Dear Editor and Authors,

Please find attached my review of Franke et al. (manuscript number: 2025-5328) with manuscript title “Review article: 30 years of airborne radar surveys on the Antarctic and Greenland ice sheets bythe Alfred Wegener Institute”.

This review paper and its associated data release is a great achievement for the polar radar community, and for AWI specifically who have done a lot of work to make 30 years of radar data across both the Arctic and Antarctica available to the wider scientific community. The data is fully available in open-access format, follows FAIR data principles, and is efficiently accessible through the new Radar Data over Polar Ice Sheets data viewer. Of equal importance, this review paper is very well written, the figures and tables are clear, and the text forms a great resource for current and future scientists wishing to interact with the AWI data and the science that came from it.

Together, there are now three large data providers (CRESIS, BAS and now AWI) that have released most of their aerogeophysical data over Antarctica and the Arctic in freely accessible formats. The repercussions that these data releases have on polar science cannot be understated, and I look forward to seeing other institutes follow through in future years with their own data release.

I have several minor comments regarding the text, figures or tables, but as a whole, I would recommend this paper to be published in The Cryosphere with minor revision. I very much look forward to seeing the updated version soon online.

With best wishes,

Julien Bodart

Dear Julien,
thank you a lot for your time and your very helpful, constructive and supportive review. Your ideas and comments clearly improved the manuscript and you will find all responses to your comments below.

General comments

– **Abstract:** I think it would be useful to give some general statistics of data coverage for the Arctic and Antarctica in the abstract. For example, line km, or area covered, etc (see Line 320 for similar statistics, although these could also be provided in % or other units so that it is easy to assess the footprint of the AWI data compared with other institutes across Antarctica). This will help the reader appreciate the importance of the accompanying data release.

We added the following sentence in the abstract:
"Over the past three decades, AWI has collected more than 1.6 million profile-kilometers of radar data, covering approximately one quarter of the Antarctic and the Greenland Ice Sheet, respectively."

− Wider geophysical data: I find it interesting that the authors mention seldomly gravity and magnetics, or onboard LIDAR (briefly mentioned in Lines 335-336 or Section 5.7, or the Conclusion). Could the authors expand here on why the paper (and the accompanying data release) focus mainly on radar data and not on the full suite of geophysical instruments that were potentially onboard during radar data acquisition? This is of interest to the wider geophysical community and a few words at the start of the paper as to why the authors decided to focus mainly on radar would maybe be useful. Along similar lines, is there plans to release this wider geophysical data (i.e., magnetics or gravity) in the future? Section 8 mentions laser scanner and orthophotos, but no mentions of magnetics or gravity.

The processing of AWI radar data over the past years has been extensive and complex due to the six different radar systems (plus the three different acquisition systems over the years for the EMR system alone) used in the Arctic and Antarctica. In our review, we aim to explain all these systems in detail, and including additional geophysical data might exceed the scope of this work. This does not mean that a simultaneous description and publication of all geophysical data would not be meaningful. It certainly would be and is definitely of wider interest to the geophysical community.

Another point is that the processing of gravity and magnetic data is at a different stage compared to the radar data. Our priority was to make the radar data available to the public as quickly as possible in a standardized and FAIR format.

In the last paragraph of the introduction, we've added the following sentence:
"Although AWI performed additional geophysical surveys (e.g., gravimetry and magnetics), this review is dedicated solely to radar systems and their data."
to make clear at the start of the paper that other geophysical data exists, but is not part of this review.

Furthermore, in Section 8, we added the aspect of gravimetric and magnetic data to be integrated in the radar viewer and to be released in the future:
"Furthermore, the integration and publication of additional data from other acquisition systems collected in parallel to radar data collection is being pursued, such as gravimetric and magnetic measurements. AWI's Antarctic magnetic data are available in the ADMAP (A Digital Magnetic Anomaly Map of the Antarctic) compilation (Golynsky et al., 2018) and similar compilations exist for Greenland (e.g., the Greenland Magnetic Map; GREENMAG; Heincke et al., 2025). Moreover, it is anticipated to incorporate airborne laser scanner data to derive surface topography and reflectivity, as well as orthophotos from various nadir-looking optical camera systems like the Modular Airborne Camera System."

Line-by-line comments:

− Line 8: “To support scientific progress, [...]” – it would maybe be more impactful to say, “As part of this paper, and to support scientific progress, [...]” – this also reflects the point made on Lines 40-41 of the Introduction.

Done.

− Line 10: add “data” between “FAIR” and “principles”. Also perhaps worth stating what FAIR stands for in the abstract. You could also reference the Wilkinson et al. 2016 paper (https://doi.org/10.1038/sdata.2016.18) for the FAIR data principles.

Added “data” and the FAIR abbreviation in the abstract. The reference Wilkinson et al, (2016), was added in the main text.

− Lines 24-25: Group the references by theme (e.g.: “ice thickness (Robin et al., 1969, Steinhage et al., 2001)”, ice stratigraphy (Bingham et al., 2015; Winter et al., 2019; Bodart et al., 2021), etc.). Right now, it looks like the references are attached to “COF”.

Done.

− Line 33: “ice sheets”

“ice sheet” is here referring to the Greenland Ice Sheet and therefore plural is not needed.

− Line 48: “polar aircrafts”

We believe that the plural of aircraft is aircraft. However, we corrected the typo “Polar”.

− Line 94: add again “respectively” to specify which resolution applies to which pulse mode.

We agree and modified the sentence to tie the range resolution with the pulse length.

− Section 3: is there a specific logic to the ordering of the radar systems in Table 1 and in the sub-sections under Section 3? Would it not make more sense to group these sub-sections by radar type (e.g., EMR, followed by UWB MCoRDS), and then group the snow and accu radars next to each other? I can't see in the text a clearly defined reason that is given for sorting the radar systems in this way, aside from the fact that this is how they are grouped in Table 1. One could argue that they could be ordered by type (as I mentioned here), or perhaps a new sub-section ordering system, consisting of "shallow" vs "deep ice" radars could be used, though admittedly this might complicate things as some radars send a shallow and deeper pulse. I note that this suggestion seems to be similar to the way that Figures 4 (snow radars), 5 (shallow radars) and 6 (deep radars) are organised, so perhaps there's room for improving the order of the sections here. I leave it up to the authors, but perhaps also making this ordering system clear in the first paragraph of Section 3 would help guide the reader, and sticking with it throughout when mentioning the radar systems. Additionally, I'd modify Figure 8 which doesn't seem to match the ordering of the radar systems from Section 3 or Table 1.

Yes, there was a rationale behind the arrangement of the radar systems in Section 3 and Table 1. However, the reviewer is entirely correct in pointing out that this logic was not explicitly addressed and was not consistently applied in the later figures.

The systems are initially sorted by manufacturer and their chronological appearance. We argue that it makes sense to first present the instruments developed by TU Hamburg-Harburg (EMR, ACCU, SNOW), as these were most frequently used together during the early period. The ASIRAS, as an ESA radar, stands somewhat apart, while the older radar systems are succeeded by the newer generation (UWB/M) from CReSIS.

Sorting by resolution, as suggested by the reviewer, would indeed be a valid alternative. However, we propose retaining the current order and clarifying this rationale at the beginning of Section 3. Here, we added the following sentence:

"We sort the radar systems by manufacturer and their chronological appearance over the past thirty years. We start with the EMR, ACCU, and SNOW systems developed at the Technical University Hamburg-Harburg, then move on to the ASIRAS system developed by the European Space Agency (ESA), and finally introduce the newer generation of AWI radar systems (UWB and UWBM) developed by the Center for Remote Sensing of Integrated System (CReSIS)."

Additionally, we have adjusted the order of radar systems in Figures 8 and 9.

− Table 1 caption: CRESIS abbreviation is already mentioned in caption of Figure 1.

Done.

− Line 175: FAIR is still not described in the paper until this point. I'd suggest stating what the abbreviation stands for in both the abstract and here where it is first used.

Done.

− Line 183: "where other radar systems of AWI were also used" – it would be useful to show a table of where and when multiple systems were used together. For example, EMR + ASIRAS as you mention in Line 183. I'm thinking of a simplified version of Table 1 of Frémand, Bodart et al., 2023; ESSD. This is somewhat similar to Figure 8 or Table A2 (which are really useful), but it would help the reader know quickly and efficiently the specific field seasons in which multiple systems were used together. For example, on Line 339, you mention that gravity instruments were used alongside the EMR system since 2022 and then UWB+gravity later. A short table describing this, which would complement Figure 8, would in my opinion be useful in the paper.

This is a good point, and we are happy to adopt the suggestion. We have added two new tables to the Appendix (Tables A3 and A4), listing the Antarctic and Arctic field seasons and geophysical instruments. These tables specify which radar systems were used in each season, as well as the deployment of the laser scanner, magnetometer, and gravimeter. We refer to these tables in Section 8 were we point out the future pathway on publishing laserscanner, magnetic and gravimetric data.

− Lines 203-205: "The position and orientation of the aircraft is determined by four NovAtel DL-V3 GPS receivers, which sample at 20 Hz. The GPS system operates with dual-frequency tracking so that the position accuracy can be enhanced during post-processing." – is this the best place to have this information? Wouldn't it be more useful to place this in Section 2 where you describe the aircrafts (you could for example highlight the different types of GPS systems used for data georeferencing throughout the last 30 years)? Otherwise, you might need to describe the specific type of GPS that is used to georeferenced the geophysical data for each system under Section 3 (i.e., this point can be made for Line 270 where you mention "on-board" GPS without specifying the type of GPS used).

Good point. We moved the respective sentence to Section 2. We specified in Line 270 that we refer to the NovAtel DL-V3 GPS data. We believe that this sentence mentioning the GPS is correct here as it describes the necessity of using the GPS data for the motion compensation, which is a relevant processing step for the UWBM data.

− Line 222: You could reference Arenas-Pingarrón et al., 2023 (https://doi.org/10.1049/rsn2.12428).

Done.

− Line 253: Reference Matsuoka et al. 2025 pre-print (in review at Reviews of Geophysics; https://doi.org/10.22541/essoar.175241971.19851046/v1) instead.

Good idea. Done.

− Line 285: fix "(?)"

Thank you for spotting this. Fixed.

− Line 302: "layer picking" – maybe replace layer with reflector, as it could mean the surface or bed too, presumably? If you insist on "layer" to mean isochrones, then maybe be more specific and add "englacial" or go straight for "IRHs"

We changed it to "reflection picking".

− Figure 7: "Geo-Software": could you be more specific? Is this accessible to the wider public (i.e., SEGY data)? This is not mentioned in the text as far as I can see but it would be good to know that this data is available to users (this is at least what I understand from this Figure)

With this illustration we mean that radar data in segy format, radar data metadata (e.g., twt, sample interval, and coordinates) serve as input for AWI-internal commercial geo software where we do the layer tracing. However, we acknowledge that the SEGY format is also readable with open-source software. The SEGY data is not accessible via Pangaea to the wider public but can be obtained via request.

In the figure we added that this is "AWI-internal" commercial geo software.

− Sub-section 4.2: what about the bed reflector? It's definitely worth mentioning here.

We added Section 4.3:

4.3 Ice base reflection determination

The picks of the ice base are provided for several radar data products and was traced using different criteria. For all UWB products with a vertical resolution of 5 m or better, the base reflection was predominantly picked at the local maximum of the base reflection. For the EMR products, which has a range resolution of ~ 5 – 50 m, the pick was made at the steepest part of the gradient to the local maximum, as the basal reflection return is very broad for this radar product.

Ice base picks are not consistently provided for all radar data sets. Current and future efforts are being made to revise the ice base picks and ice thickness archive from AWI radar measurements. In the future, each dataset on Pangaea and in the Radar Viewer will include a link to the corresponding curated ice base pick and ice thickness dataset.

− Figure 8-9 (and anywhere else): Again, I wouldn't repeat the abbreviations again (i.e., EMR). I like 8h and 9g, this is really useful information.

Done.

− Line 329: make "In Greenland, [...]" a separate paragraph to improve readability.

Done.

− Line 336: "which, however," – a bit awkward grammar.

We rephrased the sentence.

− Line 336-346: could the authors expand on why EMR is still in use today? I have been thinking about this for a while now, and find the reason given here (i.e., "for glaciological objectives and projects.") rather vague. This is for personal interest, but it might be of interest of the wider non-AWI community to know why EMR is still in use today and what guides AWI to still maintain it if, as the authors suggest, the "improved configuration and processing capabilities of the UWB system provide better range and along-track resolution of the bed topography"

We rephrased the sentence in a way that the EMR radar was replaced by the UWB radar for **most** glaciological objectives and projects. Moreover, we explain now in more detail why the EMR is still in use today:

"For aerogeophysical surveys, the simpler and lighter EMR system remains a standard system for combination with gravity and magnetic sensors due to its generally reduced weight and thus greater range. Additionally, for logistical reasons, it can be advantageous to use the EMR when the UWB system is currently in use in the Arctic or not operational."

− Lines 359-368: would this be more appropriate in Section 5.6?

Good point. We decided to keep the parts about subglacial water that are directly linked to statements about basal properties, but to remove the last two sentences. The work of Humbert et al. (2018) is already part of Section 5.6.

− Line 375: I like this introductory sentence, and feel this is currently missing in Section 5.1 (which is historically why we have been acquiring radar data in Antarctica and Greenland)

Good idea. We added: *"The initial historic reason for surveying the polar ice sheets with radar was to map the bed topography beneath the ice."* as an introductory sentence for Section 5.1.

− Line 377: add reference to Bingham et al., 2025 here too.

Done.

− Line 384: "which had a final length of 2774.15m (Wilhelms et al., 2014)." – this is a bit out of the blue information – I'd recommend removing it

Removed.

− Section 5.3: you could also include Karlsson et al. (2018) here as its main focus was on using the airborne radar data to assess oldest ice. You could also add Young et al. 2017 (https://doi.org/10.5194/tc-11-1897-2017) and to another extent either in this section or another Van Liefferinge et al. (2018; https://doi.org/10.5194/tc-12-2773-2018), who use AWI data. It might be worth doing one more pass through the reference list to see if you haven't forgotten any paper that use AWI data as a significant data source in their findings.

Thanks a lot for pointing this out. This was a complete oversight on our part to neglect these references. We added an additional paragraph in Section 5.3:

"Moreover, AWI radar data were crucial in identifying promising sites for 1.5-million-year-old ice in Antarctica. AWI's surveys in the Dome Fuji region (2014/15 and 2016/17) revealed detailed subglacial topography, which refined thermokinematic models to predict frozen basal ice locations (Karlsson et al., 2018). In the Dome C region, AWI radar data, combined with other datasets, identified areas with low basal roughness and minimal subglacial water, which are key for preserving ancient ice (Young et al., 2017). These data were integrated with thermodynamic modeling to constrain geothermal heat flux thresholds, pinpointing Dome Fuji and Dome C as ideal candidates for retrieving old ice cores (Liefferinge et al., 2018)."

− Line 398: "global bipolar" after "typically" implies to me like it's the case for most IRHs. I would rephrase this sentence as many IRHs are also caused by local (or at least non bipolar/global) sources.

Good point. We added the sentence:
"However, a wide range of internal reflection horizons (IRHs) can also originate from local or non-bipolar volcanic eruptions."

− Lines 449-450: Should these two examples be moved to Section 5.8: Ice shelf bathymetry and stability?

Good point. It is not fully clear to us which of the four references in lines 449-550 the reviewer is referring to. However, we see the thematic overlap of these references with Section 5.8. Considering that all four references do also appear in Section 5.8, we'd argue that they are already part of this section. Therefore, we decided to keep the references in lines 449-450.

− Figure 11: you could add the new coverage from Bodart et al., 2026 (TC, in review, https://doi.org/10.5194/egusphere-2025-5381) to Figure 11c over Dronning Maud Land.

Good point. We've added the coverage of IRHs from Bodart et al. 2026 for Dronning Maud Land.

− Figure 12 caption and Lines 466-467: is it worth pointing the reader to papers which discuss these phenomenon in radar data (I'm thinking of Culberg et al., 2021 https://doi.org/10.1038/s41467-021-22656-5, for example)

Good point. We cited Culberg et al. (2021) in the corresponding lines but not in the caption of Figure 12.

− Line 519 and 531-534: I think these sentences need referencing, even if it seems like they come from the references in the sentence preceding them.

Done for L531-534. The sentence in Line 519 refers back to the sentences before. To make the statement clearer we cut the comparison to Japan and cite Ruppel et al. (2018).

− Line 548: add "estimates" after SMB

Done.

− Line 575: You can also add the in-review paper from Bodart et al. 2026 (link above)

Done.

− Line 585: replace “up to the entire ice sheet” to “continental-scale” or similar

Done, but replaced with “up to continental-scale”.

− Line 593: You could reference Bodart et al. 2026 here too

Done.

− Line 601: “how reliable conclusions are only possible” – improve grammar here

Done. Rephrased to:

“The study also emphasized that reliable conclusions can only be drawn when ice thickness is accurately resolved, as shown by contrasting simulations of two adjacent outlet glaciers, only one of which had dense radar profile coverage.”

− Line 664: add “directly from our data portal” after “[...] for download [...]” to specify that the data still is downloadable, but from BAS and CRESIS portals instead.

Very good point and changed accordingly.

− Table A2: At times in the paper, AWI coverage in the northern hemisphere is either called “Greenland” or Arctic. In the caption of Table A2, you mention “Arctic (Greenland and Canada)”. It might be worth finding a way early in the manuscript to refer to this region and stick with it throughout.

This is not straightforward, as flights in the Northern Hemisphere typically refer to surveys over Greenland, though a small number were conducted in the Canadian Arctic. However, it would also be misleading to use the term "Arctic" broadly, as it implies a much larger geographic area. To address this, we have now clarified at the beginning of Section 5 as follows:

"The vast majority of flights were conducted over the Antarctic and Greenland ice sheets, but individual ice caps and glaciers in both Greenland and the Canadian Arctic were also surveyed."

− Section 7.2 (or 7.1.2): I think it might be useful to add a Table (perhaps in the SI) that lists the variables present in the netCFD files for the radar data (see Table 4 of Frémand, Bodart et al., 2023; ESSD as an example). This would be really useful for users who might not be

familiar with the structure of AWI radar data (e.g., you often include the AGC data product in the files, without really explaining what this is except for a brief mention in Section 7.1.2). I know the netCDF files have metadata, but still, I think this has its place somewhere in the paper particularly for future users of your data

Done.