Comparison of Instrumentation to Measure Air and Soil-Surface Temperature Variability in Northern Alaska

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COMPARISON OF INSTRUMENTATION TO MEASURE AIR AND SOIL-SURFACE TEMPERATURE VARIABILITY IN NORTHERN ALASKA

By

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Undergraduate Thesis

Presented in partial fulfillment of the requirements for the degree of

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Comparison of Instrumentation to Measure Air and Soil-Surface Temperature Variability in Northern Alaska

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The Circumpolar Active Layer Monitoring (CALM) project has been observing permafrost (perennially frozen ground) and its overlaying active layer (which freezes and thaws annually) in northern Alaska’s Kuparuk River watershed and throughout the polar regions since the mid 1990’s to detect long-term responses to climatic change. The soil-surface temperature data is collected by thermistors that were positioned immediately below the surface of the ground at nine locations within a transect of 1-ha plots arranged from north to south across the region. Locations within each plot were individually selected to represent a full range of microsite conditions, with distinctions in vegetation, moisture, and microtopography. For my research, I have compared temperature measurements from three different generations of datalogger models from the same manufacturer deployed in pairs over 1-year durations from 2005-2006 and 2011-2012. Diagrams comparing daily soil-surface and air temperature differences between the different instrumentation models show systematic variations due to vegetation, air temperature, and moisture. The temporal variability in the differences between instrumentation is systematically related to seasonal cycles of temperature, with the largest differences being in the summer when the active layer thaws and is the most dynamic. Spatial variability within the plots was examined, showing that the larger temperature differences are at the warmer, drier sites. These instrumentation statistics were necessary to quantify the reliability and consistency of the 18-year CALM dataset. This dataset contributes to the greater understanding of our complicated climatic system, as the thickening of the active layer in Arctic regions may potentially discharge further greenhouse gases into the atmosphere, thus yielding a variety of ecological feedbacks and further intensification of climate change.
ACKNOWLEDGEMENTS

Without the knowledge and commitment of Dr. Anna E. Klene, this project would not have been possible. Thank you, Anna, for patiently guiding me throughout the entirety of this research. Thank you to Dr. Johnnie N. Moore for his input and adeptness. Much appreciation to the University of Montana’s Davidson Honors College for providing me with a 2014 Undergraduate Research Award to encourage the success and significance of this research. Funding for the data acquisition was provided by U.S. National Science Foundation (NSF) grants OPP-9529783, OPP0352958, and OPP-0856421. British Petroleum provided access to sites located within the Prudhoe Bay oil field. Thanks to my dear friends for tolerantly listening to me talk about this project all semester. Cheers to my wonderful parents, sisters, and family for always being a welcoming inspiration and support system throughout my life.
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1 INTRODUCTION

Ground surface and subsurface soil properties are monitored globally for a wide range of purposes, including to observe climate change feedbacks. Permafrost (sub-surface earth remaining frozen for more than 2 years; Muller, 1943), which underlies nearly a quarter of the Earth's land surface, is considered potentially vulnerable to a warming climate. The active layer is the upper several centimeters to several meters of the soil column that freezes and thaws annually (Muller, 2008) and is where most chemical, biological, and hydrological processes occur in permafrost regions. This research is a contribution to a long-term study examining the changes in northern Alaska’s active layer of permafrost. Concerns of potential impacts of widespread increase in the thickness of the active layer largely focus on a positive feedback of greenhouse gases currently stored in the frozen sediment (Harden et al., 2012), soil subsidence posing a significant hazard for human infrastructure including roads, pipelines, and nuclear power plants (especially in areas of ice-rich permafrost; Nelson et al., 2001), and extensive landscape changes as a deeper thawed volume allows for shrub and tree expansion and an associated cascade of ecosystem effects (Rowland et al., 2011).

It is no surprise that these permafrost territories are difficult to monitor due to the remoteness of their locations. However, the scientific community, through the World Meteorological Organization’s Global Climate Observing System and Global Terrestrial Observing Network, has designated active-layer thickness and permafrost temperatures to be one of the essential climatic variables to monitor in a changing world. Thus, granting agencies have provided support to access these places to measure characteristics sites.
The Circumpolar Active Layer Monitoring (CALM) project has developed
standardized methodologies for measurements, supported data collection at some sites,
and established an open data repository for active-layer data, which can be used to
examine the impacts of climate change on the upper portion of permafrost. As of 2011,
CALM had over 260 sites in the northern and southern hemispheres (Shiklomanov et al.,
2012). Thermal monitoring of deeper permafrost is done under the auspices of the
Global Terrestrial Network for Permafrost (GTN-P) which has established monitoring
protocols and a data archive as well and coordinates with CALM.

Data from the CALM sites used in this study have been used to study climatic
change within the region (Streletskiy et al., 2008), ecosystem-level responses (Nyland et
al., 2012), improve modelling efforts (Klene et al., 2001a, 2001b, 2008), and predict soil
subsidence (a hazard for human infrastructure such as roads and pipelines; Liu et al.,
2010). Observations based on the active-layer data collected by CALM has also provided
a widespread circumpolar record which has been used to confirm geocryological
(Shiklomanov et al., 2007) and hydrological (Rawlins et al., 2003) models.

CALM will continue to perform their 18-year study of this active-layer response
to climate change to further the understanding of active-layer thickening.

1.1 OBJECTIVES

The purpose of this study is to help quantify the reliability of an 18-year air and
soil-surface temperature dataset in northern Alaska. This thesis utilized temperature data
obtained by paired dataloggers co-located at microsites within seven 1-ha plots and a
series of meteorological sites in northern Alaska’s Kuparuk River watershed. These dataloggers represent older and newer models manufactured by one company.

The null hypothesis would be no differences between the datalogger measurements. Any differences recorded were hypothesized to be due seasonal differences in air temperatures, which could approach the operational limits of the instrumentation or related to spatial variability between the microtopography which affects soil moisture.

Although instrumentation comparison is standard practice, the statistics generated from these specific data have not been analyzed until now. Substantiation of the consistency of this northern Alaska dataset will allow CALM to further contribute to the greater understanding of the complex climate system.

1.2 STUDY AREA

Alaska’s Kuparuk River flows northward from the Brooks Range to the Beaufort Sea (Figure 1). The Kuparuk River watershed spans several distinct bioclimatic zones with soil/vegetation associations ranging from moist acidic to non-acidic tundra, and two physiographic provinces (Wahrhaftig, 1965). These sites were chosen to represent regional variability within the watershed as part of the Arctic Flux Study proposed in the early 1990s (Weller et al., 1995; Kane and Reeburgh, 1998). Each plot (Figure 2) was studied intensively to characterize the soils (Michaelson et al., 1996; Bockheim et al., 1998), active-layer (Nelson et al., 1997), vegetation/ecology (Walker et al., 1998), and micro-climatic (Eugster et al., 1997) conditions within the 1 ha plot. Tables 1 and 2 describe the characteristics of each site following Walker and Bockheim (1995).
Figure 1. Overview map of Alaska with the Flux Study sites marked.

Figure 2. Alaska’s North Slope marked with Flux Study sites 1-10 between the Brooks Mountain Range and the Beaufort Sea. Site 5 was largely deactivated due to its extreme mountainous location, Site 9 was washed away from a flood, and a site was added at mile “56” on the highway at the southern-most margin of the coastal plain just north of the foothills physiographic province. See Tables 1 and 2 for detailed descriptions.
Table 1. Characteristics of the Flux Study plots reprinted from Klene (2000). Landcover, provinces, elevation, soil information, orientation, slope, and organic-layer thickness are from Walker and Bockheim (1995).

<table>
<thead>
<tr>
<th>Flux Site</th>
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<th>Longitude (W)</th>
<th>Elevation (m)</th>
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<th>Active Layer ('95 – '97 end-of-season avg.) (cm)</th>
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<tr>
<td>95-1</td>
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<td>Moist Nonacidic Coastal Plain</td>
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<td>148° 53.648'</td>
<td>12</td>
<td>pergelic cryoborolls</td>
<td>Flat</td>
<td>42.2</td>
<td>12+/-1.7</td>
</tr>
<tr>
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<td>SW 7°</td>
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<td>trace</td>
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<td>938</td>
<td>pergelic cryaquepts</td>
<td>W 15°</td>
<td>44.3</td>
<td>15+/-1.9</td>
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<tr>
<td>95-9</td>
<td>Riparian Island</td>
<td>Shrubland Northern Foothills</td>
<td>69° 03.870'</td>
<td>148° 44.910'</td>
<td>349</td>
<td>pergelic cryorthents</td>
<td>Flat</td>
<td>--</td>
<td>1+/-0.2</td>
</tr>
<tr>
<td>95-10</td>
<td>Water Track</td>
<td>Water Track Northern Foothills</td>
<td>69° 07.730'</td>
<td>148° 35.490'</td>
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<td>histic pergelic cryaquolls</td>
<td>SE 4°</td>
<td>44.5</td>
<td>19+/-0.9</td>
</tr>
</tbody>
</table>
Table 2. *Descriptions of the five main land-cover classes in the Kuparuk River Basin with characteristic species (Walker and Bockheim, 1995) and Flux plot most representative of each class reprinted from Klene et al., 2001a.*

1. **Moist acidic tundra.** Tussocks dominate the surface. Vegetation includes *Betula nana*, *Eriophrum vaginatum*, *Hylocomium splendens*, *Salix pulchra*, and *Sphagnum* mosses. (Plot 95-4).

2. **Moist nonacidic tundra.** Cryoturbated frost scars are common. *Carex bigelowii*, *Eriophorum triste*, *E. vaginatum*, *Dryas integrifolia*, *Hylocomium splendens*, *Juncus biglumis*, *Ochrolechia frigida*, *Racomitrium lanuginosum*, *Thamnolia subuliformis*, *Tomentypnum nitens*, *Salix reticulata*, and *Saxifraga oppositifolia*. (Plot 95-3).

3. **Wet tundra.** Creeks, areas with standing water and raised border areas are included. *Betula nana*, *Carex rotundata*, *C. aquatilis*, *C. rariflora*, *Drepanocladus revolvens*, *Dryas integrifolia*, *Eriophorum scheuchzeri*, *E. augustinolium*, *E. triste*, *E. vaginatum*, *Hippuris vulgaris*, *Salix fuscescens*, *Scorpidium scorpiodes*, *Sparganium hyperboreum*, *Sphagnum orientale*, *S. lenense*, *Thamnolia subuliformis*, and *Tomentypnum nitens* are found at different microsites. (Plots 95-2 and 95-7).

4. **Shrublands.** These areas support the lushest and tallest vegetation in the foothills. Average vegetation height is 18.4 cm. Dry areas support *Arctous rubra*, *Hedysarum mackenzii*, *Hylocomium splendens*, *Salix glauca*, and *S. lanata*. Wetter areas have *Betula nana*, *Carex bigelowii*, *C. capillaris*, *Distichium capilaceum*, *Equisetum variegatum*, *Petasites frigidus*, *Rubus chamaemorus*, *S. pulchra*, and *Sphagnum* mosses. (Plots 95-9 and 95-10).

5. **Barren ground.** The scarcity of vegetation is demonstrated by the 0.1-cm mean vegetation height. Only a thin, sporadic organic layer is present. Protected micro-sites have *Carex microchaeta*, *Polytichnum pilifernum*, and *Salix phlebophylla*. Vegetated exposed-site species are *Alectoria nigricans*, *Douglasia ochotensis*, and *S. phlebophylla*. (Plot 95-5).
2 METHODOLOGY

2.1 TEMPERATURE DATA PROCESSING

At each 1-ha plot, a set of dataloggers manufactured by Onset Computer Corporation®¹ which measure and record air and soil-surface temperatures were installed in summer 1995. Site 56-mile was the exception, installed in summer 1996 to include a site at the southern extent of the coastal plain. The thermistors were positioned immediately below the surface of the ground at each site, which were each selected to represent the full range of microsite conditions within each plot. The micro-site locations have descriptions (such as “grassy”, “top of ice-wedge polygon rim”, “moist polygon trough”, “dry center, small grassy tussock”, “low mossy area”, “high dry polygon rim”, “very wet trough”, etc.) recorded in metadata collected when during initial installation in 1995 and summarized in Klene (2000). Photographs of each micro-site location were also recorded in 2005 by Klene and made available for this project.

In hourly and bi-hour intervals, the thermistors register temperatures and the data are recorded and stored for download each August. In 2005 and 2011, older instrumentation was replaced with newer models with longer battery life and better water-proof cases; the paired instrumentation was run side-by-side for 1 year. The three models of instrumentation (Stowaway, Hobo Pro, and Hobo Pro V2) are shown in Figure 3. It should be noted that several iterations of the Stowaway logger were produced and used interchangeably in the 1990s as the technology improved (e.g. memory capacity was just 8 kb in the earliest versions). The Hobo Pros used for this study had a temperature design range from 50°C to 30°C, a precision of 0.02°C, and an accuracy of 0.2°C near the freezing point. Designs specifications for the Stowaways and Hobo Pro

¹ Onset Computer Corporation, Bourne, MA.
V2s were very similar. Comparing the temperature readings of these different datalogger models allows us to test the replicability of the installation technique and performance of the dataloggers as well as this dataset.

The extreme Arctic environmental conditions of the Kuparuk River watershed has resulted in the destruction or unwanted transportation of some of the dataloggers from animals (chewing, shooting, moving, or removal) and extreme weather events (primarily flooding). This caused several paired models to have obviously inaccurate data or been entirely lost and these were not included in this study.

![Figure 3. Onset Computer Corporation® dataloggers used from newest (top) to oldest (bottom right). Top: Hobo Pro V2 logger installed in August 2011. Bottom left: Hobo Pro logger installed August 2005. Bottom right: Stowaway logger installed in 1995.](image-url)
The temperature data were transferred from the instrument onto a laptop from the field, which allowed the data to be exported into a usable format with Boxcar© software, processed into daily statistics using a FORTRAN code if applicable, and then compiled within Excel. Data from the newer and older models were then paired for examination, and temperatures from the older model were subtracted from the newer model’s observations to produce differences. Statistics were generated for the original observations from each datalogger as well as from the temperature change values, including maximum, mean, and minimum for each value.

Field notes from the 2005-2006 and 2011-2012 seasons were reviewed to distinguish reasons for apparent logger error. The field notes revealed a number of potential causes of error at individual sites, ranging from animals chewing the loggers, instruments being displaced out of the ground likely by extreme weather events or soil heave in frost boils (a periglacial feature which experiences high soil movement). Apparent error between the logger pairs also arose from installation timing. In several cases unreasonably high apparent temperature differences (>10°C) were caused because the newer model (the Hobo Pro in 2005 and the V2 in 2011) began taking measurements before they were installed in the ground. These so-called “backpack” measurements were deleted from the study, as were the others where some disruption had caused the thermistor of one or both instruments in the pair to be dislodged from the ground.

2.2 2005-2006 HOBO PRO VS. STOWAWAY COMPARISONS

While miniature, relatively low-cost (US ~ $100) dataloggers were a modern technological development in the early 1990s, Onset Computer Corporation’s Stowaway

2 Produced by Onset Computer Corporation, Bourne, MA.
was not a weather-proof design, and so deploying it in the field required them to be secured within a water-proof container. The method developed by Klene’s colleagues involved a polyvinyl chloride (PVC) canister with a screw-top lid that was then caulked with silicone caulk which had to be removed and replaced each time the dataloggers were services (downloaded, and desiccant and batteries replaced). The thermistors were run through a small hole in the bottom of the canister which was also caulked. The failure rate of data retrieval from the dataloggers operating in this container was approximately 40%. The weather-proof Hobo Pro design featuring an O-ring and screw had been field tested at the request of Onset Computer Corporation by Klene who left the instruments running over winter in shallow ponds near Barrow, Alaska. Successful performance and much easier servicing of the dataloggers led to the decision to replace all of the older instruments.

In August 2005, a substantial upgrade to the temperature network occurred with the installation of the Hobo Pros. The Stowaway models were removed from the sites after the year-long comparison was complete in August 2006, whilst the Hobo Pro models remained installed until the introduction of the Hobo Pro V2 design. Some of the Stowaway loggers had been operating for 10 years when the Hobo Pros were installed and the impressive performance of the test Pros the year before led to only a cursory comparison of the two models.

Mean daily temperature measurements from paired Hobo Pro and Stowaway loggers (n=7) were compared from 2005-2006. Maximum, mean, and minimum daily temperatures are the standard format archived on the CALM website (www.gwu.edu/~calm/). Thus, it makes sense to evaluate the performance of the
dataloggers on the most commonly used product generated by these observations. This was done using the 2005-6 data.

2.3 2011-2012 HOBO PRO V2 VS. HOBO PRO COMPARISONS

Further improvements by Onset led them to suggest a replacement of the instrumentation when they released the Hobo Pro V2 design which featured a much smaller opening and O-ring which could be compromised and an interface which meant that the logger could be downloaded without stopping or opening the datalogger container. This time, a more complete instrumentation comparison was performed. Bi-hourly temperature measurements from paired Hobo Pro V2 and Hobo Pro loggers (n=53) were compared from August 2011 to 2012. After the comparison was completed, the Hobo Pro loggers were removed from the sites, leaving only Hobo Pro V2’s in place for future monitoring.

Occasionally, the bi-hourly temperature data are utilized from these sites (for instance as a means of estimating snow-cover duration; 2014), so for the 2011-12 comparison the bi-hourly observations and differences were examined. This is also a more accurate comparison of the performance of the instrumentation itself.

2.4 STATISTICAL METHODS

When each new datalogger was installed, great care was taken to put the new thermistor as close as possible to the thermistor already in place. As much as possible, they were parallel and literally touching along their length. Thus, the two measurements
should be almost identical, and so evaluation focused upon differences between each pair of bi-hourly observation.

Summary statistics of these differences were calculated, including maximum, mean and minimum differences. In addition, four metrics that are often used to examine model results were calculated as well: the mean bias error (MBE), the mean average error (MAE), the root-mean-square error (RMSE; Willmott and Matsuura, 2006), and the index of agreement (d₁; Willmott et al., 2012). The MBE is the averaged value of the difference between the predicted (older model) minus the observed (newer model) values, and this calculation indicates the average bias of the newer observations relative to the older. The MAE is the sum of the absolute values of errors (which yields the total error) divided by the number of samples. The RMSE is calculated by squaring the differences between the observed (newer) and predicted (older) values, then taking the mean of those squared differences, and then taking the square root, emphasizing the prevalence of larger errors between paired observations. The index of agreement is similar to a Pearson’s Product-Moment Correlation Coefficient, r, in that it ranges from 0.0 to 1.0. However, unlike r (which indicates the co-linearity of one variable to in reference to another), a value of 1.0 for d₁ indicates a perfect fit in the values of the observed and predicted data, making it appropriate for use in modeling (Willmott et al., 2012) and when comparing two measures of the same variable as examined here.

Time-series charts showing the observed temperatures and temperature differences over a 1-year duration were generated for each pair to illustrate the seasonal differences at each location. Graphs were also plotted showing the temperatures observed by both loggers relative to a one-to-one function. Box-and-whisker plots were
generated to summarize the minimum, median, quartile, and maximum statistics of the differences between paired mean temperature differences (newer model minus older model observations) for both time periods, 2005-2006 and 2011-2012. Finally using field descriptions of each site, trends in temperature differences were examined relative to moisture levels.
3  RESULTS AND DISCUSSION

Statistical comparisons between the 2005-2006 Stowaway/Hobo Pro daily mean temperatures and the 2011-2012 Hobo Pro/V2 bi-hourly temperatures yielded several results. First, mean differences over the period of record were low (<±0.5°C). Second, temporal variability in the differences are systematically related to seasonal cycles, with the largest differences in summer when the active layer thaws and is the most dynamic. Third, spatial variability within and between the plots is revealed by systematic differences in micro-site locations with larger differences at warmer, drier.

   Results are presented first in each section, followed by discussion.

3.1 2005-2006 HOBO PRO VS. STOWAWAY COMPARISONS

Summary statistics from the yearlong comparison of 2005-2006 Hobo Pro/Stowaway mean daily temperatures and differences revealed the consistency of the different instrumentation models. Daily temperature measurements yielded a mean temperature difference of 0.02°C between all of the compared sites. The maximum difference in mean daily temperatures among all of the pairs was 2.5°C, with an overall MAE of 0.5°C. Figure 4 is a box-and-whisker plot which show the maximum, median, minimum, and quartiles of the temperature differences between instrumentation for each paired logger. A table showing the results for each pair of loggers is presented in Appendix A.
Figure 4. The Hobo Pro/Stowaway comparison box-and-whisker plot of daily temperature differences from the available study sites (n=7), which are labeled as the “Flux Study site – logger number”, for instance Flux site 7, logger 1a is shown as “7-1a”.

3.2 2011-2012 HOBO PRO V2 VS. HOBO PRO COMPARISONS

Bi-hourly temperature measurements from paired Hobo Pro V2 and Hobo Pro loggers (n=53) were compared from August 2011 to August 2012, yielding a mean temperature difference of 0.12°C overall at the compared sites. Mean temperature
differences were low (<5°C), but larger than the mean daily temperature differences discussed in section 3.1. Figure 5 shows a box-and-whisker plot of the 2011-2012 comparison, illustrating the maximum, median, quartiles, and minimums at each pair. Appendix B is a table listing the summary statistics for each pair of instrumentation.

The mean temperature differences between the 2011-2012 paired loggers is substantially larger than differences recorded in 2005-2006 pairs, but this is clearly related to these being bi-hourly measurements rather than daily means of 24 observations taken in 2005-2006. In addition, the bi-hourly measurements compared were systematically off from each other by 1-hour, believed to be due to a Microsoft date/time issue in which if an automatic daylight-savings time conversion is not turned off, all of the times are “adjusted”. If a dataset is opened on any computer which has this setting, the timestamp can be changed permanently when saved. This may partially explain the large temperature discrepancies, but cannot be assumed, so further investigation into the handling and processing of the datafiles should be done and the analysis checked for validity.
Figure 5. The HoboPro V2/Hobo Pro comparison box-and-whisker plot of bi-hourly temperature differences from the available study sites (n=53), which are labeled as “Flux Study site – logger number”.

3.3 2005-2006 AND 2011-2012 SEASONAL VARIABILITY

Time-series graphs of the mean daily temperatures and the differences in those between paired dataloggers from 2005-2006 (Figure 6) revealed a distinct seasonal variability, as hypothesized. Figure 7 shows a photograph of the microsite location with those instruments installed. However, in contrast to the hypothesis, variability did not increase near the operational limits of the instrumentation (50°C to 30°C), rather there was less variability in winter months when the active layer was frozen and more variation in
the summer months when the soils were thawed. This pattern was also evident in the bi-hourly temperature differences in 2011-2012. Figures 8-13 show three examples of time-series graphs and micro-site locations from the Hobo Pro V2 and Hobo Pro comparison, although all of the photographs were taken in 2005. These graphs show that even in the individual measurements, there is much less difference between temperature observations when the soils are frozen. Figure 14 is an example of a one-to-one plot of the bi-hourly temperature observations, which clearly show the close correlation of data at colder temperatures, with increasing variability above the freezing point.

In the summer there is a much larger amount of moisture movement within the soil column compared to when the active layer is frozen in winter. The thermal gradient in the upper-portion of the soil column is also less in winter than summer, which could lead to larger differences due to even very small differences in thermistor locations. These may contribute to the temperature differences between paired instrumentation being so much greater in the summer months compared to the winter months.
Figure 6. Flux Study Plot 8, logger 7. Graph showing the temperatures from the Stowaway, Hobo Pro, and the difference between them recorded at the microsite shown in Figure 8. The annual mean difference was 0.32°C.

Figure 7. Flux site 8, logger 7. Located at Imnavait Creek, a moist acidic site with watertracks. Unit 7 is a muddy inter-tussock microsite.
Figure 8. Flux 1, Logger 8. Plot showing the temperatures from the V2, Hobo Pro, and the difference between them recorded at the microsite shown in Figure 10. The annual mean difference was 0.02°C.

Figure 9. Flux site 1, logger 8. Located at Sagwon, a moist non-acidic tundra site. Unit 8 is a very wet microsite in an ice-wedge trough.
Figure 10. Flux 2, logger 5. Plot showing the temperatures from the V2, Hobo Pro, and the difference between them recorded at the microsite shown in Figure 12. The annual mean difference was 0.06°C.

Figure 11. Flux site 2, logger 5. Located at Betty Pingo, a wet site on the coastal plain by Prudhoe Bay. The site is flat with low-centered polygons and wet, non-acidic tundra. Unit 5 is within a low-centered polygon microsite.
Figure 12. Flux 3, logger 3. Plot showing the temperatures from the V2, Hobo Pro, and the difference between them recorded at the microsite shown in Figure 14. The annual mean difference was 0.03°C.

Figure 13. Flux site 3, logger 3. Located at Sagwon, a moist non-acidic site in the northern foothills. The site has a northwest-facing slope of 4° with non-sorted circles. Unit 3 is a dry, high microsite on the edge of a tussock.
Figure 14. The difference between the Hobo Pro V2 and Hobo Pro instruments located at Flux Site 9 from 2011-2012. Larger difference between instrumentation was observed in the summer months when the active layer thawed.

3.4 2011-2012 HOBO PRO V2 VS HOBO PRO SPATIAL VARIABILITY

Spatial variability between and within the Flux Plots exposed a relationship between micro-site moisture levels, with greater temperature differences between instrumentation models being at warm, dry sites and smaller temperature differences at the wet sites (Figure 15). Of the sites examined in the 2011-2012 study, seven were described as dry and 12 were described as wet, with the remainder of the sites not having a description mentioning moisture. The mean minimum temperature difference at the dry sites was −9.52°C and for the wet sites −9.12°C. The mean maximum temperature difference at the dry sites was 8.77°C, and 6.95°C for the wet sites.
This spatial variability may be due to the amount of fluctuating moisture within the soil column, or elevation differences between the plots but it is difficult to make these assumptions with the small range of available data.

**Figure 15.** An examination of the spatial variability between wet vs. dry microsite conditions of the examined Flux sites. The study sites are labeled as “Flux Study site . logger number”. The temperature differences between paired instrumentation at the dry sites were slightly greater than the differences at the wet sites, although the differences were not incredibly significant.
4 CONCLUSIONS

This analysis helped quantify the reliability of the CALM’s northern Alaskan air and soil-surface temperature archive. Statistical comparisons between the 2005-2006 Stowaway/ Hobo Pro and the 2011-2012 Hobo Pro/ Hobo ProV2 bi-hourly temperature differences yielded several results. First, mean differences over the period of record were low (<±0.5°C). Second, temporal variability in the differences were systematically related to seasonal cycles, with the largest differences in summer when the active layer thaws and most biogeochemical processes are occurring. Third, spatial variability within and between the plots was revealed by systematic though small differences in micro-site locations with larger differences at warmer, drier sites.

Future research should include resolving the date/time issue in the 2011-2012 dataset, repeating this so that the variability of daily and bi-hourly datasets for both periods, and further investigation of the spatial variability between these data in relation to moisture conditions.

The research that is being conducted by CALM project is vital to improve understanding of the response of the active layer of permafrost to climatic change. The thickening of the active layer in northern Alaska and other Arctic regions has the potential to lead to the discharge of further greenhouse gases into our atmosphere, resulting in a further intensification of climate change, as well as cause a variety of ecological feedbacks, and impact human livelihoods in the region.
BIBLIOGRAPHY


APPENDIX A:

Table A: 2005-2006 daily temperature differences from the newer “observed” (Hobo Pro) instrumentation versus the older “predicted” (Stowaway) datalogger models. Mean bias error (MBE), mean absolute error (MAE), and root mean square error (RMSE), and the index of agreement ($d_1$) are shown for each logger comparison.

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APPENDIX B

Table B: 2011-2012 bi-hourly temperature differences from the newer “observed” (Hobo Pro V2) instrumentation versus the older “predicted” (Hobo Pro) datalogger models. Mean bias error (MBE), mean absolute error (MAE), and root mean square error (RMSE), and the index of agreement ($d_1$) are shown for each logger comparison.

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