land are more complex to be conducted. Given these criteria, our study selected ARs from nine spring days between 2011 and 2020."

Can you explain the relation of ARs and warm air intrusions (L116)?
Response: Arctic events designated as warm or moist air intrusions can often be classified as atmospheric river, as the intrusions are in conjunction with strong transport of moist airmasses. Due to their subpolar origin, the airmasses are preferably warm compared to predominant arctic conditions. Accordingly, we will add an overarching description in the manuscript.

Regarding CARRA, the authors should "[…] clarify the extent to which km-scale variability of moisture transport can be assessed. The grid spacing (how determined?) and effective resolution of such gridded data are certainly different."
Response: The documentation of CARRA specifies an equidistant 2.5 km grid spacing over the entire model domain. Indeed, the grid spacing differs to the effective resolution of moisture transport. At least, Koltzow et al. (2022) illustrates the significant improvement of the decorrelation length for surface-near wind speed compared to ERA5. According to observations, the correlation decreases rapidly below 0.6 for distances longer than 50 km, roughly the ERA5 resolution in the Arctic. Nonetheless, we are aware that surface near wind is much more affected than upper levels, especially also when over complex terrain. In the manuscript, we will hence add: "Koltzow et al. (2022) verified the improved representation of CARRA in arctic surface-near meteorological conditions by decorrelation lengths of wind speed approaching observations more than ERA5."
It is obvious that the resolution of CARRA is certainly different to the effective resolution. If we consider the results from Skamarowk et al. (2014, https://doi.org/10.1175/JAS-D-14-0114.1) designating an effective model resolution of approximately six times the grid spacing, we can still assume that moisture transport can be resolved in the order of several 20 kilometers in CARRA. Using ERA5, we would thus remain in the range of ~100 kilometers and would be in the order of magnitude of envisioned sonde resolution, and cannot make robust statements.
Nevertheless, further investigation of the added value of CARRA in representing ARs is definitely very interesting. For our study, however, we see a risk to overload its content and hope that our study instead motivates further research of ARs using the novel reanalysis CARRA. We come back to this in the conclusions.

Why do you use pressure level data only and how might the rather low number of vertical levels influence the results (L374)? What is the separation of the levels in the lower troposphere?
The advantage and our reason for the usage the pressure-level CARRA data results from the consistency of pressure-levels allowing an easy calculation of the vertically integrated moisture transport (IVT) following Eq. 1. Moreover, when deriving the moisture transport divergence, the values at unique pressure values do not require any further interpolation. The separation of the levels can be depicted from the dots in Fig7-9.
In an exemplary case (not shown), we have used the model-level data and basically find higher variability in the vertical profile for wind and moisture, but the effect on IVT and IVT divergence is minor, and in particular does not change our overall results significantly (not shown). Still, we recommend using the higher resolution model data in the conclusion for follow-up studies.

L152f (why are radiometer/radar relevant?)
Response: We will rephrase the sentence to:
"Our 1 Hz representation of the aircraft location is in line with the operational resolution of common airborne remote-sensing products (e.g. Mech et al., 2014; Konow et al., 2019) that can complement dropsonde-based moisture data."

Arctic ARs: I recommend adding a more detailed discussion about the determined characteristics of Arctic ARs (e.g., L315ff, results of Fig.1 and 10). This should involve a discussion of the communalities and differences of the presented nine cases. The large case to case variability should be better discussed.

Response: We will extend the description of our selected AR events. For that, we restructure the second paragraph of the modified Section 2.2, that introduces our AR cases and split it into two subparagraphs. First, we emphasize the inter-case variability with respect to communalities/differences in the synoptic situation. Second, we describe the actual AR pathways seen for our selection (aligned to the preprint version), as follows: "Low-pressure systems forcing large-scale meridional transport represent a common synoptic composition where ARs can evolve on the eastern cyclone flank and reach into the Arctic (Papritz et al., 2020). Similarly, blocking situations can favor meridional circulation. For our nine ARs (Fig. 1), we confirm a large case-to-case variability regarding the synoptic situation. While some ARs (AR2, AR3, AR4, AR9) have evolved along the eastern flank of large-scale troughs over Greenland, AR5 and AR6 are more steered by blocking high pressure over the Barent Sea. AR1 and AR7 are, in turn, reinforced by a mesoscale cyclone situated over the Fram Strait and reach very close into the cyclone center.

The synoptic compositions cause the ARs in Fig. 1 to extend over the North Atlantic and Arctic Ocean; the typical arctic moisture transport pathways (Papritz et al., 2021). Some ARs exhibit straight meridional moisture transport north of Iceland and approach or exceed Svalbard (AR1, AR2, AR3). AR4 and AR7 show more elongated filaments along the Norwegian coast but still reach far north. We consider eight independent AR events wherein AR5 is also considered for the consecutive day (AR6). At this stage, the centre of AR6 reaches close to the North Pole. AR8 originates from Siberia that represents another significant roadway for arctic moisture intrusions causing ARs (Komatsu et al., 2018). The last events in 2020 (AR8, AR9) are accompanied by a warm air intrusion period observed by the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition (Shupe et al., 2022), studied in (Kirbus et al., 2023)."

Unclear statement", L119ff "picking (…) from catalogue")

Response: we will modify the beginning of the paragraph as follows:
"A caveat of our selection is that a number of nine AR cases is rather small to make general statements about IVT variability in arctic atmospheric rivers. Therefore, we place our cases in the context of the climatology of arctic ARs in spring. Using the entirety of spring ARs along the Atlantic pathway from the catalogue of Guan (2022), […]"
Furthermore, we put our following statements in a more logical order to clarify that our AR sample is representative for the rather strong AR cases.

2.3 Flight pattern and emulated observations

Removal of initial Section 2.1:

Response: Due to the removal, slightly more description of flight performance and dropsonde characteristics to be emulated are given in Section 2.3. In the following our remarks regarding the flight strategy will be responded.

I did not get how the flight tracks were defined. Isn't the zig-zag pattern only the consequence of sufficiently long cross-frontal legs at two latitudes that are required to capture the lateral heterogeneity and to be able to derive divergence?

Response: For the divergence purposes, the cross-frontal legs are of relevance and actually sufficient. We discussed to keep our term "zig-zag pattern" due to the fact that a single aircraft has to perform an internal flight leg in order to connect both cross-sections (a relevant time constraint also for our analysis). Nonetheless, we agree to put more emphasis on the cross-section legs themselves when introducing our flight pattern. Accordingly, we will reformulate: "Instead, the high lateral variability in AR transport characteristics requires long flight legs across the AR front to better capture divergence heterogeneity. Such cross-sections can be connected via an internal flight leg in a zig-zag flight pattern (Fig. 3). The zig-zag pattern thus observes AR corridors, along its transport direction. The boundary cross-section legs perpendicular to the major flow quantify the corridor in- and outflow, i.e. in- and outgoing IVT over the entire lateral AR extension and enable simplified divergence calculations." Information about diagonal legs and the moisture budget closure will still be given, but as a site note.

Are all terminologies for the flight pattern (AR corridor, boundaries, boxes, sectors etc.) needed or would it be enough to describe two cross-sections at separate latitudes that are then classified in sectors? What defined the latitudinal spacing?
Response: We will reduce the terminologies accordingly and speak of cross-section legs rather than "zig-zag" whenever sufficient. The latitudinal spacing was adapted in a way that no landmasses reduce the cross-section length in the outgoing cross-section and that the northern leg is at least 100 km away from the ingoing cross-section.

It is sometimes confusing what data is used. I actually thought that the flight duration was not considered for the "continuous" (L394, 426). "Continuous" was also used earlier (see e.g., Fig. 14 caption), however, I think it referred to the high-resolution cross section profiles. I suggest a clear structure and description.
Response: We apologize for imprecise terms as they are very essential for the comprehension of our work. Therefore, in our restructuring of Section 2 and 3, we will add the definition of the "continuous representation" at the end of Sect. 2.3.1 to make clear that this represents the "ideal" sampling of moisture transport from the moving aircraft.

L233ff should be moved to the method section.'
Response: We will move the definition of the TIVT to the Section 2.4 dealing with the sonde-based divergence derivation and are convinced that now this section is more compact.

The advantages and limitations of the applied methods should be considered in view of other approaches.
Response: We will extend our description of the applied methods and contrast more the advantages and limitations of our cross-section pattern for divergence calculations. One obvious limitation are the open boundaries that the cross-sections leave. The major advantage we see in the ability of the cross-sections to derive the divergence in different sectors across the AR embedded front more or less simultaneously. Similar as in Norris et al. 2020, that investigated the airborne divergence pattern and subdivide the examined AR corridors, the sensitivity to different spatial scales can be assessed.

Unclear L182:
Response: We assume that the connection to the precedent sentence was unclear, as well as the vague statement of "two impacts". We will rephrase the sentence to:
"The convergence/divergence of moisture transport thus affects the moisture transformation via two composites that we can attribute when splitting ∇IVT as follows:"

I do not understand the sector classification: Please specify the "requirements" in Cobb et al. (L198ff). In L194 the prefrontal, core and postfrontal are differentiated. Then you come up with a threshold definition for the AR edges. How does this all fit together and how are the sectors defined? Please move relevant information about Arctic ARs to the introduction.
Response: We will rephrase the description of our sector classification and explain the requirements of Cobb et al. in more detail, especially how we adapt those requirements to arctic conditions we found in Fig. 2.
With the term "AR edges", we mean the outer boundaries of the frontal sectors. At some lateral distance, the moisture transport (IVT) becomes too weak to be considered as atmospheric river. The requirements will be described as follows:
"Therefore, we conduct a similar sector-based decomposition of IVT divergence for our arctic AR events in CARRA. As in Guan et al. (2020) and Cobb et al. (2021a), our decomposition relies on the IVT characteristics along the cross-section (as depicted for an exemplary cross-

section in Fig. 4). The central AR core represents the region of strongest IVT (> 80% of maximum IVT). East of the core we situate the pre-frontal sector and west the post-frontal sector. Yet, their outer edges are less trivial as ARs basically have open outer boundaries. To account for case-specific relative values, we assign frontal edges where IVT ≤ 0.33 IVT_{max}. As a secondary threshold, we declare a moisture transport with IVT ≤ 100 kg $m^{-1}s^{-1}$ as too weak to be assigned as AR-IVT. Both form the outer edges of the AR where the pre- and post-frontal sectors end (Fig. 4). Note that the latter threshold to define the AR edges follows the approach of Cobb et al. (2021a). However, we lower their mid-latitude based IVT threshold from 250 to 100 kg $m^{-1}s^{-1}$. By this, we refer to common polar moisture transport magnitudes that exceed the 95th percentile of climatology and are declared as ARs in the detection of Guan and Waliser (2015). Otherwise, as statistics in Fig. 2 indicate, we would either exclude most ARs north of 70◦N, or would shrink the AR cross-section that strong that most transport is ignored." To facilitate the connection of our terminologies, we will provide a Figure (listed as Fig. 4) illustrating the IVT-based frontal sector classification along AR cross-sections. Afterwards, we display how the sondes are located correspondingly in both cross-sections (then Fig. 5).

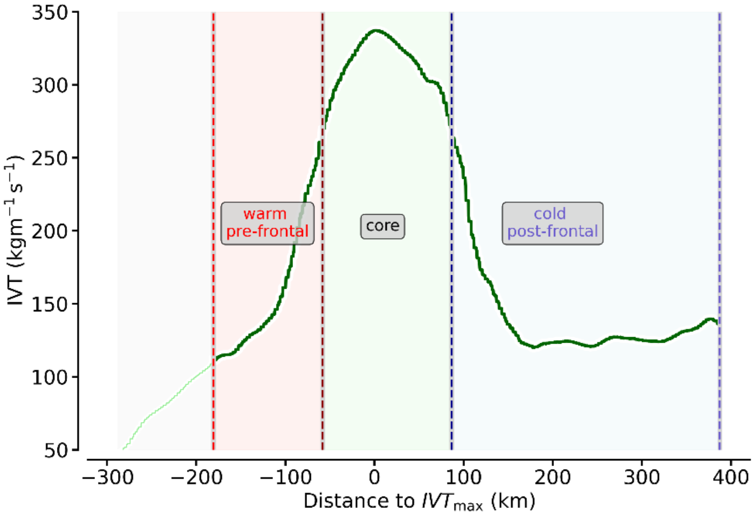

Figure 4 (in manuscript): Frontal sector decomposition for an exemplary AR IVT cross-section using the criteria described in Sect. 2.5. The colored shadings and text boxes indicate each frontal sector. The grey shading on the left represents moisture transport (i.e. IVT) that is not considered as AR because it is too weak.

Comment: In the following the Figure labels still rely on the original numbering.

Section 2 specific comments:

L202: I cannot see the three dropsondes that calculate IVT.

Response: We will specify our misleading explanation: […], six synthetic sondes (three from the in- and outflow leg each) calculate the IVT divergence for each frontal sector respectively.

L204 (putative? inconsistency?)

Response: we delete both words as they do not provide any added values.

Section 3: Moisture transport in Arctic AR cross-sections from soundings

General remarks:

The paper lacks a thorough discussion of the results, either within the result section or in a separated section at the end. [..] a few references within the result section, however, not detailed enough (see above) so that the added value of the paper becomes clear.

Response: We agree that the discussion of results is worth improving. We decided to manifold and strengthen the discussions in the respective result sections rather than merging them in a

separated “discussion” section. We restructure concerning paragraphs in order to still unravel the discussions of results more stringently. We strengthen the interpretation of our results in a more connected comparison to findings from literature (mostly based on mid-latitude ARs).
In the following, you will find specific responses for the relevant sections, whereby many reviewer remarks are applicable for several paragraphs throughout our results sections.

Add more references to figure panels within the text whenever appropriate.
Response: Yes, this improves readability. We will add them especially in our result sections.

Sect. 3.1: Shape of IVT across arctic ARs

I recommend adding more detailed discussion about determined characteristics of Arctic ARs.
Response: We will take up this point for Sec 3.1, as the IVT shape of ARs in the Arctic is here first presented in more detail, and we find that comparisons are helpful here to categorize our cases. Accordingly, we added some more discussions about the IVT strength for our AR cases with respect to mid-latitude cases (Cobb et al, 2021) and arctic cases studies (Viceto et al, 2022). This is will be done as:
“Summarizing all cross-sections of our ARs from Sect. 2.2, most arctic AR cross-sections show this typical bell-shaped IVT curve over widths of roughly 400 -800 km and exhibit pronounced IVT maxima in the core of 300-600 kg m^{-1} s^{-1} (not shown). Only for the weak AR8, this structure is less pronounced. We find that our arctic AR are not substantially narrower than the AR widths of global climatology (Guan et al., 2015) or observed mid-latitudes events (Cobb et al., 2021). The flight planning should thus consider cross-section lengths around 500-1000 km similar to the mid-latitudes, but not only restrict to regions with IVT>250 kg m^{-1} s^{-1}, that is broadly used threshold for mid-latitude ARs (e.g. in Ralph et al., 2019). The maximum IVT for the arctic events, is roughly half as high as the majority of mid-latitude AR from airborne studies in Cobb et al., 2021. Moreover, the IVT magnitudes strongly differ between our cases and synoptic conditions. The strongest ARs with maximum IVT (IVT_{max}) exceeding 500 kg m^{-1} s^{-1} are found for intense Greenland troughs, while weaker ARs along the Siberian pathway (see Fig. 1). Compared to other arctic cases, e.g. Viceto et al. (2022), we include stronger ARs.”

Additional Response: We will specify the comparison between ERA5 and CARRA: “Viceto et al. (2022) documented the improved representation of arctic AR characteristics in ERA5 against coarser reanalysis data. In our comparison of CARRA and ERA5, the location and horizontal pattern of the ARs agree quite well (not shown). For all cross-sections, we ascertain plausible IVT values from CARRA with respect to ERA5. In particular, we highlight that maximum (mean) values of IVT per cross-section increase by roughly 9 % (8 %) from ERA5 to CARRA on average. CARRA further increases the IVT variability by roughly 11 %. We attribute this to horizontal resolution being higher than in ERA5.”

Should there be a strategy to place one dropsonde at a simulated maximum IVT (L223)?
Response: The restructured discussion of results will follow this suggestion as:
“The Gaussian fit to reproduce the IVT shape (Fig.4) is very sensitive to the actual positions of dropsondes. While the centered sonde is positioned close to IVT_{max}, a slight shift of this sounding, which easily occurs in real observations, can quickly lead to an underestimation of the moisture transport in the AR core. Flight planning should thus imply a sonde release in the vicinity of predicted IVT_{max} and place additional sondes symmetrically around the core. While sonde positions in Fig. 6 are suitable to represent the cross-section IVT, other AR evince more complexity in being accurately represented by this number of soundings. We need further inspections on how sounding intervals deteriorate the AR moisture transport observability.

Sec. 3.2 Sonde-based total cross-section moisture transport

I suggest adding a recommendation for the spatial separation (L252, L425) instead of a number per flight which depends on the flight performance. Figure 6: Change “seconds” to “minutes”.

Response: Indeed, a recommendation for the spatial separation is more universal with respect to flight performance. We will change the descriptions in this way and we also changed the axis of Fig. 6 to distances (km). Yet, since measurement operators frequently rely on specified time intervals when performing sonde releases manually, we add a light secondary axis referring to the spacing time. It is true that the duration depends on the flight performance, however, the values are valid for a common groundspeed at cruising level above 10 km.

Fig. 6: The median lines for the grey boxplots are hard to see. I guess that these distributions are calculated from the boot-strapping method (add information to caption). How many cross-sections? Please add what percentiles the box and whiskers represent.

Response: We add the information about the median lines, that are now illustrated bolder. We change seconds to minutes. The qualitive meaning of the colour-coding is now specified in the caption. Yes, the statistics are based on the boot-strapping approach considering hundred positions of sondes per cross-section. In total, this includes 900 cross-sections. The boxes show the quartiles while the whiskers extend to show the rest of the distribution, except for outliers (depicted as markers).

How sensitive are these results to the length of the flight pattern?

Response: Indeed, the TIVT values are always dependent on the flight lengths. We also compared the TIVT values of the arctic ARs in more detail with mid-latitude observations, where we also point out the different AR widths between arctic and mid-latitude ARs, if one would restrict to the same thresholds defining the outer edges. Regardless the actual AR width on which we also align the flight length, we stick to our recommendation of seven sondes that should be envisioned to be released in order to derive IVT divergence in the three different frontal sectors (pre- and post-frontal, and the core). Since the stronger ARs (in terms of IVT_{max}) are also broader, Fig. 6 demonstrates that the minimum required sonde spacing is less sensitive to the actual AR width. However, we admit that robust conclusions in this sense should involve a much higher number of AR events.

Sec 3.3: Variability of moisture and wind in arctic ARs

Response (according to a more detailed discussion) and vague relation to other studies (L266f): In this section, we also put more emphasis on clearly disentangling results (e.g. Fig. 7) and on discussions that we manifold. We compare vertical profiles in Fig. 7 with those of radiosondes in an arctic early summer AR period studied in Viceto et al. (2022) and synthesize communalities and differences to mid-latitude AR soundings in more detail.

L274f: How can you see this in Fig.7? Winds also strongly vary and the transport distribution (grey shading) resembles the wind distribution (red shading). The sentence in L275f contains redundant information.

Response: We referred imprecisely to the strong AR case (AR3) represented by error bars and not by the shadings in Fig. 7. We will separate our descriptions for the entirety of ARs and AR3 more obviously and rephrase the discussion of moisture transport variability and the role of wind and moisture:

“The cross-section variability of both moisture and winds strongly affects IVT variability. The shadings in Fig. 7 indicate that the standard deviation of moisture transport resembles the standard deviation of the winds for the lower levels up to 850 hPa, before moisture transport variability is apparently driven by the standard deviation of moisture in upper levels above 500 hPa, although the wind standard deviation here becomes highest. For the most intense AR3, Figure 7 depicts the LLJ with high wind speeds above 30 m s^{-1} that causes strong moisture transport whereas moisture is more or less average. While strong moisture transport in AR3 originates from overall strong winds, moisture varies strongly and seemingly dominates the moisture transport variability. Hence, we can hypothesize more specifically that in strong arctic ARs with intense winds, primarily moisture variability causes IVT variability and leads to to the bell-shaped IV T cross-section pattern (Sect. 3.1).”

L285f: Do you have an explanation for the increased variability in the free troposphere? Fig. 10 shows that your cross-sections pick up dry post-frontal subsidence regions and also dry Arctic air eastward of the AR feature, which likely impacts this result. Or maybe this is what your last sentence wants to say? How much sense does it make to calculate horizontal means for such heterogeneous sections?

Response: Indeed, the subsidence of dry airmasses is one of the major explanations for the increased variability in q. Since you also refer to Fig. 10, we would like to take up with this question again in Sec 4.4. Here, Fig. 10 enables an illustrative explanation.

Your last remark opens a very crucial discussion that results from the question of what do we consider as the “AR itself”? Here, the scientific perception strongly differs between the horizontal and vertical perspective. In the large majority (and as this study does), moisture transport with respect to vertical integrated quantities (IVT and/or IWV) is designated as AR where a certain threshold is exceeded. Even if the thresholds may change between AR detection algorithm for various reasons, they mostly have in common that they project the AR from 3D (horizontal and vertical) to 2D (horizontal). No matter if different air masses are entrained at certain vertical levels, the domain is still considered as AR, as long as moisture / or moisture transport are sufficiently high in the vertical integral.

The vertical atmosphere may thus still hold two airmasses (dry post-frontal subsidence regions and a moist air mass smaller than the ‘plume’ in the AR core). How both airmasses interact across this interface is a question for itself. The degree of mixing can have strong impact on cloud and precipitation formation (beyond the scope of this study). However, due to this fact, we pretend that is worth to consider such edges where we find a coexistence of air masses. Also, in the perspective of practical flight planning, forecasts of IWV and IVT represent the quick identification of the AR object to locate the flight tracks in.

Wouldn’t it be more interesting to focus on the AR itself and check how much the fluctuations at small scales contribute to IVT?

We highlight that we applied our cross-sections with respect to the AR edges from the AR catalogue (Guan, 2022) and can confirm that less than 5% of the flight tracks reach out of moisture transport that is declared as AR. This can also be seen in Fig. 11, where the AR edges (outer edges of the frontal sectors) are partially even more restrictively defined than in Guan (2022). Accordingly, we assure our results are representative for AR internal variability. By our frontal decomposition, we also put more focus of the central AR core.

Sect. 3.4: Coherence of moisture and wind

L289-291: Better explain the meaning of “correlated” and “coherent”.

Response: we will specify that we mean the correlation of both variables along the cross-section and here now just speak of “connected of pattern”. We stated more explicitly that the non-coherent transport consists of the individual means of moisture and winds ($\overline{q} \cdot \overline{v}$).

Like for Fig 10: This should involve a discussion of the communalities and differences of the presented nine cases. The large case to case variability should be better discussed.

Response: We will restructure the paragraph describing Fig. 10 and insist in more detail on large case-to-case variability with more direct relations to the references given. We will extend the discussion to mid-latitude ARs and focus on the discrepancies to AR schematics as in Ralph et al., 2017 when arctic wind and moisture pattern do not coincide. We highlight on the differences in AR corridors that are closer located to the AR center (e.g. AR5) against those corridors situated in the outflow region (e.g. AR7/9). In this regard, we refer to Terpstra et al. 2021 that also detected missing coincidence in a polar AR outflow, but rather in the vertical axis than we do in the horizontal.

With the added comparison, we specify the role of dry subsiding airmasses that become more effective if there is upper-level advection from Greenland air masses. We note that our analysis from Fig. 10 can still be manifold in various perspectives and details. At a certain point, however, we need to refocus on our research question and investigate the correlation between moisture and wind for the given cases and how the patterns contribute to IVT and its variability.

Section 3 specific comments:

L225 (maintain?)
Response: Changed to "show"

L322f: If there is little information from small scale fluctuations, why should one care about supplementary q observations?
Response: Yes, this is valid point. However, if one is still willing to improve the measurements, then one should focus on supplementary moisture observations. Accordingly, we will rephrase L322 to: "An improvement of observing the moisture transport variability should thus rely on supplementary moisture measurements rather than for the winds."

L260 (why intuitive?),
Response: rephrased to "simplified"

L268 (behaves more homogeneous?),
Response: changed to: "remains more homogeneous"

L277 (How?)
Response: rephrased to: "The identification of the more variable quantity out of q and v can be useful for the improvement of measurement strategies for moisture transport. Specifically, moisture can be derived from supplementary remote sensing devices on long-range research aircraft and thus complements sporadic sonde-based data."

L278 ("long-term aircraft"?)
Response: typo, changed to long-range

L289-291 (e.g., "carefully correlated observations?", "cross-sectoral")
Response: changed to "collocated" and "cross-section variability"

L322 ("narrowed moisture columns here form"?)
Response: Rephrased to: "Instead, narrow but high-reaching moisture plumes in the core control the moisture transport variability."

Section 4: Moisture transport divergence from sondes

4.1 Sectoral in- and outgoing moisture transport

Fig. 11 "frontal specific AR sectors" is unclear. I […] wonder that the dotted lines at negative distances are warm pre-frontal areas? I do not understand the two sentences "Leg specific … (lines)" – please rephrase. What is "corridor IVT convergence"?
Response: We will rephrase the figure caption: "Figure 11: AR-IVT of inflow (outflow) section in blue (orange) for all nine corridors in the AR. Changes in line styles denote the frontal sector classifications (Sect. 2.5). Dotted lines represent cross-section periods belonging to pre-frontal sectors, while dashed lines refer to post-frontal sectors. The legend specifies TIVT values for the in- and outflow cross-section for the parts situated within the actual AR. They include IVT internal of determined AR borders (Sect. 2.5). Arrows, scaled in length and width, indicate the TIVT difference between in- and outflow leg. As described in Sect. 3.4, they can be viewed as simple estimates for the IVT divergence in between both legs. Upward (downward) arrow scales represent estimated convergence (divergence) magnitudes. Note that the axis orientation has to be mirrored for west-east orientation. "

It did not become clear to me how the cross-sectional IVT gradients (Fig. 11) are connected to the dynamical situation and the results are contrasting the impression that I got from Fig. 1.

Response: We suppose that the axis orientation confuses the reader. Negative distance values refer to the eastern end, while positive values refer to the western end of our cross-section legs. Thus, the cross-section pattern should be mirrored when comparing with Figure 1. We will add a clarifying explanation in the Figure caption (see above). Then we cannot detect such inconsistencies to Figure 1. For example, the steep decline in the post-frontal sector of AR2 (Fig. 11b) is well in conjunction with IVT pattern shown in Fig. 1. Similarly, the gradients of in- and outflow legs for AR2, AR7 are consistent with the outflow IVT pattern in Fig. 1.

Still, later in the section, we will highlight that a comparison for estimating IVT divergence can be misleading in some cases. Note that the IVT cross-sections are (although continuous) based on flight duration and not on an instantaneous snapshot as we get from Fig 1.

The TIVT discussion (Fig. 11) could focus more on the AR area: Why is the divergence dominating in what you call warm sector – isn't that surprising?

Response: We will restructure the section: The first paragraph will cover TIVT as a whole, the second paragraph the cross-section differences, the last paragraph will investigate in more detail the TIVT gradients for the frontal sectors in the last paragraph. We remind that all three sectors do only consider moisture transport inside the AR area. We will highlight surprising findings more, but point out the limits in estimating divergence purely from IVT magnitudes. Thus, the two last paragraphs will be composed as:

"Figure 11 further separates the AR cross-sections in the three sectors (pre-frontal, core, post-frontal). Although the AR cores are roughly 200–300 km narrow (slim lines in Fig. 11), they provide more than half of the entire AR-TIVT. This contribution of the AR core agrees with Cobb et al. (2021a) in mid-latitude ARs. Except for AR2 and AR7, weaker slopes of IVT are generally in the cold sector as opposed to the warm sector. The steep post-frontal IVT decline in AR2 and AR7 suggests different evolution processes associated with a high pressure ridge, favored by anticyclonic Rossby wave breaking (Zavadoff and Kirtman, 2018).

Comparing both legs (Fig. 11), some arctic AR cross-section TIVT tend to decrease downstream. Higher IVT and higher TIVT in the inflow leg suggests potential total convergence in the AR corridor. Still, we detect cases with weak stream-ward tendencies in total moisture transport or with slight increases of TIVT. The downstream difference of TIVT is distributed unevenly over the cross-section IVT. We mainly find IVT decreasing towards the outflow leg within the AR core (e.g. AR3, AR9) and thus obtain an impression of convergence. Yet, we occasionally find different behavior in the frontal sectors that partially compensates the core. As in AR6, the overcome-pensating increase of warm sector IVT towards the outflow conveys a seeming divergence in the warm sector. This is in contrast to the findings in Guan et al. (2020), where the pre-frontal sector is denoted as rather converging. Although the IVT pattern of AR5 and AR6 (Fig. 1) may allow slight divergence in the pre-frontal sector, we emphasize that a TIVT-based interpretation of predominant moisture transport divergence underlies strong idealization. Neither it considers moisture flow being not flight perpendicular, nor it does separate contributions of moisture advection and mass convergence. We insist on the regression approach to diagnose moisture transport divergence in each sector of arctic ARs."

It is sometimes confusing what data is used. I actually thought that the flight duration was not considered for the "continuous" (L394, 426). "Continuous" was also used earlier (see e.g., Fig. 14 caption), however, I think it referred to the high-resolution cross section profiles. I suggest a clear structure and description.

Response: We apologize for the missing clarity of the term "continuous". We will add a clear statement in the method section (2.3.1) that underlines our definition of "continuous" cross-sections. We will refer to the Sect. when speaking of "continuous" in the remainder of the study.

Section 4.2: Sonde-based divergence and its representativeness

missing detail about the related work: L352f, L355f, L358f:

Response: We will specify our reference to related work and will state more precisely how we build on the precedent studies of Guan et al. (2020) and Norris et al. (2020). We will reformulate this as:

“This section depicts the regression-based (Sect. 2.4) IVT divergence *(∇IVT)* in arctic ARs. Moisture transport divergence is specified for the frontal sectors (Sect. 2.5) using the decomposed terms, namely moisture advection *ADV* and mass convergence *CONV* (Eq. 5). We compare ∇IV T in our arctic ARs with those based on statistics for mid-latitude ARs in Guan et al. (2020). The results we obtain from the continuous cross-section flight legs (Sect. 2.3) interpolated from CARRA represent our idealized reference. For them and seven synthetic sondes per cross-section (as in Fig. 4), we apply the regression method to derive *ADV* and *CONV*. In doing so, we build on the Norris et al. (2020), who pioneered the airborne derivation of all moisture budget components, including moisture transport divergence, by investigating a mid-latitude AR event. With our framework, we can assess uncertainties of sonde-based determination of ∇IVT in arctic ARs.”

Erratum modifications: As mentioned in the beginning, the divergence results have changed due to the correction in the vectorized divergence calculation code. The replaced figures will be illustrated below, with bullet points highlighting differences to the preprint version.

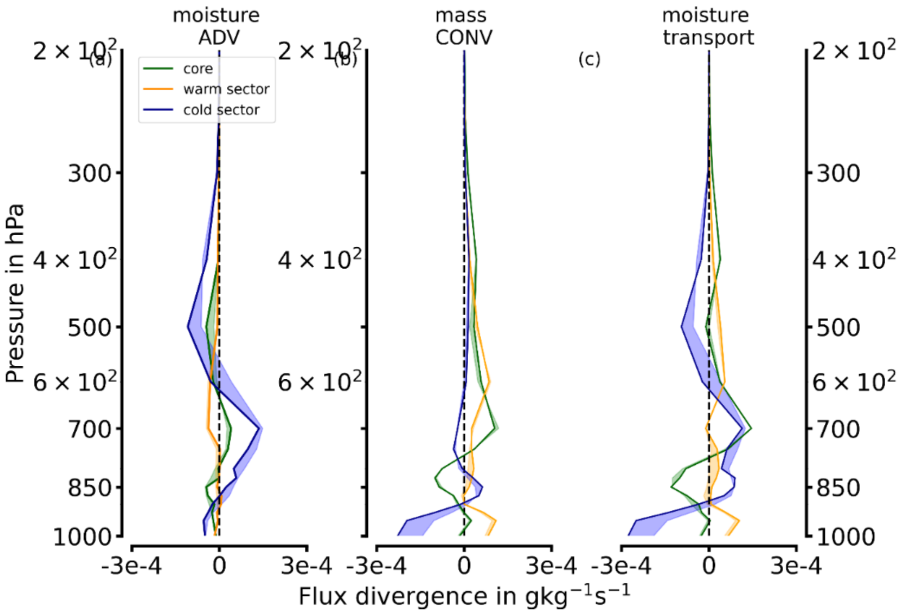

Figure 12 in manuscript): Vertical contributions from *ADV* (a) and *CONV* (b) to the moisture transport divergence (c) for the frontal sectors in AR3. Bold lines represent sonde-based values while filled areas denote the deviation to values based on continuous AR representation. ***Comment: the additional tick-labels will be removed in the final version***

Changes to preprint results:

- Slightly smaller magnitudes in all components
- warm sector and core values became more positive (less moisture advection and mass convergence). In particular, the warm sector became rather divergent (Fig. 12c).
- Low-level mass convergence in the cold-sector (exhibited divergence before).

Explanations: Before, we did not consider the u and v components of the wind separately. This directionality, in turn, substantially affects the results. Since the winds are partly elongated with respect to the moisture pattern, we find relevant contributions of cross-section parallel gradients (e.g. in $u \cdot \frac{\delta q}{\delta x}$ and $q \cdot \frac{\delta u}{\delta x}$), that were not pronounced in the previous approach. The current dominant post-frontal mass convergence results from strong changes in wind direction and superimposes rather weak changes in wind speed.

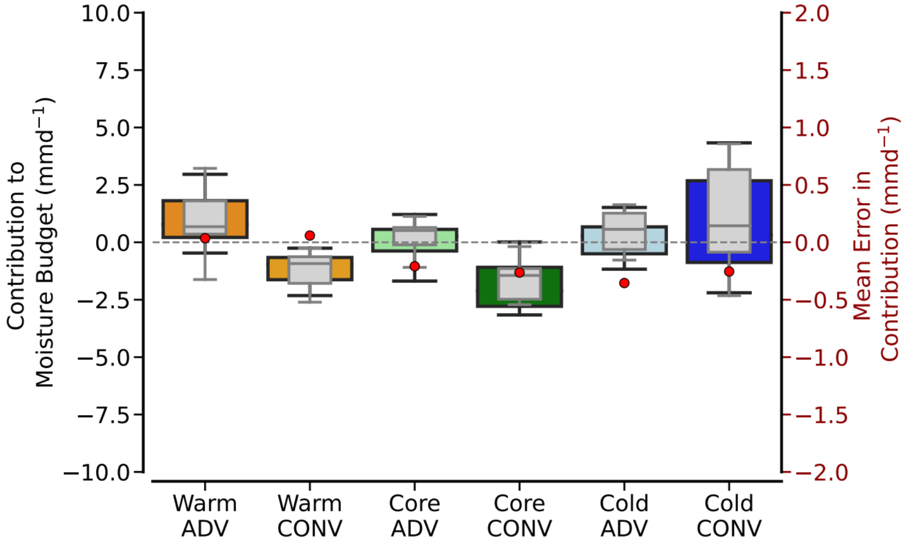

Figure 13: Box plot of moisture transport divergence contributions to daily moisture budget for all nine ARs specifies both components (ADV, CONV) in each frontal AR sector. The continuous AR representation (coloured box-whiskers) is compared to sonde-based values (grey box-whiskers). Boxes refer to quartiles and horizontal lines specify the respective mean.

Changes to preprint results:

- Smaller magnitudes in moisture budget contributions than before
- Less frontal gradient, meaning less positive contribution in the pre-frontal sector and less negative contribution in the post-frontal sector
- Mass convergence does not exhibit a clear gradient along the front. In particular, the post-frontal sector now shows the strongest mass convergence against all the other sectors (before divergent).

We will update the text in Sect. 5.2, accordingly. To account for the findings of related work in a more concise way, we will separate the paragraphs that describe our results from the respective discussions referring to mid-latitude statistics given in Guan et al. 2020. Surprising findings, such as the mass divergence in the core are carved out.

Section 4 specific minor comments:

L333ff (What is the "simplified understanding of divergence"?, "benchmarks…"?)

Response: We merge both expressions in a connected sentence as: "The comparison of *TIVT* in both legs reveals first simplified benchmarks of the prevailing divergence. Idealizing that no entrainment into the AR corridor (Sect. 3) takes place, Figure 11 contrasts TIVT of in- and outflow cross-section to estimate whether convergence or divergence of moisture transport exists inside the AR corridor.

L358 ("behave differently"):

Response: formulation rephrased to: "*ADV* and *CONV* exhibit different vertical profiles throughout the frontal cross-section"

L360 ("lower atmosphere")

Response: changed to lower troposphere

L364f ("integrate along the vertical axis")

Response: The respective sentence will be removed because not valid for updated results

L373ff unclear

Response: We will reformulate the sentences to: "When we place our sonde results in the context of the airborne study by Norris et al. (2020) using real dropsondes, we recognize the strength of true sondes with a high vertical resolution, which provides much greater vertical variability. Thus, the quite low divergence displayed in Fig. 11 is likely not only due to less divergence prevailing in Arctic ARs compared to mid-latitude ARs, but may also result from the coarser vertical grid that average out larger values."

L392 ("our arctic AR composition"?)

Response: changed to: "for our sample of arctic ARs"

Section 5: Deterioration by non-instantaneous sounding

Like in Section 4, the divergence results for the instantaneous perspective have changed, causing modified figures. Both figures are displayed here equivalently.

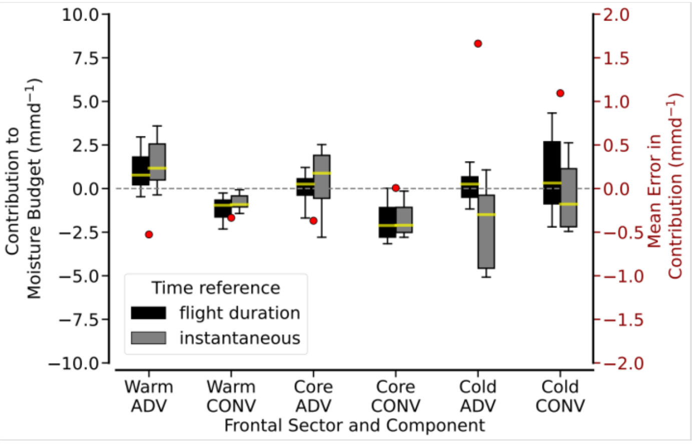

Figure 1: Comparison of divergence component contributions to daily moisture budget from the continuous AR representation referring either on the time-propagating flight values or when using the values for the centered hour. Values are given for each frontal sector. Black error bars are identical to the coloured boxes in Fig. 2 (13 in manuscript). Grey values represent the centered hour based values.

Changes to preprint results:

- Instantaneous whiskers follow the modified frontal tendencies (smaller magnitudes and weaker gradients along the front)
- Mean errors in contribution (red-dots are less affected) by updated divergence calculations the post-frontal sector
- Highest mean error in cold sector advection remains. Robust dry advection visible in instantaneous view on post-frontal sector

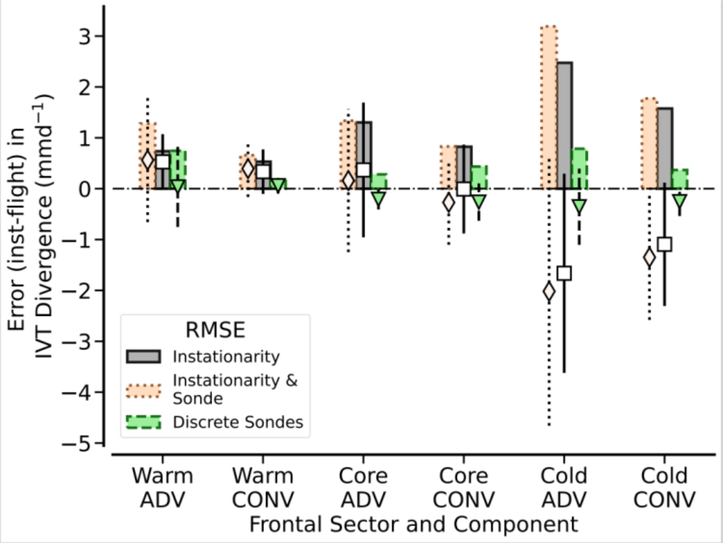

Figure 2: Total (orange) and individual errors only by discrete sondes (green) and only by instationarity (grey) for daily IVT divergence in each frontal sector and divergence component (Eq.). For all AR cross-sections, positive bars indicate the root-mean square error while error markers and lines depict mean errors in combination with their standard deviations.

Changes to preprint results:

- Minor changes in magnitudes
- Equivalent key messages: Non-instationarity counts more than sounding frequency for the sonde-based misrepresentation of moisture transport divergence

Section 5: Specific minor comments

L403f (unclear)

Response: changed to: **“**Within the AR corridor, the temporal AR evolution can distort the airborne representation of Eulerian IVT divergence.”

L485 (unclear)

Response: changed to: “Contrasting in- and outflow TIVT through the AR transects, we overall expect divergence in moisture transport.”

Section 6: Summary and Conclusions

[…] *should synopsize and synthesize the key results and identify the contribution to research on Arctic ARs. I think it will strongly profit from an improved discussion of the results.*
Response: In the following, we will list how we will improve our conclusions in terms of clarity in structure and the discussions of our key results. We refer to your more specific comments:
So far, the first paragraph is a repetition of what was done. The second paragraph claims that higher resolution reanalyzes increase our understanding of arctic moisture transformation and precipitation efficiency, which I don’t see is addressed.
Response: Our reason for the summary of our synthetic framework is to remind which perspective this feasibility study has chosen. We are confident, that such a repetition of the synthetic approach facilitates the readability in later discussions, as well as the interpretation of our conclusions. However, we admit that we listed to many details and will erase to detailed information (e.g. the regression method used).
In accordance with the remarks of reviewer 2, who suggests to put more emphasis on the general arctic AR conditions rather than airborne perspective, we will restructure our conclusions. First, we will synopsize the basic AR IVT characteristics in the Arctic we found

before specifying the airborne perspective. By that, we can also get rid of the second paragraph which lacks clear structure and key messages. Instead, we summarize our considered IVT magnitudes in the Arctic. This comprises IVT shape, AR widths, maximum IVT, how they differ to mid-latitude ARs and specify how CARRA outperforms the IVT variability compared to ERA5. By that, we aim to achieve a more logical order, when approaching the concrete perspective of our study (the observability of arctic AR IVT divergence by dropsondes). Here, we then find appropriate to repeat how the synthetic soundings were established to answers of our research questions.

The authors should try to better synthesize the central message of their results to each of the RQs in view of the gained knowledge. I suggest a separate discussion of how the obtained results may affect future flight planning and the deployment of dropsondes (Q1, Q4).

Response: We will update the central messages to our research questions and conduct a stronger connection to individual flight planning which is achieved by an improved structure. We will extend the specifications in our recommendations for future dedicated flight planning. We here give a suggestion on how we plan to modify the bullet points for Q1: “For the sonde-based determination of Total Integrated Water Vapour Transport (TIVT) in arctic AR cross-sections, sonde spacings below 100 km have to be envisioned to certainly keep TIVT errors below 10 % (Fig. 6). In strong ARs with IVT exceeding 500 kg $m^{-1}s^{-1}$, too coarse IVT representation at the AR core leads to TIVT underestimation. Gaussian fits help reproduce the cross-sectoral IVT shape but are sensitive to how sondes estimate maximum IVT and its location. Precedent flight planning should thus aim for a sonde release at forecasted IVT maximum and place the additional sondes symmetrically around. For the arctic AR widths of 400-800 km we found, we suggest a minimum of seven soundings per cross-section (roughly 60 to 120 km spacing) to derive TIVT in both cross-section legs. Not necessarily, larger AR width is associated with higher IVT variability, maximum IVT is more correlated to IVT variability causing TIVT errors. The planning of sonde releases should also rely on the steepness of IVT along the cross-section. Furthermore, we highlight that the meridional differences of TIVT between the in- and outflow cross-sections remains at 2-15% of the TIVT magnitude (Fig. 11). Therefore, estimates of moisture transport divergence using TIVT from both cross-sections only become robust, if the TIVT uncertainty for a single leg is considerably lower.”

We already gave some suggestions for future flight pattern in the preprint’s conclusion, but in a poor structure. We will improve the structure of our concluding implications on flight planning emerging out of the conclusions from Q1-Q4 as:“ Overall, we confirm the observability of moisture transport divergence in arctic AR corridors by releasing sondes in such dedicated flight patterns. A maximum sonde spacing of 100 km within the AR cross-section can principally characterise the divergence between both cross-sections at the given uncertainties of ≤ 10 %. For the duration needed to perform the flight pattern, we obtain the entire moisture transport divergence specified for the frontal sectors with an uncertainty lower than 25 %. For the frontal-sector investigation, we deduce that sonde undersampling matters and recommend a sequence of at least seven sondes per cross-section, given the widths of arctic ARs this represents a sonde spacing of maximum 100 km. Yet, notwithstanding that we could release a much higher number of sondes, it is the temporal AR evolution over flight duration that leads to higher deviations in divergence components rather than sonde undersampling. Thus, dedicated planning of such sonde-based observation purposes should not only involve dropsonde positioning but rather pursue minimizing the flight duration. The placement of the cross-section legs and their separation should carefully consider the AR displacement during flight. Lower meridional distances between the cross-sections do not only shorten the flight duration, they also reduce the area which is enclosed by the sondes. For the AR and frontal-sector widths found in the Arctic, the two cross-sections should not be more than 100-200 km apart. For several of our larger AR corridors, we have to expect substantial sub-grid scale variability in the flow parallel direction. Therefore, we postulate collocated flights by two aircraft where both cross-sections are not far apart and are sampled simultaneously as the optimum and still feasible strategy. When faced with a limited amount of dropsondes, supplementary measurements of moisture should be prioritized, as moisture represents the more varying quantity in our AR and moisture advection is mostly dominating the moisture transport divergence in the arctic AR corridor.”

After these implications we will add a description of the limitations of our study that covers several points mentioned in your remarks (vertical resolution of CARRA used, limits of regression approach) that needed to be discussed more thoroughly and we will mention specific suggestions for arctic AR follow-up studies using CARRA.

Finally, we summarize the necessity of assessing the sonde-based observability and of deriving uncertainties for model-observation intercomparison.