Experimental assessment of screen bias in an early Arctic air temperature time Series

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Key points:

Screen bias is assessed for an Arctic air temperature time series from the mid 19^{th}-century

Abstract

Historical surface air temperature records used to reconstruct extended time series for climate studies often lack sufficient metadata to evaluate sources of bias in the recorded data. Occasionally, it is possible to reproduce the original environment to the extent that an objective measure of bias can be obtained and correction factors can be determined to increase the data's accuracy. There exists a large collection of unanalyzed hourly air temperature data from September 1852 to July 1854 taken near Point Barrow, Alaska by officers of the HMS *Plover* using a thermometer encased in a radiation screen. This data set is especially valuable due to it being recorded extensively in a time and place where data are sparse. This location is only 3 km northeast from the present day location of a NOAA observatory recording meteorological measurements, presenting the opportunity to assess bias of the historical data in comparison to modern data. For this investigation, a platinum resistance thermometer inside a previously constructed replica of the *Plover* radiation screen was placed adjacent to the observatory's sensors. Henceforth, surface air temperature time series were obtained from both the replica's and observatory's sensors. Data show that relative magnitudes of the biases associated with the Plover's radiation screen are on average 0.35 °C and up to 2 °C, generally varying by the sun exposure of the screen. These seemingly small inaccuracies are significant in the context of climate change, which is on the scale of a few degrees. Our results indicate screen bias is very

large and therefore the interpretation of this and similar Arctic historical temperature data first require correction factors to be implemented to the data set.

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Index terms:

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3394 Instruments and techniques, 9315 Arctic region

Keywords:

Arctic change, meteorological records, history, exploration, Alaska

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TEXT

1.Introduction

Significant sea-ice retreats like those of the Arctic in 2007 (Lindsay et al., 2009) and recent unusual meteorology highlight the sensitivity of the Arctic to climate change and its potential as an omen of future global climate change (Rothrock et al., 1999). Recent economic developments have also accelerated efforts to collect data and study environmental impacts (Streever et al., 2011). To discern abnormal climate patterns from infrequent but typical fluctuations, historical data is needed to compare with current measurements. Sources of historical weather data include logbooks and journals of scientists and sailors who have recorded climatic and environmental conditions encountered during travels (e.g Maguire, 1988). Climate studies that depend on long-term baseline data motivate interest in recovering sparse historical data.

Due to the Arctic's remoteness and low population density there is a small quantity of historical weather data that can be used to help conduct inter-comparison studies relating modern data with old data (Steele et al., 2008). Although in the past century, exploration has been accelerated for commercial benefits, more observations have contributed to the understanding of the Arctic's geography than its climate. Therefore, meteorological and oceanographic data collected in the Arctic region first began being recorded on a relatively consistent basis in the 1900s (Serreze & Barry, 2005). Additionally, in the middle of the 19th century, Britain's navy mandated a system of extensive data collection, thus resulting in fairly reliable Arctic weather data such as the data from the HMS *Plover* (Brohan et al., 2009).

Older historical data are of great interest but are also of unknown quality and often lack the metadata needed to evaluate them (Vincent & Gullet, 1999). This is an issue when attempting to compare and interpret these data in the context of modern measurements because historical data were generally recorded using different types of equipment than in use today which may result in inaccurate measurements.

Hourly air temperature observations obtained by the HMS *Plover* provide an excellent case study. The *Plover* was anchored at Point Barrow, Alaska, between 1852 and 1854 (Figure 1), as part of the Royal Navy's search for the lost Arctic expedition lead by Sir John Franklin. While there, Dr. Simpson recorded air temperature measurements hourly with an alcohol thermometer, mounted on a post 90 feet away from the ship to distance the instrumentation from the impacts of the ship (SIMPSON JOURNAL, OFFICIAL REF TO COME LATER). The data from the *Plover* is of great interest in light of modern-day climate change in the Arctic, but a common problem that must be confronted when utilizing historical weather data, is that

Figure 1: Satellite image of Barrow, Alaska Observatory and approximate location of HMS Plover winter quarters (Source: Google Earth)

differences in observation methods and instruments make comparisons with modern data difficult. The *Plover's* thermometer was installed in a non-standard radiation screen, and the effects of this screen on the temperature measurements are not known and therefore, the readings are susceptible to unknown bias caused by the screen. Air temperature measurements must be made 'in the shade' and the purpose of a radiation screen is to prevent the sun from shining directly on the thermometer while allowing the free exchange of ambient air. However, different screen designs accomplish this purpose with varying results. Therefore, determining the bias of the screen design in use is a critical step before comparing historical and modern air temperature data.

Screen bias is not only a concern for historical Arctic data; it should be taken into account anywhere there was a replacement of antiquated shelters by automatic weather stations or Stevenson screens (Nordli et al., 1997). A previous study by Brunet et al. (2009) highlighted that data uncorrected for screen bias will provide results that incorrectly estimate the long term rate of temperature change.

In this study, the problem of screen bias was investigated by collecting two years of parallel data using identical platinum resistance thermometers (Resistance Thermocouple Devices, RTDs), deployed side-by-side at the National Oceanic and Atmospheric Administration (NOAA) Observatory in Barrow, Alaska. One RTD was installed in a replica screen built according to the design described by the *Plover's* surgeon (and science officer) (Simpson 1858), and the other was the observatory's standard RTD in an aspirated screen (i.e. with fan-driven air exchange). The daily means of the thermometer readings were analyzed for screen bias. This investigation has revealed clear patterns of bias throughout the two years; the *Plover* RTD recorded lower readings than the standard RTD during winter months, while recording higher readings during summer months. Temperature readings are inaccurate by an average of 0.35°C. In the context of climate change, where a change of a couple of degrees Celsius is a drastic change, this inaccuracy is significant (Voiland, 2009).

2. Materials and Methods

Thermometer Screen

The replicated thermometer screen was constructed to emulate the HMS Plover's bias as closely as possible. For this study, a replica of the HMS *Plover's* thermometer screen was constructed based on the description by Simpson (1858), where the specific details about the dimensions, materials, color, and special features of the thermometer screen are provided. These descriptions were used to create schematics of the thermometer screen (Figure 2a) that were used by a sheet metal fabrication company to construct the replica thermometer screen (Figure 2b).

Barrow, Alaska Setup

The replica thermometer screen was sent to the NOAA Observatory, located about 2 km southeast from the shore of the Arctic Ocean at Barrow, Alaska at coordinates: 71°32'30"N 156°61'14"W (Figure 1). The observatory is ~3 km southwest from the approximate location of *HMS Plover* winter quarters in Elson Lagoon.

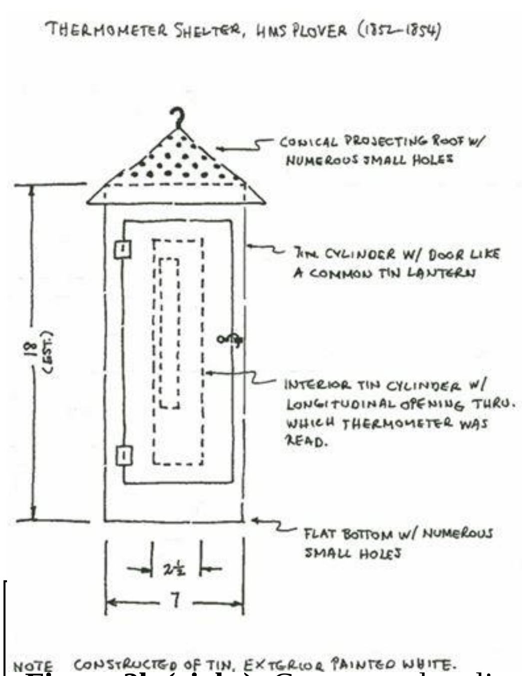


Figure 2b (right): Constructed replica thermometer screen.

A modern day thermometer (Logan Enterprises Model 4159 Resistance Thermocouple Device (RTD)) was housed in the replica thermometer screen. This RTD recorded air temperature alongside the standard RTD of the same model at 2 m above ground level (Figure 3). Wind and barometric pressure were recorded at 10 m above ground level. These variables were analyzed to determine their impact on the temperature readings from the Plover RTD, therefore providing insight on how atmospheric conditions relate to screen bias. All data were collected at one-minute intervals from November 10, 2011, to the current day. Data collected in 2012 and 2013 have been used for this study.

Figure 3: HMS *Plover* replica screen and 2 meter standard installation at the NOAA Barrow Observatory.

Without adequate air flow, solar radiation from the sun would have warmed the exposed RTD, therefore biasing the readings for actual temperature with which were compared the Plover RTD readings with. However, an AC fan properly aerated the inside of the exposed RTD. Air was pulled in at the bottom of the housing, past the RTD, and finally pushed out at through the top of the replica thermometer screen.

The location of data collection is optimal because it is close to the area of harsh environmental conditions that the thermometer used on the HMS *Plover* was exposed to. Similar to the environment the HMS *Plover* was stationed in, the NOAA observatory at Barrow, Alaska has an Arctic maritime climate affected by the variations of weather and sea ice conditions of the Arctic. The prevailing east-northeast wind off the Beaufort Sea at the observatory provides constant measurements of wind speed and wind direction (Carmack & Kulikov, 1998).

For this study, one data point was recorded every minute for two years. Each data point included the temperature readings of the two RTDs, wind speed and atmospheric pressure.

Computer Program and Data Analysis

A computer program was coded in Java to organize the data to facilitate analysis. The data were downloaded off an FTP database and then, using Microsoft command prompt, transformed into Excel files (.xls) from text files (Figure 4). From the Excel files the data were able to be selectively extracted with a second Java program using the JXL API.

To determine if there is a significant difference between meteorological and air temperature difference between the two RTDs, a two-tailed Analysis of Variance (ANOVA) tests were done.

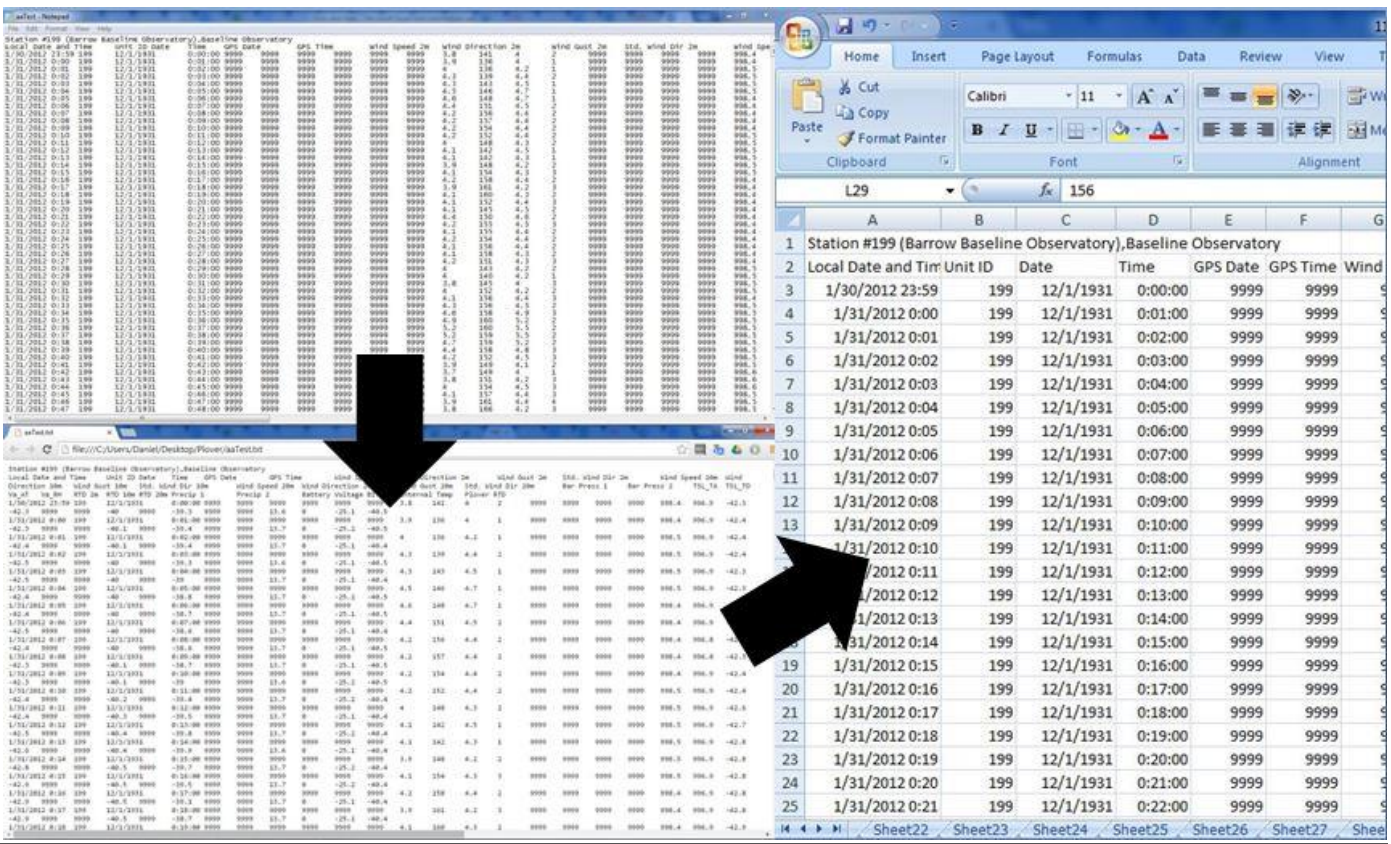
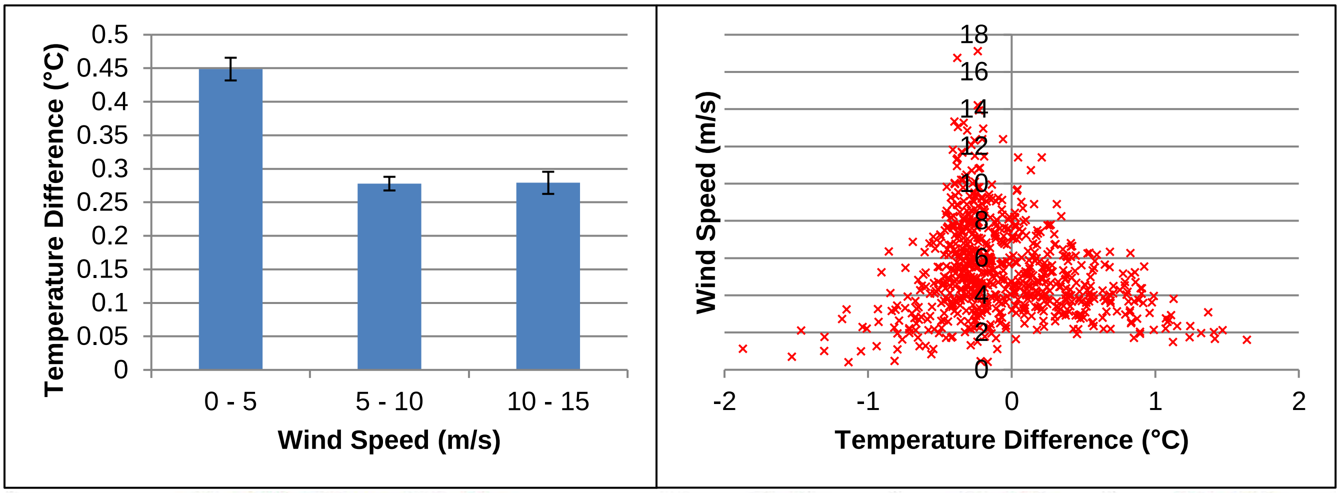


Figure 4: Data conversation for weather data collected throughout 2012-2013 at the NOAAObservatory at Barrow, Alaska.The upper-left window represents the original data on the FTP database. The bottom-left window represents the data after being converted to a .txt file format in Notepad. The right window represents the data after being converted into a .xls file.

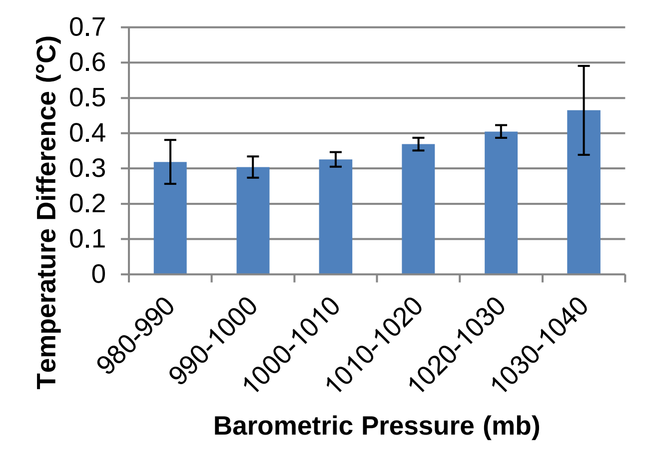
3. Results

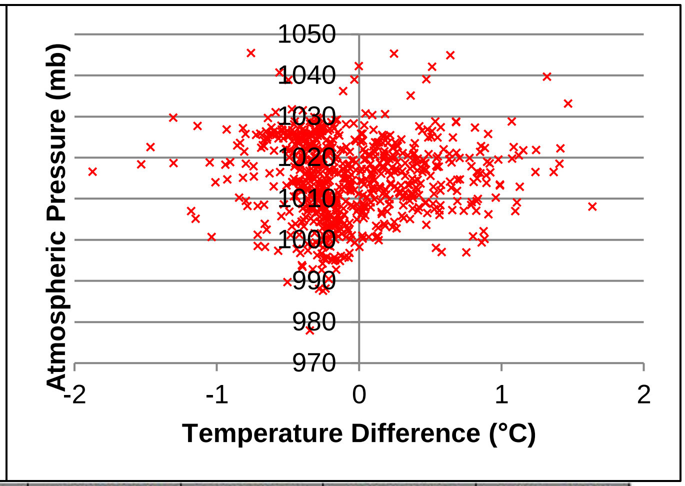


10m Wind Speed (m/s)	(0, 5)	[5, 10)	[10, 15)
Absolute Average Temperature Innacuracy (°C)	0.4487±0.0169	0.2779±0.0102	0.2791±0.0165

Figure 5a (left): Average temperature difference at different wind speed intervals (Error bars = standard error)
Figure 5b (right): Temperature difference (°C) of Plover RTD and RTD 2m against wind speed (m/s)
Table 1 (bottom): Absolute average temperature between the exposed and *Plover* RTD inaccuracies at different wind speed intervals at 10 m.

Wind speed affects the bias of the *Plover* screen; windier conditions result in less bias compared to the standard RTD. Wind speed at 10 m above the ground below 5 m/s cause the *Plover* RTD to have an average bias of 0.4487±0.0169 °C, between 5 and 10 m/s the average bias is 0.2779±0.0102 °C, and at wind speeds between 10 and 15 m/s the average bias is 0.2791±0.0165 °C (Figure 5a). Figure 5b makes evident that as wind speed at 10 m increases, the *Plover* RTD performs more like the exposed RTD. At wind speeds of ~8 m/s and greater, temperature difference between the two RTDs is not more than .5 °C.

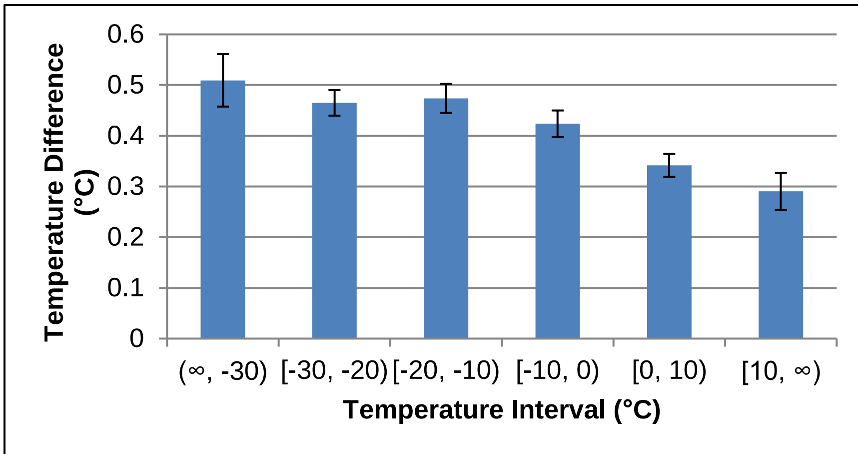


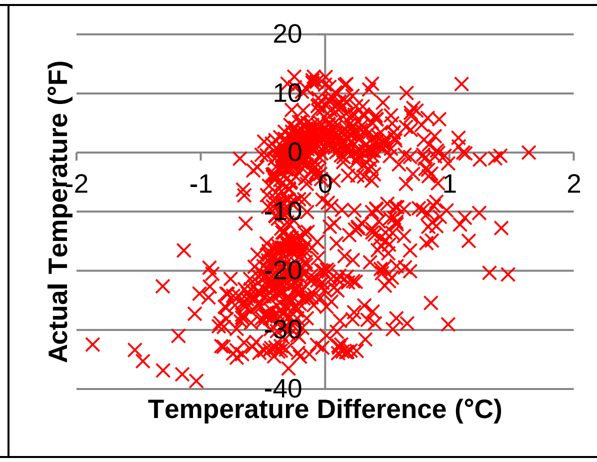


Atmospheric Pressure (mb)	(980, 990]	(990, 1000]	(1000, 1010]	(1010, 1020]	(1020, 1030]	(1030, 1040]
Absolute Avg. Temp. Innacuracy (°C)	0.3188±0.0622	0.3040±0.030	0.3258±0.0207	0.3690±0.018	0.4049±0.0180	0.4647±0.1260

Figure 6a (left): Average temperature difference at different atmospheric pressure intervals (Error bars = standard error)
Figure 6b (right): Temperature difference (°C) of Plover RTD and RTD 2m against Atmospheric Pressure (mb)
Table 2 (bottom): Absolute average temperature between the exposed and *Plover* RTD inaccuracies at different atmospheric pressures at 10 m.

As atmospheric pressure increases the bias also increases. When exposed to atmospheric pressures between 980 and 990 mb, the observed bias was 0.3188±0.0622 °C. At atmospheric pressures between 1030 and 1040 mb, the variation of the temperature between the two RTDs was on average between 0.4647±0.1260 °C (Figure 6a).From Figure 6b, it can be noted that as atmospheric pressure increases, bias of the *Plover* screen generally increases.





Temp. Interval (°C)	(∞, -30)	[-30, -20)	[-20, -10)	[-10, 0)	[0, 10)	[10, ∞)
Absolute Avg. Temp. Innacuracy (°C)	0.5094±0.0517	0.4650±0.0252	0.4737±0.0263	0.4236±0.02026	0.3416±0.0226	0.2905±0.0364

Figure 7a (left): Average temperature difference at different actual temperature intervals (Error bars = standard error)
Figure 7b (right): Temperature difference (°C) of Plover RTD and RTD 2m against actual temperature (°C)
Table 3 (bottom): Absolute average temperature between the exposed and *Plover* RTD inaccuracies at different actual temperatures.

Screen bias decreases as temperature increases. Exposure to temperatures below -30 °C causes a significant average bias of 0.5094±0.0518 °C between the *Plover* RTD and exposed RTD. When the air temperature is greater than 10 °C, the average temperature difference is 0.2905±0.0364 °C (Figure 7a).Figure 7bshows that the *Plover* RTD measuring a higher average temperature greater than 0.5 °C than the exposed RTD happens more often than the *Plover* RTD measuring a lower average air temperature greater than 0.5 °C than the exposed RTD.

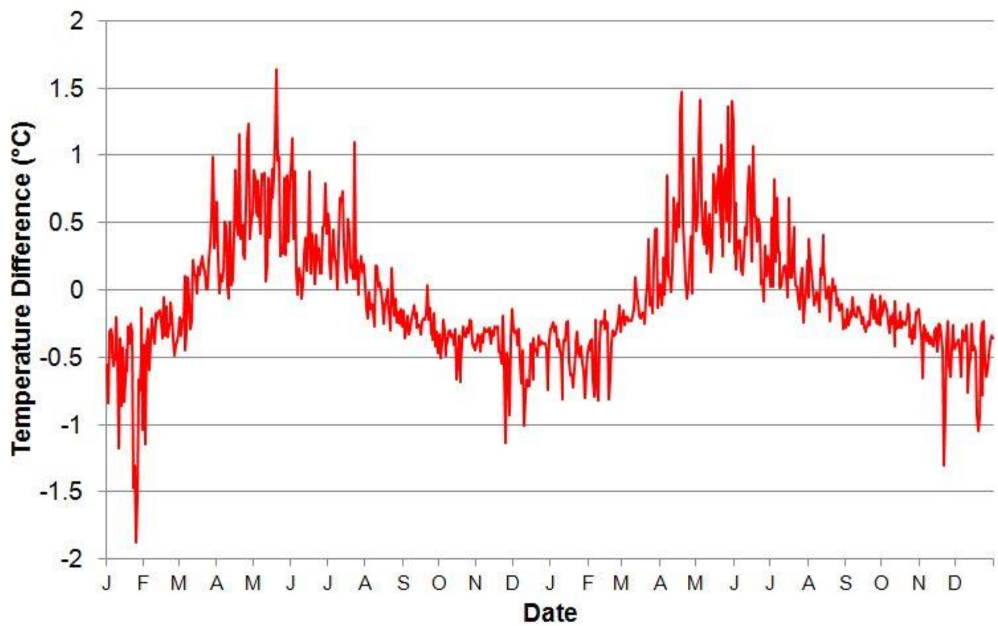


Figure 8: Plot of temperature difference of Plover RTD and RTD 2m for 2 years (2012-2013) by Julian day

From April to August, the observed temperatures are higher than the actual temperatures, and from August to April, the observed temperatures are lower than the actual temperatures. When time, in months, and temperature, in degrees Celsius, is graphed on the x and y-axes respectively, the resulting graph resembles a negative sine graph (Figure 8). This shows that from August to April, and from April to August, the temperature accuracy generally decreases up until the month of June and January respectively where the temperature accuracy beings to generally increase.

4. Discussion

Previous studies have shown that screen bias is related to the time of the year when data of the instrument within the thermometer screen are being recorded (Böhm et al., 2009, Nordli et al., 1997). Results from this study agree with those of Böhm et al. in that temperatures recorded in the summer half of the year were biased warm and temperatures recorded in the winter half were biased cold. This effect can be explained by how in places north of the Arctic Circle, the sun is visible for the full 24 hours of the day during the summer months and the sun cannot be seen for the entire day during winter months. The constant or lack of sun exposure introduces a heating or cooling element respectively within the screen caused by the thermal radiation of the sun.

It is important to verify all conditions that may induce bias that may result in unreliable analyses. The results of this study show that low wind speed and high atmospheric pressure (typical of calm settled weather and peak radiation) increase the bias of a non-aspirated thermometer screen relative to an aspirated one. Given that each thermometer screen design will have its own unique biases, future studies develop bias assessments over a range of meteorological conditions

There are limiting factors in this study. The original thermometer screen was not able to be utilized for this study; the replica screen was built as close to the original screen design as possible, but differences in the type of metal, paint, and attachment points among the screen, the inner RTD tube, and the Observatory instrument mast may have induced biases not found in the original setup. Most importantly, it would have been ideal to simultaneously test the *Plover* screen against multiple modern types, including a Stevenson screen and other non-aspirated designs. However, the results obtained are almost certainly worst-case: the relative screen bias compared to other non-aspirated screens is likely less in all conditions than observed here. Despite the limitations, the results of this study demonstrate that replica screens can be compared with modern installations to derive useful insight and the information needed to derive correction factors. Instead of being further neglected, these valuable sources of data can be utilized to their full potential if the bias of the measuring apparatus is properly determined. Given reliable metadata, bias estimates needed to compare historical and modern data can be deduced.

5. Conclusions and Future Work

The experimental assessment of the *Plover* radiation screen demonstrated that under certain meteorological conditions, screen bias can reach 2°C, a significant amount in the context of climate change and global warming. To illustrate, published studies demonstrate only maximum temperature anomalies of 2.5°C over a decade in certain locations of the world (Voiland, 2009). Therefore, if uncorrected, screen bias can heavily distort the results of studies comparing modern with historical air temperature data by falsely portraying global warming or cooling.

It should be highlighted that this study analyzed only daily mean data calculated from hourly data. The screen effect on temperature maxima and minima remains to be investigated, and the potential effects of thermal lag associated with the Arctic seasonal cycle needs to be analyzed in greater detail**.**

The results from this study show that historical data like that collected by the officers of the HMS *Plover* can be used to investigate Arctic climate change, given careful assessment of metadata and application of resulting correction factors.

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