WMO Evaluation of Northern Hemispheric Coldest Temperature: -69.6°C at Klinck Greenland, 22 December 1991

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ABSTRACT. A World Meteorological Organization (WMO) Extremes Evaluation Committee investigated an observation of -69.6°C by Klinck Automatic Weather Station (AWS) in Greenland on 22 December, 1991 as the lowest temperature observed in Greenland, thereby making it the lowest recorded near-surface air temperature for the Northern and Western Hemispheres and for WMO Region VI. The committee examined the metadata and observations of the station as well as the regional synoptic circulation. The committee concluded that the observation is credible in terms of instrument calibration, monitoring of the station and the synoptic situation. Consequently, the WMO Rapporteur accepted the observation as the officially lowest observed near-surface air temperature for Greenland, the Northern and Western Hemisphere and for WMO Region VI. As a supplement to this investigation, the committee also recommends that opportunities be investigated such that AWS data from Greenland can be efficiently incorporated into real-time weather forecasts and hence into reanalysis datasets.

1. Introduction

In 2007, the World Meteorological Organization (WMO)'s Commission for Climatology (CCl) established an online archive of officially recognized weather and climate extremes (e.g., highest recorded near surface global temperature, highest wind speed, most deadly tropical cyclone) (Cerveny, 2019). That WMO Archive of Weather and Climate Extremes (https://wmo.asu.edu/) maintains a listing of existing records and evaluates new extremes when they are brought to the attention of the WMO. In particular, many older historical records are now currently being reexamined as potential records. Some of these potential records were initially overlooked by their respective observing networks/organizations at the time of their original observation. In part, because of the existence of the WMO Archive of Weather and Climate Extremes, we are now able to investigate critically many of these older records and secure a better global record of not only current, but also historical, records of climate extremes.

Such is the case with the evaluation of a December 1991 temperature observation in Greenland. Recently, a climate record historian informed the WMO that his examination of Greenland temperatures indicated that the existing low-temperature extreme records for the Western Hemisphere and for WMO Region VI, a value of -66.1°C (-87°F) recorded at North Ice Greenland on 9 January, 1954, had been exceeded. His research suggested that an observation of -69.6°C (-93°F) at Klinck Automatic Weather Station (AWS) on 22 December 1991 would be the lowest temperature observed in Greenland, making it the lowest recorded temperature for the Northern and Western Hemispheres and for WMO Region VI. WMO Region VI corresponds primarily to the continent of Europe with political additions of Greenland and parts of the Middle East (e.g., Israel). All records in the WMO Archive of Weather and Climate Extremes are linked to the six corresponding WMO Regional Associations, or, in the case of the Antarctic, the region labeled informally in some units of the WMO as WMO Region 7.

Evaluations of new or existing records in the WMO Archive of Weather and Climate Extremes are conducted by WMO extremes evaluation committees employing available documentation using a set of standard queries (Cerveny 2019). These queries provide the initial, but not necessarily final, discussion points for a given committee:

(a) Is there need for more raw data or documentation on this event to determine its validity or invalidity? Are more data available? Do members of this committee know of other data or other analyses corresponding to this time/place temperature extreme event?

(b) Are there any concerns as to equipment, calibration, measurement procedures, or other processes/procedures associated with the measurement of the event?

(c) Are there any concerns associated with the nature of the event that would raise questions regarding the validity of the record?

(d) Are there any other concerns associated with this event that you think should be raised?

(e) Fundamentally, does the documentation support or refute this current world or regional weather record?

An initial WMO limited inquiry suggested validity assigned to the observation as a record extreme. Consequently, a full WMO international panel of atmospheric scientists was tasked with an analysis and verification of -69.6°C made by the Klinck AWS in Greenland on 22 December, 1991. As this evaluation touches upon a set of interesting concerns involving the use of automated stations and the incorporation of such data in reanalysis datasets, this evaluation's specifics contain important information for the scientific community, and for the public and media at large.

2. Background

The Klinck AWS was situated at 72.31°N, 40.48°W at an elevation of 3105 m, close to the topographic summit of the Greenland Ice Sheet, and was part of the Greenland AWS network that was established by the University of Wisconsin-Madison, USA to support ice-coring programmes in the region (Figure 1). The AWS transmitted data to the programme scientists via the Argos location and data collection system (Argos 2019). Although the calibrations and metadata of this observation were made nearly twenty-eight years ago, the committee found that the raw data and metadata were still intact and had been quality maintained by the station's original project scientists. The network was installed in three stages. The initial AWS named Cathy (all stations were named after programme personnel) was installed in May, 1987 near the proposed site of the Greenland Ice Sheet Project 2 (GISP2) drill site to provide basic meteorological data prior to station construction.

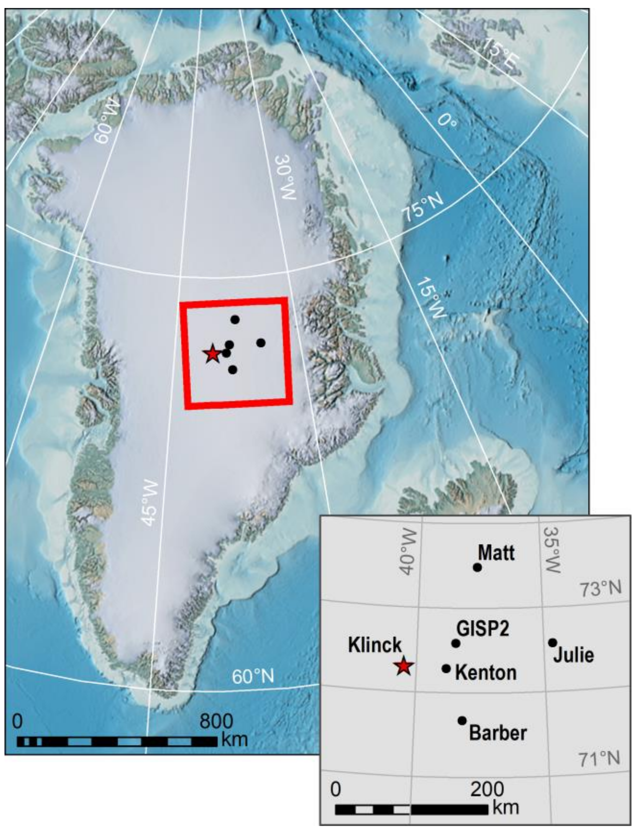

Figure 1. Locator map with shaded relief of Klinck AWS in Greenland at 72°18'N, 40°28'W, elevation 3,216 m (starred) with inset map showing Klinck's location in relation to other nearby stations mentioned in text (Matt, GISP2, Julie, Kenton and Barber).

In 1989, three stations were installed at the GISP2 and Greenland Ice Core Project (GRIP) drill sites along with the Fresh Air site named Kenton AWS with the Cathy AWS also being moved to that location. The GRIP AWS was deployed for only one year. These three AWSs formed a triangle with station separation of thirty kilometers, equivalent to the Clean Air sector at the South Pole, Antarctica.

In the third phase, another four AWSs were deployed from 1989 to 1991 with distances of 100 kilometers between these four AWSs and the GRIP drill site. This network included Klinck AWS, which was named after Jay Klinck who was the camp manager at Summit Station during the 1990s. The four AWSs were in the four cardinal directions from GISP2/Summit (Shuman et al. 2001). This initial array's purpose was to provide basic meteorological data for the Fresh Air sector experiments and establish a real-time record at the two drill sites. The intent was to establish a record of the actual air and snow temperatures for future ice coring. These station setups were for approximate four-meter tower height (at installation). Specified sensor heights are approximate since sensor placements are dependent on the depth to which the tower is placed below the snow surface and anchored. Additionally, the structure of the Rohn tower constrains placement of sensors by the tower lattice structure resulting in some deviation from specified sensor heights.

The Klinck AWS (Argos ID 8938) only recorded an air temperature at an initial height of ~ 3.5 m and a temperature difference using a two-junction thermocouple (delta-T) which had upper sensor junctions at the air temperature height and the lower sensor junctions on a 1 m horizontal bar. The initial deployment of Klinck AWS in August of 1990 resulted in a standard (at installation) ~ 3.5 m tower (see Figure 2B). As mentioned above, specified sensor heights are approximate due to depth of tower placement below the snow surface and the constraints of sensor placement.

WMO guidelines for measuring air temperature specify a height between 1.25 and 2.0 m (CIMO 2014). We determined the height of the air temperature sensor at the time of the observed low temperature as follows. The initial height of the lower delta-T sensor mounting bar was between 1.1 m and 1.2 m The air temperature sensor and lower delta-T junctions were 0.2 m below their mounting bars (initially ~3.3 m height and 0.9 m to 1.0 m respectively) The lower delta-T junctions appeared to become buried in September, 1991 based on the AWS temperature sensor data. Assuming an additional accumulation of about a quarter of the annual accumulation (~ 15-20 cm) from September until the observed low temperature, the estimated height of the air temperature sensor at the time of the record would be approximately 1.9 to 2.0 m.

To provide another estimate we referenced a field report in which Jay Klinck reported that in the 1992 servicing of Klinck AWS, that "only the top section of tower was above the snow surface" (Polar Ice Coring Office field summary report - 1995). Assuming 3/4 of the annual accumulation (45 – 60 cm) from December 1991 through the end of June 1992, the best estimate of the tower temperature sensor height at the end of December 1991 would be 1.8 to 2.0 m, matching the previous estimate that the air temperature sensor was within the WMO specified 1.25-2 meter height range.

The AWS stations used in Greenland were all second or third generation AWS redesigned by the University of Wisconsin-Madison's Space Science and Engineering Center using precision resisters and individually "tuning" the temperature measurement circuits. The Klinck AWS was assembled using new electronics boards in 1990. Calibration of the temperature sensors was done so as to tune the AWS to read 0.0 C (+/- 0.125C) using a precision (0.05%) 1000 ohm resister to simulate a Weed Platinum Resistance Thermometer (PRT) (specified to 1000 ohms at 0°C and +/- 0.1°C at 0°C). In 1995, the Klinck AWS was sent to the German Antarctic Programme at the Alfred Wegener Institute, (AWI). Temperature sensing circuits of the station were again calibrated in the fall of 1994, prior to shipment to AWI. From Weidner's lab notes, the calibration points of 0°C and -75°C were within +/- 0.25°C of the original calibration temperatures. The Weed specification sheet states an accuracy of +/- 0.5°C at –100°C not accounting for sensor drift with time. In using the Weed PRTs for 30 years, the long-term stability has been very good remaining within the +/- 0.125°C resolution of the AWS stations used in Greenland. We are thus confident that the AWS temperatures system (sensor and circuitry) error is within the range of +/- 0.75°C.

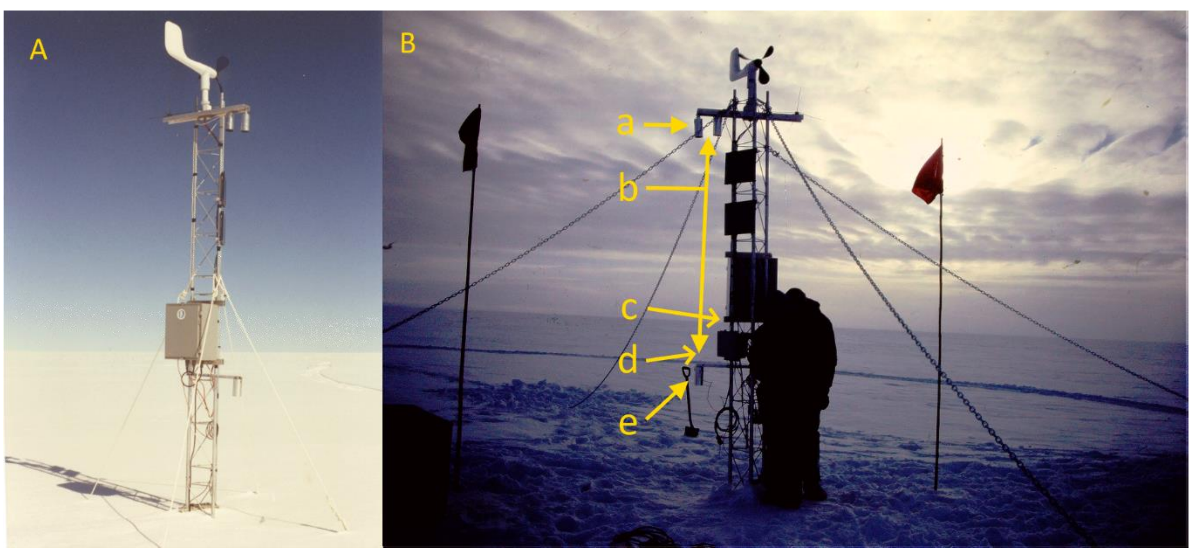

Figure 2. A. Unaltered Klinck AWS photograph as photographed in 1994 during a maintenance check. Photograph by Mark Seefeldt. B. Annotated 1990 Klinck AWS installation photograph: a) air temperature probe at 3.3 meters after installation, b) 2.0 – 2.2 meters above snow surface (at time of time of 22 Dec. 1991 -69.6°C temperature observation), c) estimated snow level in July 1992, d) estimated snow level at time of 22 Dec. 1991 -69.6°C temperature observation, and

d) lower temperature probe installed at ~0.9 meter above snow surface at installation (became buried in September 1991, based on the AWS data). Photograph by Dr. Julie Palais.

One issue that the committee also addressed was possible radiation errors (following a recent paper on high Antarctic temperatures by another WMO extremes evaluation committee, Laska et al. 2018). However, the observation currently under investigation occurred during the polar night, so solar radiation errors are not an issue. However, there is a possibility that, in the absence of solar radiation, a poorly-aspirated temperature sensor could under-read as a result of longwave cooling of the radiation shield and sensor. Solar radiation errors in "naturally-ventilated" radiation shields were quantified in a polar environment by Genthon et al. (2011). They mentioned possible longwave errors but did not quantify them, although those authors stated that they are unlikely to exceed 2°C. Richardson et al (1999) quantified longwave errors in naturally-ventilated shields at a midlatitude site and concluded that such errors were generally less than 0.5°C.

While it is difficult to quantify longwave radiation (LW) errors in air temperature measurement, the committee evaluated the following metadata. The temperature shield used at the Greenland AWS sites is a 7.6 cm diameter aluminum tube 15.2 cm in length. The inner surface was coated with ultra-flat black paint and the exterior was covered by a thin Mylar tape. The Weed PRT probe was a 0.3 cm tube, was directed down 90 degrees to the snow surface to minimize its area to the surface, and was recessed into the shield. Consequently, it would have had a minimal amount of exposure to the snow surface. Additionally, it was covered with the Mylar tape (which is highly reflective including in the infrared) and thermally isolated from the sensor boom by a five cm plastic spacer. Since the surface area of the cylindrical shield was normal to the surface, the infrared radiative balance would have been primarily with the atmosphere. Air was free to move vertically in the shield so that if the shield was colder than the surrounding air, cooled air would be free to sink out of the shield. Consequently, the committee concluded that equipment LW bias was likely minimal.

Additionally, the committee concluded that a significant LW radiation error might be possible with a warm cloud layer close to the surface at Klinck, thereby creating a warm bias. However, this is not indicated by the ERA or parcel charts. The steady fall in temperatures at Klinck (Figure 3b) suggests clear conditions in absence of any advection. Indeed, past studies have suggested that LW bias might lead to higher temperatures (e.g., Erell et al. 2005). Based on these available data, the committee concluded that infrared radiative errors were likely negligible for the event under examination.

The AWS showed calm conditions at the time of the minimum and riming has been observed at the Greenland AWS sites. However, leading into the period of temperatures below -65°C winds gradually decreased to below 1 m/s and as wind speeds picked up beginning around 1600 UTC on December 22, temperatures began to rise with increasing wind speed. The Belfort Aerovane is a large wind sensor with the three-bladed prop that begins turning at wind speeds greater than 2 m/s. The Klinck AWS wind direction data during this time was fixed at 172 deg. The Belfort wind sensors were found to lock up at very low temperatures without riming conditions. In cases of riming, the wind speed data typically is 0 m/s until there is enough warming or high enough wind speed to turn the prop and move the vane. This is seen as a sudden jump from calm conditions to wind speeds typically greater than 4-5 m/s. That was not observed at Klinck AWS.

In figure 3, 2 m temperatures at Klinck are compared with those from nearby AWSs during December 1991. Temperatures from all of the AWSs (which range from 56 km to 199 km in distance from Klinck) track those at Klinck quite closely at all times, with all stations reaching an extreme minimum for the month on 22 December. The general agreement between neighboring stations provides increased confidence in the measurements made at Klinck.

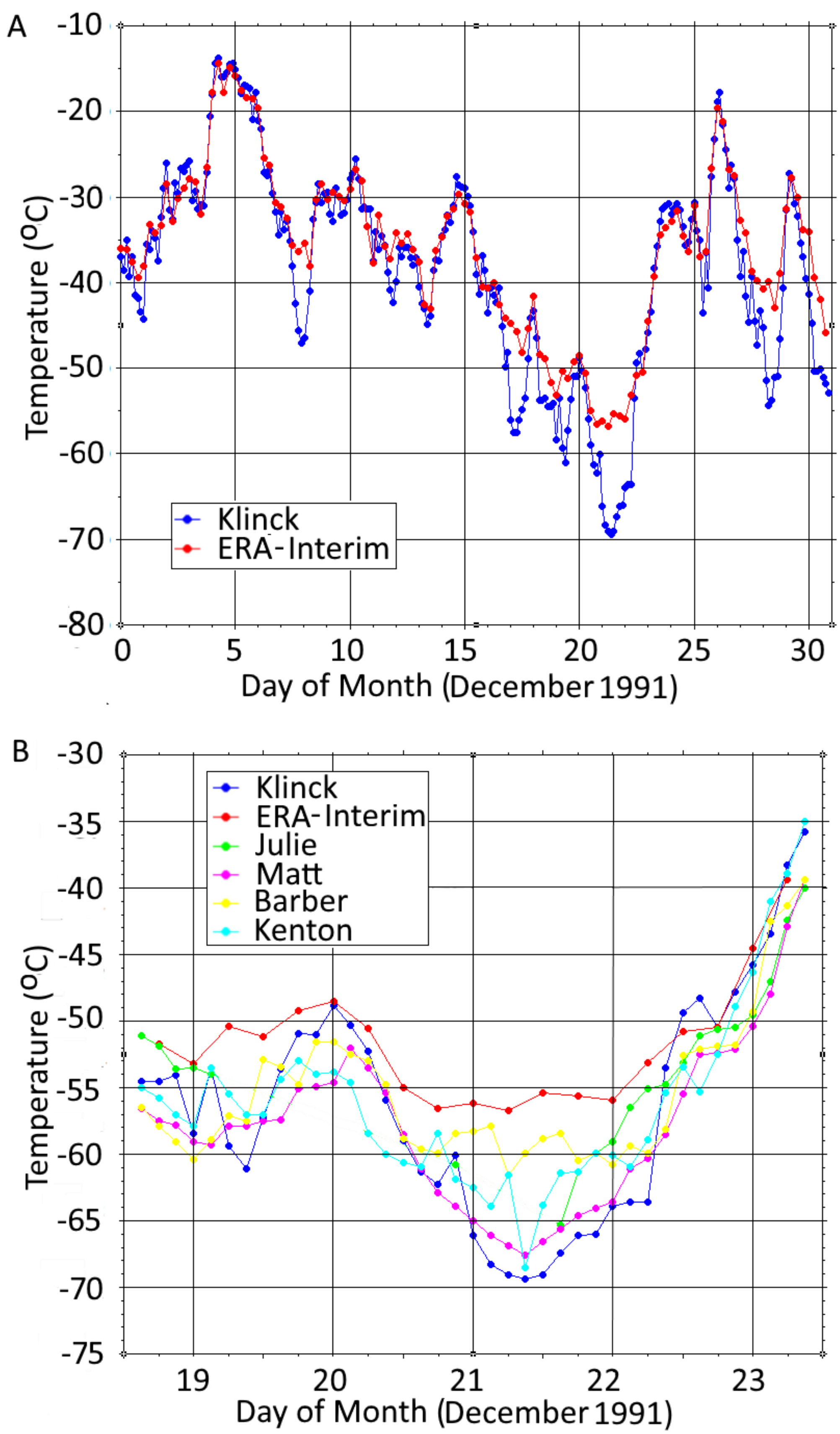
A
Klinck
ERA-Interim
Temperature (°C)
Day of Month (December 1991)
B
Klinck
ERA-Interim
Julie
Matt
Barber
Kenton
Temperature (°C)
Day of Month (December 1991)

Figure 3. A. Time series plot (x axis, time in 3-hour increments, December 1991; y-axis temperature in °C) for Klinck AWS (blue) and the ERA-Interim reanalysis (red). B. Detailed time series plot of December 18-23 (x axis, time in 3-hour increments; y-axis temperature in °C) for Klinck AWS (blue) , the ERA-Interim reanalysis (red), Julie (green; discontinuous due to missing data), Matt (purple), Barber (yellow) and Kenton (light blue).

3. Synoptic situation

The committee examined the synoptic background to the 22 December 1991 extreme minimum temperature event using data from the European Centre for Medium-Range Weather Forecasts interim reanalysis (ERA-Interim, Dee et al., 2011). During the week leading up to the extreme minimum temperature event, weak gradients of mean sea level pressure and of lower troposphere geopotential height prevailed over Greenland. The geopotential height field at the 650 hPa level (close to surface level at Klinck) exhibited a clear blocking pattern in the days before the observed extreme (Figure 4). The weak gradients associated with this blocked flow led to weak near-surface winds (wind speed at the surface is zero) over central Greenland that, together with rapid radiative cooling of the surface, led to the development of a strong, shallow surface-based inversion and hence very low near-surface air temperatures.

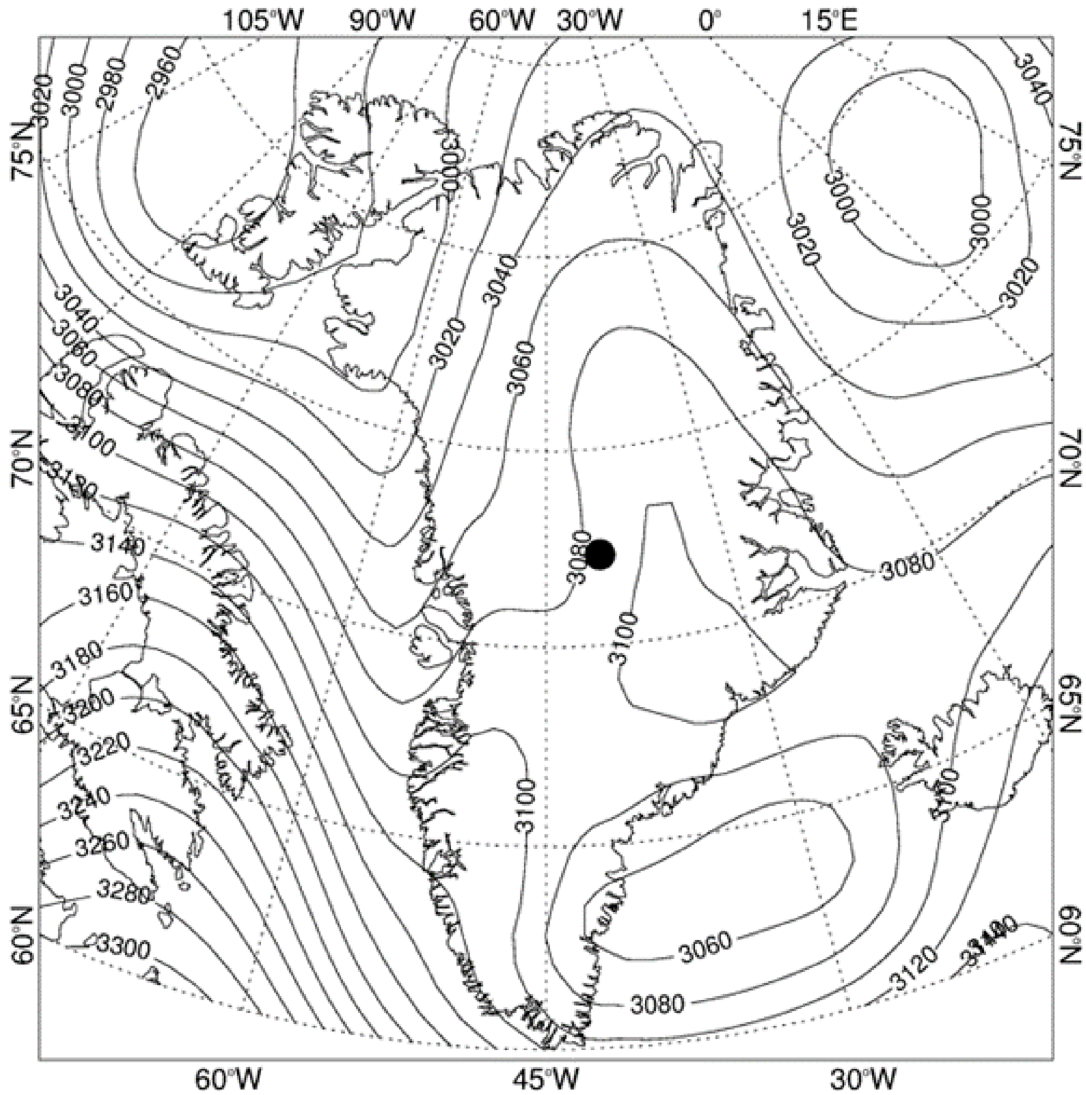

Figure 4. Geopotential height (in geopotential metres) at the 650 hPa pressure level over Greenland at 0000 UTC on 19 December 1991. Data obtained from the ERA-Interim reanalysis, contours in geopotential metres. The filled circle marks the location of the Klinck AWS.

At the time of the extreme minimum event, a weak anticyclonic vortex is apparent in the surface wind field around Klinck (Figure 5). As a result of this circulation, near-surface air became trapped over central Greenland and cooled over an extended period. Figure 6 shows 8-day back trajectories of air parcels arriving at 100 m above Klinck, computed using the HYSPLIT model (Stein et al., 2015). Air parcels arriving at the time of the observed extreme minimum had been recirculating over central Greenland for around 6 days, during which period they would have cooled by longwave radiation and through exchange of heat with the underlying ice surface. Air parcels arriving a few days before and after the event originated in the Canadian Arctic but followed more direct paths to Klinck, with much shorter residence times over the Greenland ice sheet, and, consequently, less potential for cooling particularly as shown in the HYSPLIT 24 December trajectory analysis (Figure 6). The extended trapping, and subsequent cooling, of near-surface air over central Greenland, which isolated the Klinck AWS from warmer air masses, is likely the proximal cause of the observed record minimum temperature. Interestingly, a similar extended isolation (albeit on a somewhat larger spatial scale) and subsequent cooling of air in the vicinity of Vostok station, Antarctica, was identified by Turner et al. (2009) as the cause of the world record minimum temperature of -89.2°C observed at that station on 21 July 1983. While pooling of very cold air over the extremely flat terrain overlying Subglacial Lake Vostok undoubtedly contributed to the extreme minimum temperature at the station, Scambos et al. (2018) have used satellite observations to show that even lower temperatures have occurred along the summit of the broad ridge above Vostok when the region is isolated atmospherically from lower latitudes. This latter location is topographically analogous to the location of Klinck, which is situated close to the crest of the Greenland summit ridge. Based on the topographic information available from early surveys, slopes from GRIP to other AWSs in the network do not exceed 2m per km. Consequently, any cold-air drainage would likely occur very slowly.

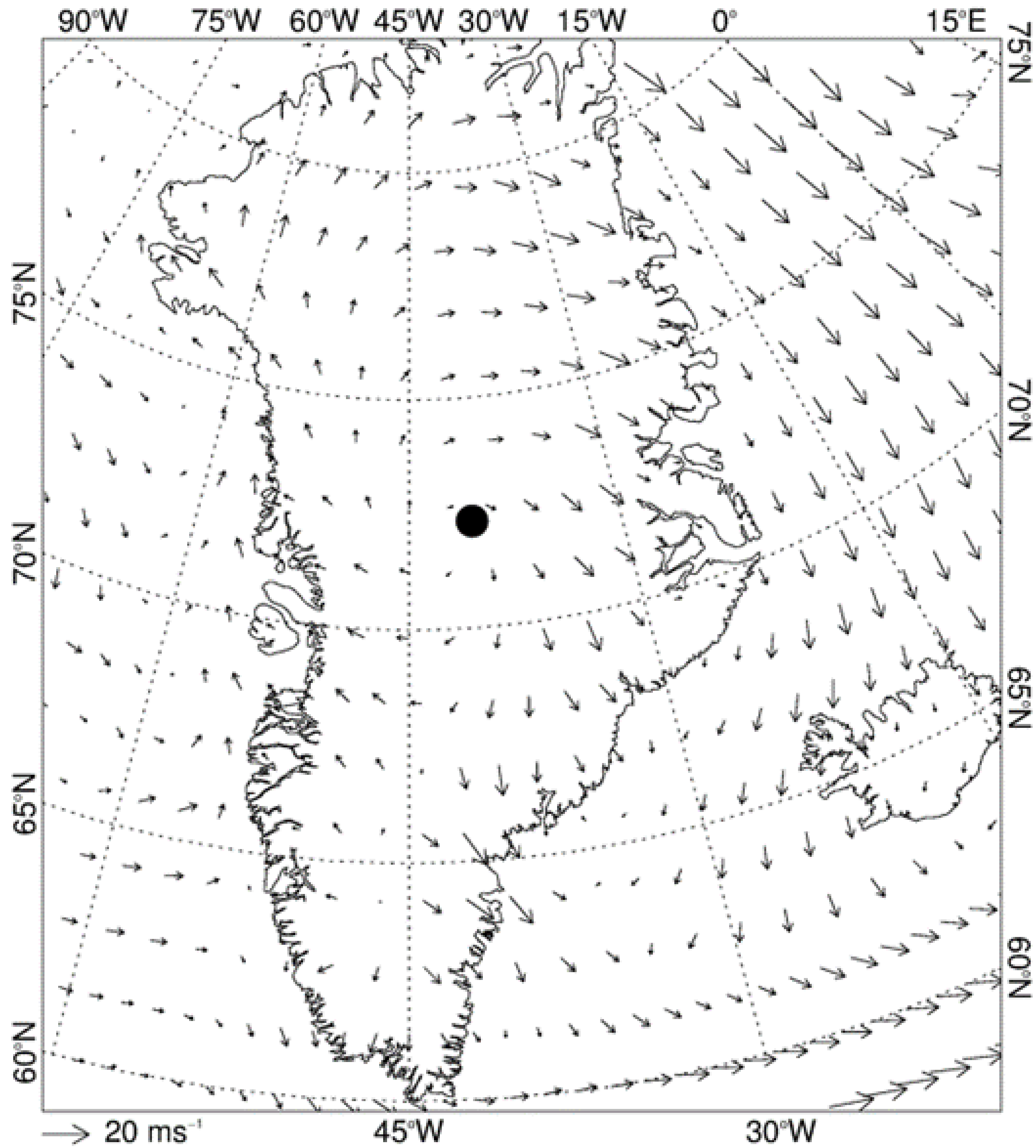

Figure 5. 10 m wind vectors over Greenland at 0000 UTC on 20 December, 1991. Data obtained from the ERA-Interim reanalysis. The filled circle marks the location of the Klinck AWS. Wind scale noted in lower left corner.

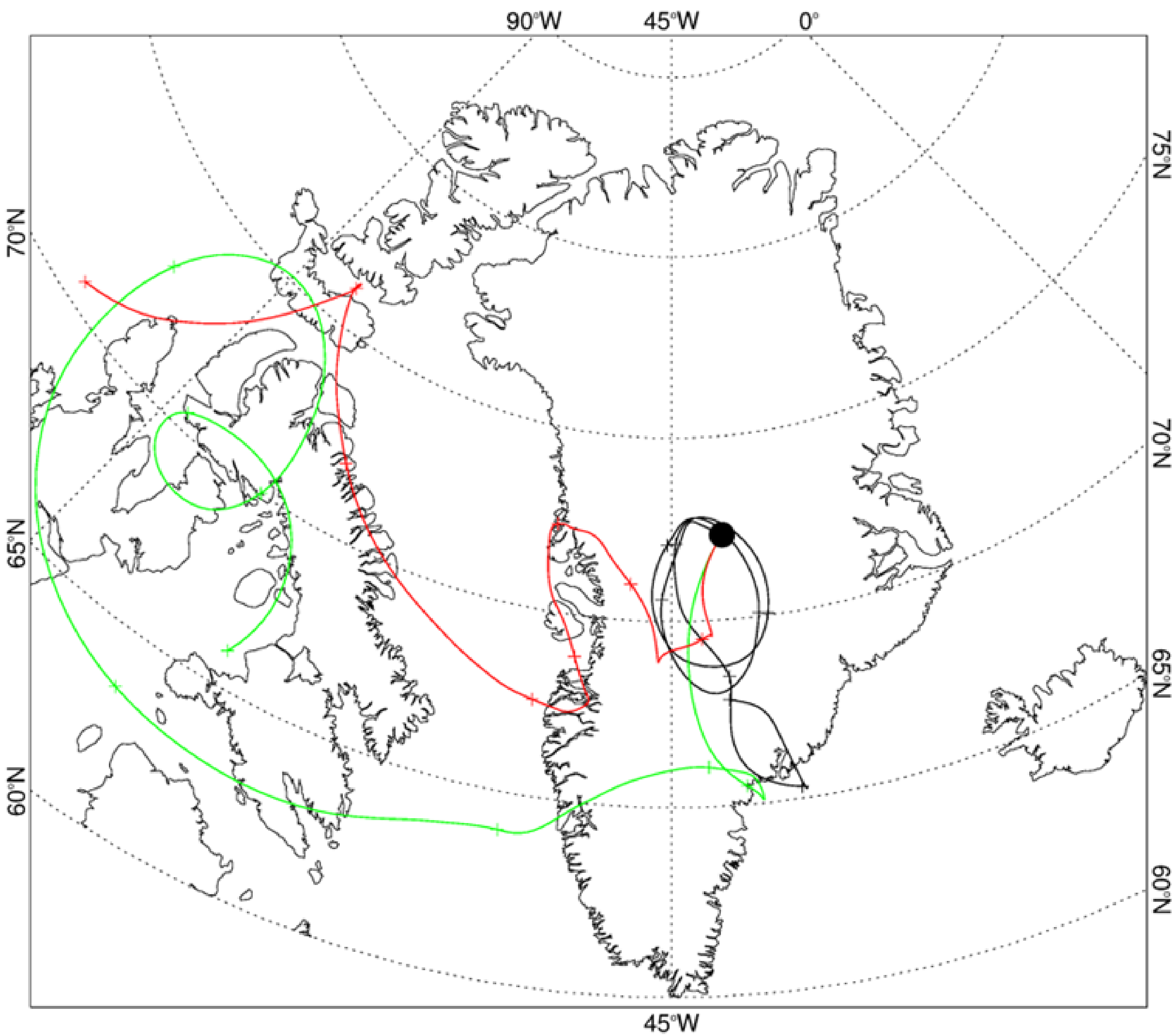

Figure 6. 8-day back trajectories of air parcels arriving at 100 m above the Klinck AWS (filled circle) at 0600 UTC on 16 December 1991 (green), 22 December 1991 (black) and 24 December 1991 (red). Crosses mark the air parcel locations at 24-hour intervals. Trajectories were calculated from National Centers for Environmental Prediction/National Center for Atmospheric Research reanalysis data (Kistler et al., 2001) using the online version of the HYSPLIT trajectory model (www.ready.noaa.gov/HYSPLIT.php).

3. Reanalysis Concerns

Along with temperature measurements from Klinck and nearby AWSs, figure 3 shows 2-meter temperatures extracted at 6-hourly intervals from the ERA-Interim reanalysis that have been interpolated to the location of Klinck. The elevation of this interpolated location on the model orography (3084 m) is close to the actual station elevation (3105 m). Reanalysis temperatures follow temperature variations at Klinck quite closely throughout December but are clearly biased warm during periods when the temperature falls to a local minimum.

The vertical temperature profile above Klinck AWS at 00 UTC, 22 December 1991 extracted from the ERA-Interim reanalysis indicates a very strong near-surface temperature inversion (Fig. 7). However, the 2-meter temperature from ERA-Interim is more than 12°C higher than the observed minimum so it is clear that this reanalysis was likely struggling to reproduce the actual minimum temperature and was consequently greatly underestimating the strength of the actual inversion. This is not surprising given the extreme stability implied by the large difference between the model 600 hPa temperature and observed surface temperature. The parameterizations of turbulent fluxes of heat and momentum used in atmospheric models often perform poorly under such highly-stable conditions (Sandu et al., 2013) and it is likely that reanalyses frequently fail to capture the strength of the strongest inversions in this region. The relatively coarse horizontal resolution (~80 km) of the reanalysis could be a further reason for the reanalysis not accurately capturing the extreme minimum. However, topographic variations around Klinck on the reanalysis grid scale are small and, furthermore, the reanalysis exhibits a similar warm bias with respect to measurements at the other AWSs shown on Figure 3b, which range from 56 km to 199 km in distance from Klinck. We thus conclude that lack of horizontal resolution is not the primary reason that the reanalysis fails to capture the full magnitude of the extreme minimum event. Additionally, under a strong inversion, and all things being equal (calm, clear conditions), Klinck's 2 m air temperature observation would be colder than temperature observations at the other sites (which were estimated at 2.7 m or greater), as it was the closest temperature observation to the snow surface. The estimated air temperature measurement heights at the other stations were obtained by noting the reported boom heights either in the 1991 and 1992 field reports (both PICO's and UWs) and working forward or backward in time to arrive at the estimated temperature sensor height in December 1991, using the same annual accumulation rate as was done for Klinck site.

At 0600 UTC on 22 December, 1991, the temperature at the location of Klinck in the more recent ERA5 reanalysis was -56.7°C – identical to that from the ERA-interim reanalysis. This suggests that, even with improved physics and higher vertical resolution, the newer reanalysis is still unable to reproduce the observed extreme surface inversion realistically.

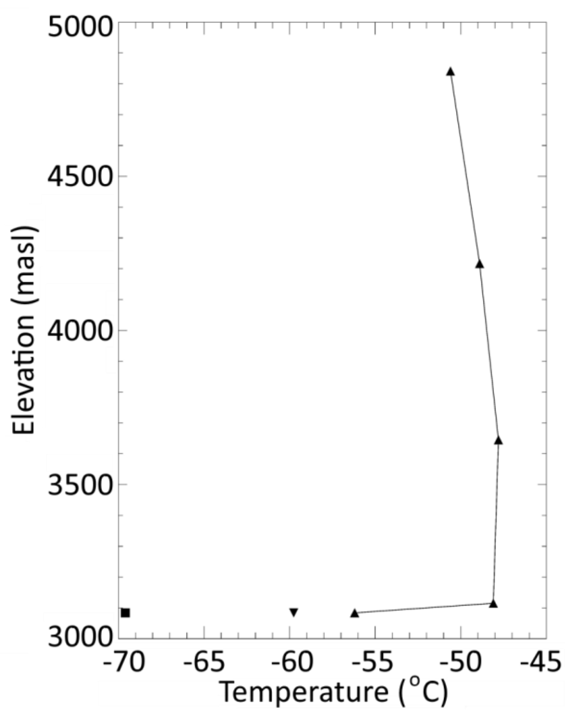

Figure 7. Vertical profile of air temperature for the Klinck location at 0600 UTC on 22December 1991 from the ERA-Interim reanalysis (solid line with upward-pointing triangles). The four points in the profile are the reanalysis temperature at 2m above the surface and those at the 650, 600, 550 and 500 hPa levels. Also shown are the reanalysis surface (skin) temperature (downward-pointing triangle) and the record air temperature measured by the AWS at 0700 UTC (square).

This highlights an additional issue addressed by the committee: given the discrepancies between reanalysis data and observed data, the committee examined whether AWS data from Greenland are being incorporated into real-time weather forecasts and hence reanalyses datasets.

The committee established that the Antarctic Region is covered by the Global Climate Observing Systems (GCOS) monitoring that is undertaken by the Scientific Committee on Antarctic Research (SCAR) Expert Group on Operational Meteorology in the Antarctic, a subgroup of the SCAR Standing Scientific Group on Physical Sciences (SSG/PS). The Antarctic Task Team is a subgroup of the WMO Executive Council team on Polar and High Mountain Observations, Research and Services (see https://legacy.bas.ac.uk/met/jds/met/SCAR_oma.htm) in charge of the Antarctica Observation Network. Interestingly, Antarctica is one of the best reporting regions within the WMO, particularly with the monitoring for the GCOS Surface Network and Upper Air Network (GSN and GUAN, respectively) sites.

However, the committee determined that, at this time, no equivalent monitoring system exists for Greenland. The committee does believe that it is possible, through work such as the present extremes work, that the opportunity for future real-time weather monitoring can arise. Consequently, at this time, the only absolute way to establish what is incorporated into a given reanalysis dataset is individually to check the given reanalysis input data. Frankly, in the committee's viewpoint, this is a cumbersome process and could/should be better addressed.

4. Conclusions

Following an inquiry by a climate historian, a WMO extremes evaluation committee was established to examine an observation of -69.6°C by Klinck AWS in Greenland on 22 December, 1991 as the lowest temperature observed in Greenland, making it the lowest recorded temperature for the Northern and Western Hemispheres and for WMO Region VI. The committee commended the station's original project scientists in maintaining the calibrations and metadata of an observation made nearly twenty-eight years ago. Such diligence indicates a high degree of detail and quality of observation. In the committee's consensus, given metadata and calibration information, the uncertainty in the measured temperature is no more than +/- 0.5°C. Committee analysis of the synoptics of the situation indicates the climatic forcing of an intense near-surface inversion as the result of weak upper-air circulation over Greenland with very cold air aloft. Such a weak circulation was clearly indicated in back-trajectory simulations of air over the region. Consequently, the WMO Rapporteur of Weather and Climate Extremes has accepted the unanimous recommendation to accept the observation of -69.6°C at Klinck AWS in Greenland on 22 December, 1991 as the lowest temperature observed in Greenland, and, consequently, as the lowest recorded temperature for the Northern and Western Hemispheres and for WMO Region VI. Finally, it is the recommendation of the committee that means be investigated such that AWS data from Greenland can be efficiently incorporated into real-time weather forecasts and hence into reanalyses datasets.

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