

The historical Greenland Climate Network (GC-Net) curated and augmented Level 1 dataset:

Authors' response to reviewers

Baptiste Vandecrux et al.

Table of Contents

Reply to Reviewer 1:	1
Reply to Reviewer 2:	3
Reply to Reviewer 3:	9

Reply to Reviewer 1:

In the following, the reviewer's comments are indented text and **our response is shown in *bold italic text***.

General

This paper describes a quality upgrade and leap in the accessibility of the (now historical) GC-Net automatic weather station (AWS) network on the Greenland ice sheet, initiated by the late dr Steffen. The authors have done the climate research community a great service with this effort. At the same time, they have done a commendable job in offering a very readable paper on how the data were collected and treated. The figures are of very good quality as is the readability of the text. I only have some textual comments below.

Thank you for the positive feedback. We address the individual comments below.

Minor and textual comments

1. 164: what is "10m" standing for here, a 10 m tower?

We replaced "The Swiss Camp 10m AWS..." by "The Swiss Camp 10 m meteorological tower..."

1. 197: " These two AWS aimed at documenting the ice-ocean interaction at Petermann Glacier " This sounds funny, AWS that document sub-shelf processes.

We rephrased "These two AWS aimed at documenting the ice-ocean interaction at Petermann Glacier" to "These two AWS provided surface climate data needed for the study of the ice-ocean interaction at Petermann Glacier"

1. 246: "While attention was made" please reformulate

We rephrased to “While efforts were made to keep the instrumentation consistent”

1. 249: " more inconsistent " -> less consistent

Updated, thanks.

1. 257: " corrected from the effect of air temperature " -> are corrected for the effect of varying air temperature

This sentence was rephrased to address a comment from Review 2:

“In the L1 dataset, these measurements are corrected for the effect of air temperature on the speed of sound according to the SR50 user manual (Campbell Scientific, 2007).”

1. 271: " unless only transmitted data are available" Is this flagged in the dataset?

We suspect that transmitted data may have been used for the generation of the pre-processed files that we use for the period 1990-2009. In those pre-processed files, there is unfortunately no flag indicating the origin of the data. We expect these instances (where only transmitted data is available) to be minor. From the introduction of CR1000 data loggers (from ~2009), all logger files could be recovered and no gap-filling with transmitted data was necessary.

1. 325: " and on the comparison with the RACMO regional climate model " Interesting. Was pressure used?

Yes, with extra checks using air temperature. We rephrase to “... and on the comparison of the measured air pressure and temperature with values from the RACMO regional climate model”

1. 393: " performed linearly" It is well known that wind profiles are far from linear, would it not have been preferable to use flux-profile relation or a simple logarithmic wind profile assumption?

We now use a logarithmic profile for the extrapolation of wind speeds to 10 m. We also use a theoretical log-profile of wind with roughness length of 0.01 m to extrapolate winds at 10 m when only a single measurement is available.

1. 437: What is "GITS"?

We replaced by “the GITS AWS”

Tables 3 and 4: Decimal zeroes are missing

They are now added. Thanks.

Reply to Reviewer 2:

We would like to thank the reviewer for taking the time to comment on our manuscript. In the following, the reviewer's comments are reproduced as indented text and our response is shown in ***bold, italic text***.

General comments:

This data paper introduces the historical Greenland Climate Network (GC-Net) automated weather station (AWS) data post-processed by the Geological Survey of Denmark and Greenland (GEUS). The AWSs are in the Greenland ice sheet, which is a difficult place to access and perform long-term detailed meteorological/glaciological measurements in general. Originally, the GC-Net AWSs have been developed and maintained by research groups in Switzerland and the U.S.; however, it is now with GEUS. This reviewer would like to express my respect to the authors' great efforts to continue the measurements for several decades.

In recent 20 ~ 30 years, the Greenland ice sheet has experienced drastic snow/ice mass losses, which induce significant global sea level rise. During the period, some AWSs of GC-Net have been operated almost continuously, which allows us to assess in-situ measured climatic changes on the rapidly changing ice sheet. Therefore, the GC-Net AWS data are of great value.

Overall, this reviewer finds that this data paper describes necessary and sufficient information of the AWS data, and it is easy to follow. Also, this reviewer does not find any major issues in not only the manuscript but also the data, therefore provides only minor/technical comments.

Thank you for the positive feedback. We address the individual comments below.

Specific comments (minor)

L. 61 ~ 62: "Ice sheet meteorology began with ~": Is the word "Ice Sheet meteorology" a technical word widely used in the research community? I know a similar technical word "polar meteorology"; however, "Ice Sheet meteorology" is new to me. In addition, I think a reference is needed for this sentence.

We rephrased to "The study of the Greenland ice sheet's meteorology began ..."

L. 127 ~ 128: It is a bit difficult for readers to recognize which AWS are in the accumulation/ablation areas or ELA. Using different colors in Fig 1a to indicate the positions of AWSs in the accumulation area, AWSs in the ablation area, and AWSs in ELA might be useful for readers. In addition, adding a column in Table 1 to indicate the characteristics of the surface condition (accumulation area or ablation area or ELA) might also be helpful for readers.

Thank you for your suggestion. We updated Figure 1 and Table 1 to indicate ablation and accumulation sites.

L. 220 ~ 221: At this stage, readers cannot understand what the authors mean by “TA3” and “TA4”. In particular, the differences between TA1 and TA3, as well as TA2 and TA4 are unclear.

We removed the mention of TA3 and TA4 and just focus on the variables with “1” or “2”:

“In the L1 dataset, the variables labeled with “1” (e.g. TA1) were measured or derived from the lower level.

The variables labeled with “2” (e.g. TA2) were measured or derived from the upper level.”

Later, in the instrumentation section 3.2., we introduce TA3 and TA4:

“The primary air temperature measurement was done by a Type-E thermocouple (variables TA1 and TA2 in the L1 dataset). Secondary air temperature readings were done by CS500 thermometers (variable TA3 for the lower level and TA4 for the upper level in the L1 dataset) but these sensors did not accurately measure temperatures below -40°C.”

L. 257 ~ 258: Regarding the effect of air temperature on the SR50 measurements, more detailed explanations here are useful for readers.

We gave further details by adding that this correction addresses the dependency of the speed of sound on the air temperature and now refer directly to the user manual (Campbell Scientific, 2007) instead of a scientific study:

“In the L1 dataset, these measurements are corrected for the effect of air temperature on the speed of sound according to the SR50 user manual (Campbell Scientific, 2007).”

We here mention this correction so that the data user knows that there is a dependency between the SR50 measurements and the air temperature. The actual equation of the correction is not needed in the text since it is the one specified in the manual.

Campbell Scientific: SR50 Sonic Ranging Sensor, Instruction Manual,

<https://s.campbellsci.com/documents/au/manuals/sr50.pdf>, last access February 28 2023, 2007.

Figure 4: Some obvious spikes are depicted in this figure (e.g., around 2008). Are they OK data for the authors?

Another round of quality checks was conducted and the spikes have been removed.

L. 374 ~ 376: Please explain more in detail about the effect of wind on the net radiation measurements. I believe such information are useful/interesting for readers.

We added details about this effect:

“The observations from both REBS Q7.1 and Kipp & Zonen NR-Lite instruments are affected by the wind-driven, convective cooling of the instrument and are consequently corrected as specified by the manufacturers (Campbell Scientific, 1996; Kipp & Zonen, n.d.).”

Just like for the SR50, we here highlight the dependency between the net radiation and wind speed measurements. We consider that the exact form of the correction does not need to be spelled out because it is specified in the user manual.

Figure 5: Also in this figure, some obvious spikes can be found at e.g., CP2, NASA-U, GITS, Humboldt, DYE-2, NASA-SE, and NGRIP. Are they OK for the authors?

Another round of quality checks was conducted and the spikes have been removed.

L. 383: “data from the GC-Net AWS”: Can be removed as the solar information are important for any in-situ radiation measurement data.

Rephrased to: “... are key variables when using any in-situ irradiance measurement.”

Table 3: Is it the list for derived 2 m air temperature? Or the data at single measured levels? Please clarify in the caption.

We added this information to the caption:

“Table 3. Seasonal average near surface air temperature. The interpolated 2 m air temperature is used when the two levels are available, otherwise a single measurement level is used.”

Figure 9: It is better to denote in the figure or caption which stations are with the interpolated 2 m air temperature or air temperature at a single measurement level. At Petermann ELA, why are the data depicted in a limited period? An explanation in the caption might be useful.

Whether the temperature could be interpolated at 2 m or not varies not only from station to station but also from year to year and month to month. E.g. in winter, low temperatures lead to more frequent malfunction of one of the sensors and making interpolation impossible. Considering the high year-to-year variability in temperatures, we considered that the addition of more years of data (including data not interpolated at 2 m) was more beneficial for the construction of these climatologies, than using only 2 m interpolated data. We updated the caption and the figure to reflect that, at Petermann ELA, winter observations are only available for two years and that we calculate climatological values only when more than five years of data are available for a given day of the year. Figure 9 and 10 and their captions were updated accordingly. E.g.: "Figure 9: Climatology of daily near-surface air temperatures. The interpolated 2 m air temperature is used

when the two levels are available, otherwise a single measurement level is used. Climatological values are calculated when at least values for five years are available."

L. 471: It seems to me that "the SWC, NAE, NAU, NEM AWS installed by GEUS within 500 m of the GC-Net stations." are not introduced before in this manuscript.

We added a reference to a GEUS news article explaining the installation of these new stations (GEUS, 2020) as well as a reference to the dataset from which these data come from (How et. al., 2022a). The stations, their locations and their instrumentation is fully documented in that dataset's metadata. A scientific publication presenting the future of GC-Net under GEUS lead is under development.

GEUS: GEUS takes over American climate stations on the Greenland ice sheet,

<https://eng.geus.dk/about/news/news-archive/2020/december/geus-takes-over-american-climate-stations-on-the-greenland-ice-sheet>, last access 1 August 2023, 2020

How, P., Abermann, J., Ahlstrøm, A.P., Andersen, S.B., Box, J. E., Citterio, M., Colgan, W.T., Fausto, R.S., Karlsson, N.B., Jakobsen, J., Langley, K., Larsen, S.H., Mankoff, K.D., Pedersen, A.Ø., Rutishauser, A., Shield, C.L., Solgaard, A.M., van As, D., Vandecrux, B., Wright, P.J.: PROMICE and GC-Net automated weather station data in Greenland, <https://doi.org/10.22008/FK2/IW73UU>, GEUS Dataverse, V8, 2022a.

Technical corrections

L. 57: Suggest adding "in-situ" before "measurement of ice sheet surface climate variables".

Updated. Thank you.

L. 57: "to improving" -> "to improve"

Updated. Thank you.

L. 61: Suggest adding "surface" before "meteorological observation on the Greenland Ice Sheet".

We rephrased to "The study of the Greenland ice sheet's meteorology began..."

L. 93: Please consider rephrasing "Japanese Meteorological Institute" -> "Meteorological Research Institute (MRI), Japan Meteorological Agency". Then, please use the abbreviation "MRI" instead of "the Japanese Meteorological Institute" at L. 95.

Updated. Thank you.

L. 94: "2011" should be "2012".

Updated. Thank you.

L. 96: According to Matoba et al. (2015, cited in this paper), the altitude of the SIGMA-D site is 2100 m a.s.l. The altitude of the SIGMA-A site (1490 m) is OK.

Updated. Thank you.

L. 144: "WSL": Its definition is needed here.

Updated. Thank you.

Figure 1b: “ARGOES”: typo.

Updated to Argos. Thank you.

Table 1: An explanation for “wgs84” is needed in the table caption.

We moved this information to the caption: “... with coordinates (in the WGS84 reference system) and ...”

L. 196: “was installed the following year” -> “was installed in the following year”

Updated. Thank you.

L. 225 ~ 237: In this paragraph, it seems to me that some special characters are not displayed as intended: e.g., 4“ (10.16 cm), 3” (7.62 cm), and 0.25“ (0.635 cm).

Updated. Thank you.

Table 2: Please consider adding short names such as TA, RH, and SW for each measurement properties in this table.

Updated. Thank you.

L. 276 & L. 286: Usually, Fortran77 is not followed by “scripts” by “codes”.

Updated. Thank you.

L. 282: Is the CR1000 logger file a binary file? Or an ascii file? Please specify.

The CR1000 files are originally in binary format and converted to UTF-8 text files by the software interacting with the logger (LoggerNet or PC400). These details are considered non-crucial and can be found in the user manual of the CR1000 logger.

L. 298 ~ 299: “Calibration coefficients” for what? Please explain.

We rephrased to “we collect the available CR1000 logger files, apply the calibration coefficients to the radiation data and append them to the pre-CR1000, historical processed files”

Figure 3: Three colors are used in this flow-chart. It is better to explain in the caption what the authors want to indicate with these different colors here.

We added this information: “Figure 3. GC-Net data processing flow. Orange boxes indicate intermediate data products, green boxes indicate operations and the blue box is the final L1 data.”

L. 354 ~ 355: “T/RH” should be “TA/RH”?

Updated. Thank you.

L. 394: “T” should be “TA”?

Updated. Thank you.

L. 395: What do the authors mean by “VW”?

Now defined in Table 2.

L. 402: “While” -> “However”?

We rephrased to “Compaction of the firn between the sensors is not accounted for in the L1 dataset although Vandecrux et al. (2020) found that on the first year following the installation, firn compaction reduces the spacing by c. 15% near the surface and c. 3% down to 10 m depth.”.

L. 428: Is the ReadMe file an ascii format file? Please specify.

We now mention a "ReadMe text file". It is encoded in UTF-8 format and not ASCII. We do not consider that the file's encoding is relevant as it can be read by any text-manipulation software.

Reply to Reviewer 3:

We are grateful to reviewer 3 for taking the time to comment on our manuscript. In the following, the reviewer's comments are reproduced as indented text and our response is shown in **bold, italic text**.

Overall this is a good paper and has good history! This is important to publish this - and in honor of Koni Stefan and his work on the network. I was going to recommend ending the history section with a "here's where the network is at today" if only a statement, etc. Perhaps on/after line 115. But, I see section 1.3 is the present day...and the plan for the future for care...this is something to reconsider in the title of the section to make that clear to the reader: "The Greenland Climate Network (GC-Net) Present and Future" or something like this... ***Line 115 is still in the section "History of Weather Stations on the Greenland Ice Sheet". I do not think that it is the place for "the GC-Net network today". Section 1.3 is a subsection of the Introduction section and is meant as an introduction of the historical GC-Net project and its AWS network. It is only in the last paragraph of section 1.3, we describe the present (overlapping period with GEUS stations) and future (continuation with GEUS stations only) of GC-Net. We would like the heading of section 1.3 to reflect our focus on the historical GC-Net data and not on the present transfer and future continuation by GEUS.***

AWS data set in the Dataverse link is a proper data repository. This is excellent. The GitHub link is good for the code, but not a proper data repository (subtle, but important note). Also, the code is GNU GPL or "copyleft" licensed, so that imposes some restrictions on reuse, but perhaps that is by design. (?) ***The "copyleft" license implies that anybody can reuse our codes as long as they distribute their modified/combined codes under the same open-code principles. We mean it as an encouragement to open-code philosophy.***

Having some of the extremes from the network would be a nice touch, but understood if that could not be done in time for publication. There is no mention of record cold from Northern Hemisphere (Weidner et al, 2020; <https://www.doi.org/10.1002/qj.3901>) and this would be a nice element to denote yet another reason why to observe - the glaciology and meteorology - climate and weather - are all important from this portion of the world!

Extreme values are by nature difficult to handle because they are very close to unrealistic values and measurement errors. We do not know at this point if the dataset is ready for such use but that is certainly a possibility. We added a mention to the Weidner et al. (2020) study in our historical review of on-ice AWS: "One of these stations captured the coldest temperature ever recorded in the northern hemisphere (-69.6 °C) in December 1991 (Weidner et al., 2020)."

Specific comments:

Line 76-77: The University of Wisconsin-Madison network was installed longer than 5 years as noted in their data repository: <https://amrddata.ssec.wisc.edu/dataset?q=greenland>. Last data available is in 1998. Having something that states the UW-Madison was there from 1987 to 1998 would be ideal.

Thank you for spotting this. We updated to: “This weather station network lasted until 1998.”

(And listed as University of Wisconsin-Madison not use University of Wisconsin)

Updated. Thank you.

Error is Figure 1b - ARGOES should be ARGOS

Updated to Argos. Thank you.

For clarity - every AWS GC-Net has 10 levels of snow/firn temperature down to 10 meters at 1 meter levels? And the “smart stake” AWS do not??

Yes. We added this information to the Instrumentation section.

Line 128 - What is ELA stand for?? This is defined on line 450, but not here - it should be on first use

Updated, thank you.

Line 143-144 - “GEUS took forward the climate monitoring at the main...” is awkward phrasing.

Updated to “GEUS took over the climate monitoring”

Line 144 - Please spell out acronyms on first use, WSL, on this line

Updated, thank you.

Line 145 - Please add discussion on how GOES and Argos are also known at DCS or Data Collection System and GOES is a geostationary platform and Argos is on a series of polar orbiting satellites.

We added these information in section 3.2.: “Two data collection systems were used to transmit the GC-Net AWS data in near real-time. For sites south of 72°N, the National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellites (GOES) system was used. For sites north of 72°N, the Argos polar orbiting satellite system was used.”

Also please spell out GOES on first usage. (You have defined much later on in the paper) (Line 268)

We removed this early mention of GOES and Argos. So GOES is now defined at first use later in the text.

Line 199 - what does NEEM stand for? This should also be spelled out. There are other places throughout the document that need to have acronyms spelled out on first use (e.g. LINE 325 - RACMO; LINE 301 correction: CSV means: comma-separated values, Line 452 what is DOY (Day of year...))

Although NEEM is more of a name rather than an acronym, we added the full name of the project for completeness: North Greenland Eemian Ice Drilling project. DOY was replaced with “day of year” and CSV definition was updated. Thank you.

Line 245 - “While attention was made to keep the instrumentation consistent...” phrasing seems to be awkward phrasing, but not a sure it is critical.

We replaced by “efforts were made to...”.

Line 297 - “...until the time when CR1000 data loggers were introduced...” (Please include the “s” on logger)

Updated, thank you.

Figure 3 What are comprehensible CR1000 logger files???

We removed “comprehensible”.

Lines 392-394 - How are these corrections made? Is the actual values - unadjusted - available? I wasn't sure based on what I am reading here.... I'm especially concerned how wind is done...it cannot be done linearly...but logarithmically, else it will give a false sense of behavior...following boundary layer studies of wind behavior, etc. (e.g. see work by Lettau, Stull, etc.). Not clear on why did you have the 1.2 meter difference in the two levels.

We here describe new variables. The actual measurements are given in the data file (see table 2) and users can decide to use their own extrapolation technique if they wish. Indeed, the logarithmic profile for wind speed made more sense. We updated our processing and now provide more details on the inter/extrapolation of TA, RH and VW in the text:

“Air temperature, relative humidity and wind speed at standardized height: In addition to the measurements at the two levels, the air temperature, relative humidity and wind speed are also provided at 2, 2, and 10 m (variables TA2m, RH2m, VW10m). For TA2m, RH2m, the inter/extrapolation is done linearly from the two measurement levels. For VW10m, we first extrapolate to 10 m using a logarithmic fit on the two measurement levels. If only one level is available or if the wind speed at the lower level is higher than at the upper level, the logarithmic fit cannot be used, we then estimate the 10 m wind speed using the upper-most available measurement and a theoretical logarithmic wind profile with a surface roughness length of 0.01 m (as used by K. Steffen in previous release of the GC-Net data).”.

The level spacing was probably a practical choice given the length of the mast sections.

Line 395: What is VW?

VW (standing for velocity of the wind) is defined in Table 2. The dataset also contains a LI_variables.csv file with the definition of all the variables.

Table 2 - Did I read this correctly that the pressure sample is every 60 minutes?? This doesn't match up with any of the other variables...10 minute or faster. This makes use of the data for real-time weather applications limited. And this doesn't meet World Meteorological Organization (WMO) standards of 10 minute or 2 minute data from an AWS (See WMO publications #8 and its appendix) However as this was a past climate network, so

this is moot. However, I do hope that next network will have data more frequently for pressure, if there will be any real-time applications.

I can confirm that for most of the years, the hourly pressure is in fact measured at the last minute of each hour. For information the next generation of GEUS AWS saves 10 min data and transmit both hourly averages and instantaneous values in line with WMO requirements.

Line 424 - CSV is at times capitalized and at times not (e.g. line 424 and other places in the manuscript). This should be corrected to be CSV capitalized.

CSV is now capitalized everywhere.

Figure 8 and Table 3 (for example) - Awkward to have figures and tables before they are referenced in the text (e.g. Figure 8 and table 3). This is editor and journal format issue in the end, and less so here in review...however it is unexpected for this reviewer expecting things to come after they are first referenced.

We will keep that in mind when the manuscript will be typeset.

Line 483 - Also see Genthon et al., <https://doi.org/10.1175/JTECH-D-11-00095.1> and Morino et al, <https://doi.org/10.1175/JTECH-D-21-0107.1>

We now mention those two studies.

Line 488 - "had insignificant control of downward irradiance on the temperature difference." perhaps substitute "correlation with"?

We rephrased to "... showed no significant correlation between temperature difference and downward irradiance"

Line 480-487 - How is ventilating the new AWS sites done with limited power??

The new GEUS AWS are equipped with Luft sensors which are aspirated. Power has indeed been an issue for the GEUS AWS at the coldest sites in the first winters. But scaling the number of batteries and keeping the ventilation time to the necessary minimum made it possible. The GEUS setup will be presented in a separate publication.

Table 4 - Is this really values giving mean errors and root mean square errors? Or just mean differences and root mean square differences. What makes the other AWS a standard or reference?

We now use "difference" instead of "error".

Line 513 - I am not sure of the snow profile set up - is there a "Reference Junction" that is installed in a CSI data logger when using thermocouples? The temperature is then determined at level X by the voltage difference between the two junctions? Or did you use a separate thermocouple to measure the box temperature and use that to measure each level an individual temperature? Hence, the 'noise' was the reference temperature junction not being stable for all levels' temperature measurements?

Indeed, we now give more details about this noise:

“The type-T thermocouples measuring snow and ice temperature are subject to noise (Cathles et al., 2007, Sampson, 2009). The cause is that thermocouples only measure the temperature difference between a given depth and a reference junction in the logger box and that this reference temperature appeared insufficiently stable, thereby affecting all measurements synchronously. This synchronous noise does not affect all sites equally and caution is recommended depending on the site and use of these snow and ice temperature data.”

On lines 74, 75, 755, and 818, Professor Charles R. Stearns name is misspelled, and it should be Stearns and not Steams.

This was corrected. Thank you.