BEST PRACTICES FOR SHALLOW GROUND TEMPERATURE MEASUREMENTS

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Geology

in the

College of Graduate Studies

University of Idaho

by

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December 2014

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Authorization to Submit Thesis

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Abstract

Shallow ground temperature measurements are commonly used to analyze geothermally active areas. In other shallow ground temperature studies, many researchers utilize temperature measurements at one meter depth on a sparse, irregularly spaced sampling interval. However, a one meter depth can be quite invasive to fragile environments and take substantial time. We propose the use of temperature probes 25 centimeters in length on a set grid with high density spacing (e.g., 72 x 72 meters with 3 x 3 meter spacing). The high density sampling interval on a set grid is superior because it allows for the development of spatial correlation relationships, and because the uncertainty of the measured temperatures decreases proportional to the square root of the total number of data points collected. Therefore, this study focuses on the best practices for collecting shallow ground temperature measurements. Additionally, this study assesses the resilience of our shallow ground temperature measurement methodology to significant changes in atmospheric conditions.

Acknowledgements

I would like to thank my advisor, Jerry Fairley, for taking me on as a graduate student and teaching me invaluable knowledge and professionalism throughout my graduate career. I also need to thank my Committee Members, Thomas Williams and Leslie Baker, for their help and ideas to make my thesis stronger. My research group, Cary Lindsey and Alex Moody, deserve a special thank you; sharing ideas with them made my research and geostatistical analyses possible. Thank you, Cary, for also helping plan some of my data collection in the Alvord Basin, Oregon and Yellowstone National Park, Wyoming.

I am no less indebted to both my data collection teams of Marian Buzon, Scott Ducar, Cary Lindsey, and Alex Moody in the Alvord Basin, OR and Erika Rader, Jennifer Light, Ben Jones, Jay Myers, Keegan Schmidt, Nick McMillan, Joe Mulvaney-Norris, Cary Lindsey, and Alex Moody in Yellowstone National Park, WY. Without them, collecting my temperature surveys would not have been possible.

My undergraduate advisor, Chad Wittkop, from Minnesota State University, Mankato deserves a special thank you, because his advising and professional guidance made my graduate career possible. I would also like to thank the rest of the Minnesota State University, Mankato faculty and the University of Idaho, Moscow faculty for giving me the knowledge and skills necessary to be successful.

I must thank Jerry Fairley and Peter Larson for finding through the National Science Foundation for data collection in Yellowstone National Park, WY. I also want to thank the GDL Foundation for providing funding to purchase research equipment.

I would like to especially thank my loving parents, Lynn and Pam, for helping me through my undergraduate and graduate career, always being there for me when things were

rough, and teaching me to be a better person. I want to thank my sister, Melissa, for being there for me and still loving me despite how much I have aggravated her while we were younger. My best friend, Trilobite, deserves a special thank you for brightening my day, no matter how it went. Lastly, I would like to thank the rest of my family and friends for their love and support. Without everyone in my life, this accomplishment would not have been possible.

Table of Contents

List of Figures

Chapter One: Shallow Ground Temperature Measurement Practices

1. Introduction

This study focuses on improving shallow ground temperature collection methods from the Alvord Basin, Oregon and applying these improved methods for collecting similar data in Yellowstone National Park, Wyoming because the original study was unable to be completed. The original study was to determine the stage of breach maturity of the relay ramps in the Alvord Basin, OR along the Borax Lake fault by using shallow ground temperature measurements as a proxy of shallow fluid flow in fractures. For this research, three shallow ground temperature surveys were conducted in the Alvord Basin, OR to analyze the relay ramps. These surveys were also conducted to practice collecting shallow ground temperature measurements for similar ground temperature surveys a few months later at Yellowstone National Park, WY. The surveys at Yellowstone National Park, WY are a part of a larger project funded by the National Science Foundation (NSF) titled, "Collaborative research: Constraining heat flux from the shallow geothermal system, Yellowstone Caldera, Wyoming (Fairley, 2013)." However, due to equipment malfunction during the data collection process in the Alvord Basin, OR, significant errors resulted in the data sets preventing the original study from being completed. Therefore, the thesis changed focus to determining the best practices for shallow ground temperature measurements to avoid these data errors in the future. This study also discusses the usual data collection methods of other shallow ground temperature studies and why our methods are superior. Additionally, a temperature grid was resampled in Yellowstone National Park, WY after significant rain events and analyzed, confirming spatial correlation structures were unaffected by moderate changes in weather.

1.1 Geologic setting of Alvord Basin, OR

The study area is located within the Alvord Basin, southeastern OR (Figure 1). The Alvord Basin is within the northern section of the Basin and Range Province. The east and west extension of the province produced many horst and grabens throughout the region (Anderson and Fairley, 2008). The Alvord Basin is a north-south trending graben, approximately 90 kilometers long and 21 kilometers wide, with the major horst block of Steens Mountain and the Pueblo Mountains to the west and the topographically lower horst block of the Trout Creek Mountains and the Sheepshead Mountains to the east (Anderson and Fairley, 2008). Several north-northeast trending normal faults are common due to regional extension; the basin is experiencing dextral shearing (Pezzopane and Weldon, 1993), producing strike slip faults (Lawrence, 1976), some of which connect the north-northeast trending normal faults (Williams and Compton, 1953; Anderson and Fairley, 2008). Displacements of normal faults bounding the basin to the west and east are 1,300 – 3,300 meters along the range front of the Steens Mountain and the Pueblo Mountains and 350 – 1,300 meters along the Trout Creek Mountains, respectively (Cleary et al., 1981; Hess et al., 2009). The Alvord fault, which runs along the base of Steens Mountain, has displayed signs of activity within the last 12,000 years (Hemphill-Haley et al., 2000). The crystalline basement rocks are exposed along the fault scarps of the Steens Mountain and Pueblo Mountains' range front that bound the basin to the west. These rocks are largely composed of Miocene volcanics including the Pike Creek Formation, consisting of rhyolite and dacite

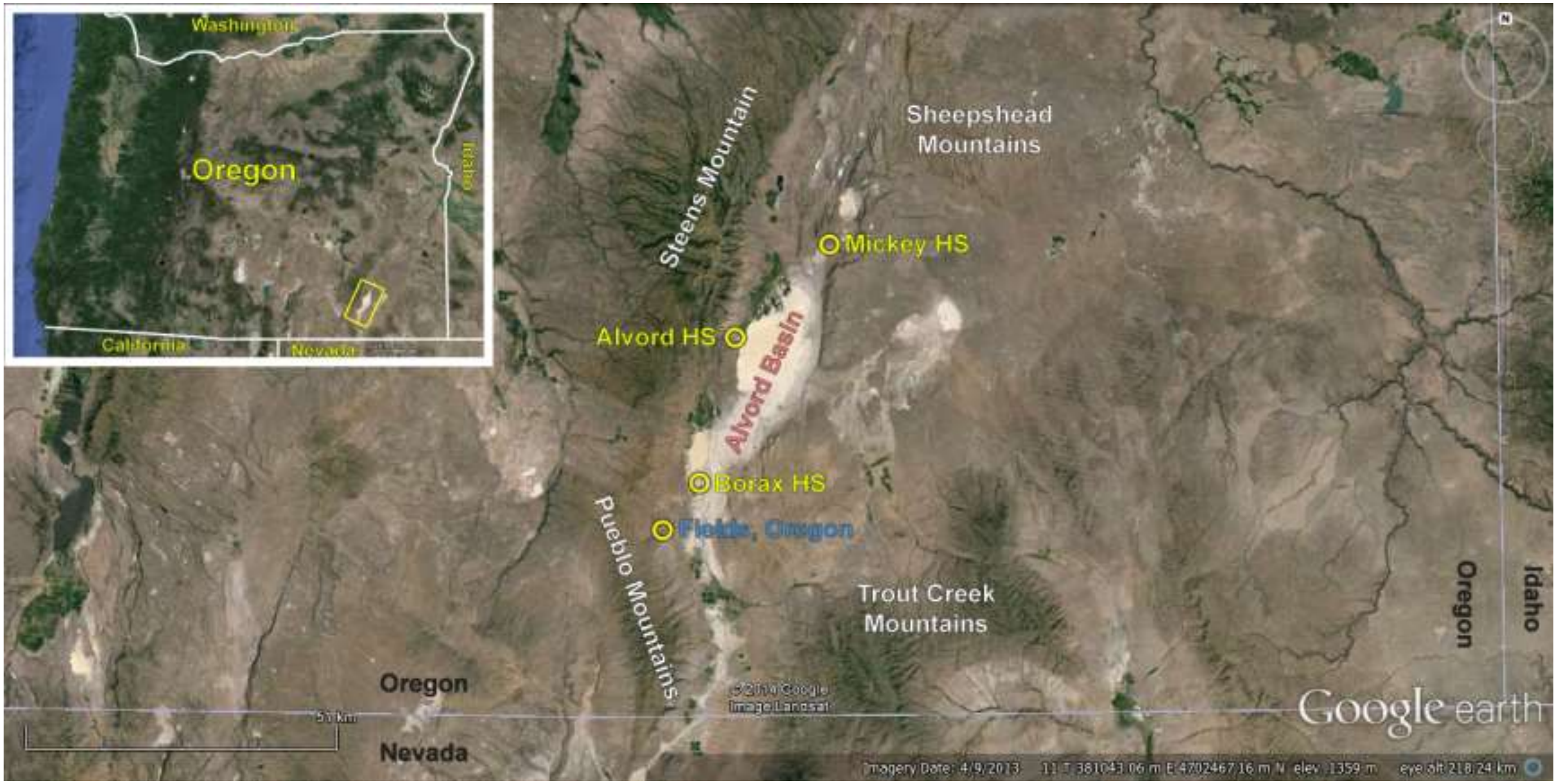

Figure 1. Google Earth image showing the location of study area at Borax Lake Hot Springs, located in the Alvord Basin, southeastern Oregon, USA.

flows, tuffs and one rhyolite ignimbrite, the Andesite series (i.e., the Steens Mountain Volcanics), a series of andesite and basaltic flows, and the Steens Basalt, a series of high-alumina olivine basalt flows with approximate thicknesses of 580 meters, 460 meters, and 900 meters respectively for each formation (Hook, 1981). Within the Alvord Basin lie poorly lithified alluvial and lacustrine sediments, intermixed with non-welded tuffs, atop siltstones and claystones that overlie Miocene volcanic rocks described above. Basin fill-in is largely variable and can reach depths near 1000 meters in the Alvord Basin (Hess et al., 2009). Geologic maps of the area (Minor et al., 1987; Rytuba et al., 1982; Sherrod et al., 1989; Walker and Repenning, 1965) provide more information on the geology and faults within and around the basin.

There are three main groups of thermal springs within the Alvord Basin, the Borax Lake Hot Springs, Alvord Hot Springs, and Mickey Hot springs groups. Borax Lake Hot Springs discharges from the Borax Lake fault and is the southernmost group found near the center of the valley. Alvord Hot Springs lies near the base of Steens Mountain and discharges from the Alvord Fault, along the western boundary of the basin. Mickey Hot Springs discharges from a range-front fault at the base of Mickey Butte on the opposite side of the basin from Alvord Hot Springs and further north (Anderson and Fairley, 2008). The isotopic signature of the thermal waters within the Alvord Basin suggests a meteoric origin (Cleary, 1974; Cummings et al., 1993; Koski and Wood, 2004) with nearby topographic highs recharging respective hot spring groups (Anderson and Fairley, 2008). Chemical and isotopic geothermometers suggest reservoir temperatures near 200 – 250°C (Cummings et al., 1993; Koski and Wood, 2004) with circulation depths of 2.0 – 2.5 kilometers for Borax Lake Hot Springs, 2.0 – 3.0 kilometers for Alvord Hot Springs, and 1.2 – 2.0 kilometers for Mickey

Hot Springs (Cummings et al., 1993; Anderson and Fairley, 2008). The heat source of the Alvord Basin geothermal system is non-magmatic (Varekamp and Buseck, 1983).

1.2 Site description for Borax Lake Hot Springs, Alvord Basin, OR

The study sites are located on the Borax Lake normal fault trending 015° azimuth; the fault lies just north of Borax Lake, Alvord Basin, OR (Figure 2). The area is named after Borax Lake, an irregularly shaped water body approximately 200 meters in diameter, at the south end of the Borax Lake fault. Borax Lake appears to be a large sinter mound and has one major and several minor vents within. Interestingly, Borax Lake is inhabited by an extremely rare chub only found within Borax Lake (Schneider and McFarland, 1995).

Blackwell et al. (1986) presents geophysical evidence that the Borax Lake fault bounds a buried horst and extends within a few meters of the land surface near the thermal springs. The topographic relief across the fault is up to three meters; however, recent geophysical data suggests up to 500 meters displacement across the fault (Heffner and Fairley, 2006). The relatively small topographic relief drives shallow groundwater flow eastward, away from the fault. The overall groundwater directional flow of the basin is northward towards Alvord Lake, however, this does not significantly influence the eastwardly flow in the study area (Fairley and Hinds, 2004a).

Borax Lake Hot Springs is comprised of about 175 thermal springs that outline the trace of the left stepping en-echelon fault that extends one kilometer north from Borax Lake. These thermal springs are divided into two groups, the North and South groups based upon their relative location north or south of the major step over area (University of Idaho Computational Hydrology, 2006). The surficial expression of the Borax Lake Hot Springs

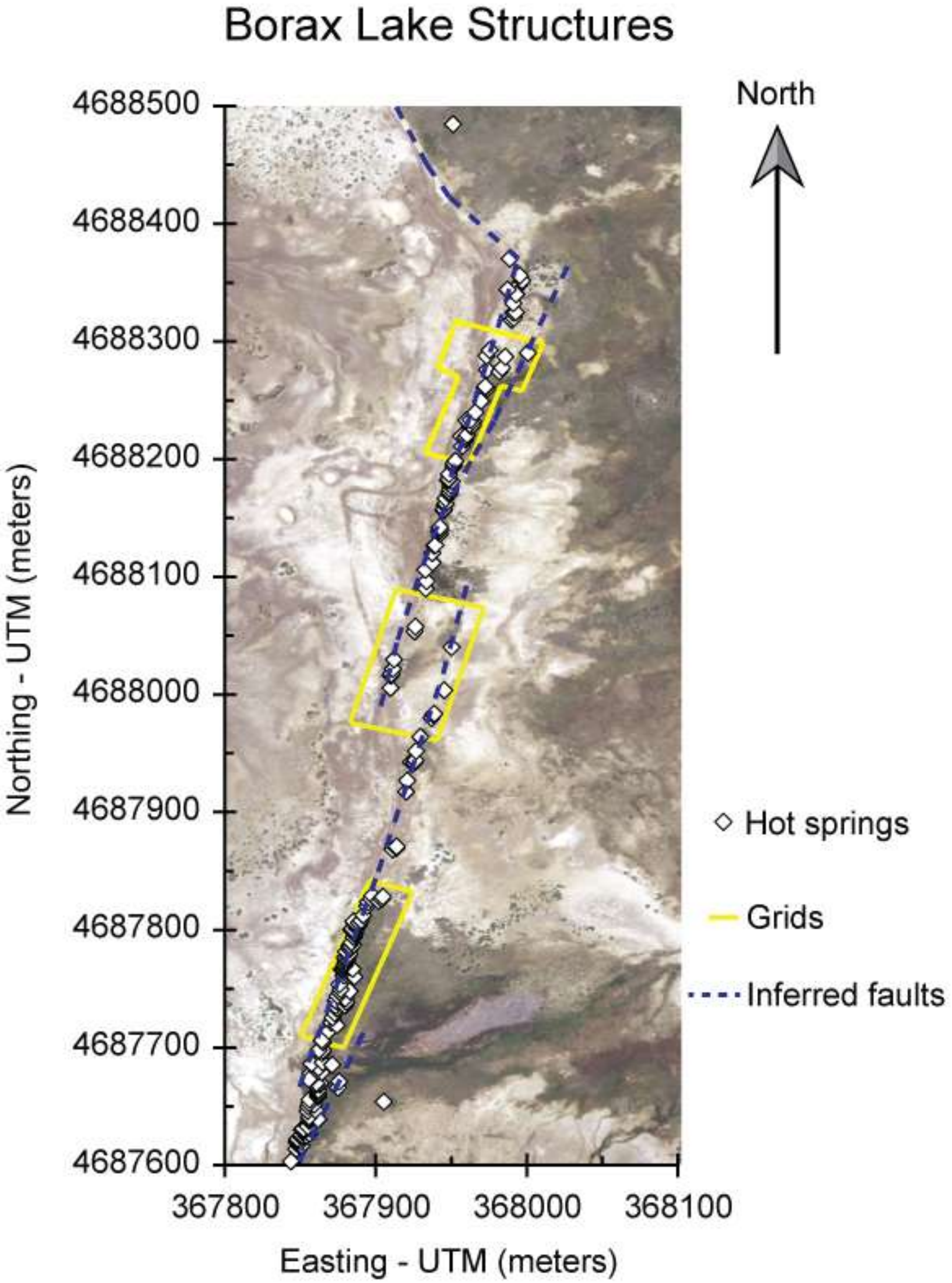

Figure 2. Orthophoto of Borax Lake Hot Springs area. The white diamonds represent the hot springs, the yellow lines are the grid boundaries, and the blue dashed lines are the inferred major faults through the area.

area and its linear alignment of hot springs suggest recent fault displacement. This is because when faults remain inactive for long periods, the high-permeability conduits eventually become cemented shut with mineral precipitates from the circulating geothermal fluids (Curewitz and Karson, 1997). Curewitz and Karson (1997) also explain how certain thermal spring groups can be kinematically maintained by their fault reopening.

The major ion chemistries of the Borax Lake Hot Springs' waters propose a common source for the thermal springs, with no obvious mixing of cool shallow groundwater (Fairley et al., 2003). The thermal spring temperatures of the Borax Lake area range from 15 – 94°C. Also, ground temperatures within the area are well above the ambient background ground temperatures with the water table intersecting the land surface in some areas of the site (Fairley and Nicholson, 2006). From these observations, ground temperature measurements are assumed to be in equilibrium with shallow subsurface fluids (~0.1 meters); this is common in heat and mass transport in porous media (Catton, 1985; Cheng, 1985; Wong and Dybbs, 1976; Anderson and Fairley, 2008).

Three shallow ground temperature surveys were performed on potential relay ramps within the Borax Lake Hot Springs area. However, since these surveys had significant data errors, only the first survey will be discussed. The first survey was performed on the relay ramp of the major step over area of the Borax Lake fault and it is referred to as the main relay ramp grid (Figure 2). This grid is 60 x 117 meters with 3 x 3 meter spacing and was set up to capture potential evidence of the main relay ramp being breached (i.e., the southern and northern sections of the Borax Lake fault being connected). The origin and baseline begin 48 meters from the B1060 spring at 285° azimuth and runs 60 meters at 105° azimuth, through the B1060 spring, respectively. With this orientation, the Y-axis of the grid runs 117 meters along the trace of the fault segments at 015° azimuth. This grid encompasses springs B1060 – B1180 in 10 naming increments (e.g., B1060, B1070, B1080, etc.) with temperatures ranging 36.0 – 86.2°C. For more information on specific thermal springs within the Borax Lake Hot Springs area, visit University of Idaho Computational Hydrology's online data base.

2. Shallow ground temperature collection methodology for Alvord Basin, OR

2.1 Introduction to collection methodology

Previous researchers in July, 2003 identified and mapped 285 thermal springs in the Alvord Basin, OR using radio-linked, dual frequency Leica global positioning system (GPS) receivers with a horizontal accuracy estimated to be better than one meter. These researchers also compiled an online database of the thermal springs at Borax Lake that contained minimum, maximum, and average temperatures, Universal Transverse Mercator (UTM) coordinates, pH, and digital photographs of springs (University of Idaho Computational Hydrology, 2006). The main relay ramp grid was georeferenced based upon the thermal spring UTM measurements from this research.

The shallow ground and spring temperatures for the main relay ramp grid in the Alvord Basin, OR were collected on March 15th, 2014. The main relay ramp grid contains 840 shallow ground and 13 spring temperature measurements. This grid was performed in less than four hours to eliminate diurnal effects.

Ground penetrating thermocouple probes accompanied with resistance meters on a set grid with high density spacing were used to collect shallow ground temperature measurements in this study. The thermocouples and resistance meters (i.e., digital thermometers) used are the Digi-Sense Type K Heavy-Duty Stainless-Steel Thermocouple Probes with T handle and the Fluke 50-Series II (Model 51) Thermocouple Thermometers with Single Input with an accuracy of 0.05% + 0.3°C. These thermocouple probes will also be referred to as ground temperature probes in this report. These ground temperature probes are 25.4 centimeters in length, have a 6.4 millimeter probe diameter, and a 50 second characteristic response time unit (Cole-Parmer, 2014). The characteristic response time is based on the equilibration time needed to collect a single temperature measurement. This equilibration time signifies how far from equilibrium the temperature measurement is from the true temperature value; the following equation represents this:

$$\mathrm{Equilibrium}(\%) = (1 - \mathrm{e}^{-\tau}) * 100\%,$$

with τ representing the number characteristic response time units passed. The ground temperature measurements were recorded after a minimum of three characteristic response time units (i.e., 150 seconds, which is 95% of the way to equilibrium).

The spring temperature measurements were also collected using the Fluke digital thermometers but were then collected with Digi-Sense Type K Small-diameter probes. These spring probes are just over 10 centimeters long, have a 1.6 millimeter probe diameter with hypodermic tip, and have a 15 second characteristic response time unit (Cole-Parmer, 2014). The spring temperature measurements were recorded after a minimum 45 seconds.

Thermocouples are used to measure temperatures by using two dissimilar conductors that contact each other in a circuit (Figure 3). In K type thermocouples, these conductors are chromel and alumel. A voltage is produced when the temperature at the contact point between the two conductors differs from the temperature at the reference points in other parts of the circuit. The measured voltage produced can be used to calculate the desired

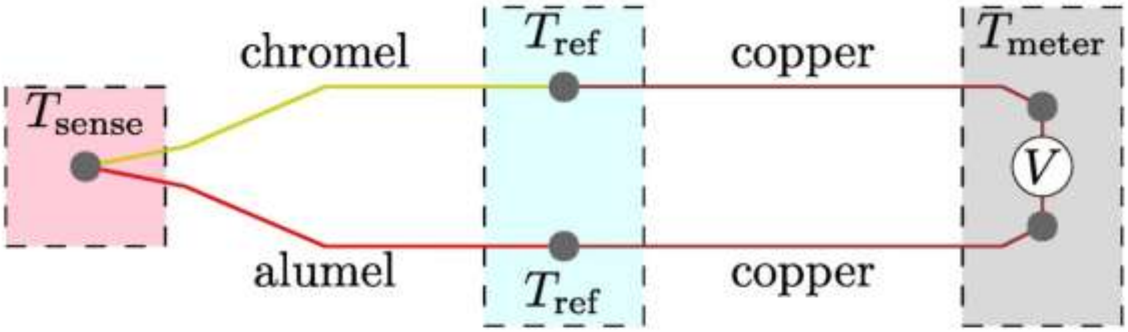

Figure 3. The construction of a typical K type thermocouple, where T_{sense} is the desired temperature, T_{ref} are the temperature reference points, V is the voltage produced, and T_{meter} is the temperature reading from the resistance meter (Wikipedia, 2014).

temperature when the temperature reference is known. If the circuit becomes damaged at any point, the thermocouple no longer performs properly. For example, if the circuit becomes incomplete at the contact point between the two conductors or anywhere else in the circuit, the thermocouple will not be able to produce a voltage. When the resistance meter is unable to measure a voltage it defaults to outputting the reference temperature (i.e., the cold junction). Another way the circuit can be damaged is if the conductors or the copper wiring come in contact with any other part of the circuit where it is not supposed to.

Thermocouple probes as opposed to typical thermometers are of particular interest to us because of their rugged construction to penetrate hard compacted ground and their ability to measure a wide range of temperatures accurately.

The depth of penetration for each thermocouple probe is exceptionally important because the length of our probes (i.e., 25 centimeters) represents a consistent temperature measurement depth along our observed temperature profiles. If we measure at any depth other than 25 centimeters, we are introducing some error into our measurements because we are now sampling at a different point along the temperature profile for that specific location. We do not know the amount of error introduced, but it is important to be aware, because it typically takes about one meter or more and ten meters depth to escape the diurnal and seasonal variations in the subsurface, respectively (Florides and Kalogirou, 2014). If there are ground temperature probe locations where they do not fully penetrate the length of your probes, it may be important to omit those data points depending on the specific temperature profile and amount of error you are introducing.

Temperature profiles are constantly changing with time and space. For example, the ground surface temperature at a specific location is constantly changing due to the time of day, time of year, and atmospheric conditions. Then different locations within a study area have different temperature profiles. For example, an area near a thermal spring may be cooler at the surface and the temperature gradually increase with depth as you become closer to the heat source, while an area not near a thermal spring may begin warmer at the surface and gradually cool with depth. It is important to note that since our measurement depths (i.e., 25 centimeters) are within the diurnal and seasonal fluctuations, we are only taking a snapshot of the shallow ground temperatures at that time.

2.2 Collection methodology

To begin collecting ground temperature measurements, the grid origin of the main relay ramp grid was determined by referencing the known thermal spring locations and using the specific orientations and lengths listed above in the site description with 100 meter measuring tapes and a Brunton compass. Once the grid origin was found, a plane table and alidade, sighting rod, and 100 meter measuring tapes were used to lay out the rest of the grid.

To collect ground temperatures on this set grid with high density spacing, we utilized a rolling grid method of 100 meter measuring tapes (Figure 4). First, the ground temperature probes were inserted into the ground, allowing time to equilibrate, and each probe was placed with its own digital thermometer to last throughout the duration of the grid. Once equilibrated, the temperature recorder walks down the line and records temperatures. As the recorder passes over a thermometer and probe set, field assistants move that thermometer and probe set to the next line in the grid (i.e., the next 100 meter measuring tape). After all ground temperatures have been recorded in one line and all the thermometer and probe sets have been moved to the next line in the grid, field assistants move that 100 meter measuring tape to the next desired grid line to repeat the process. Therefore, two 100 meter measuring

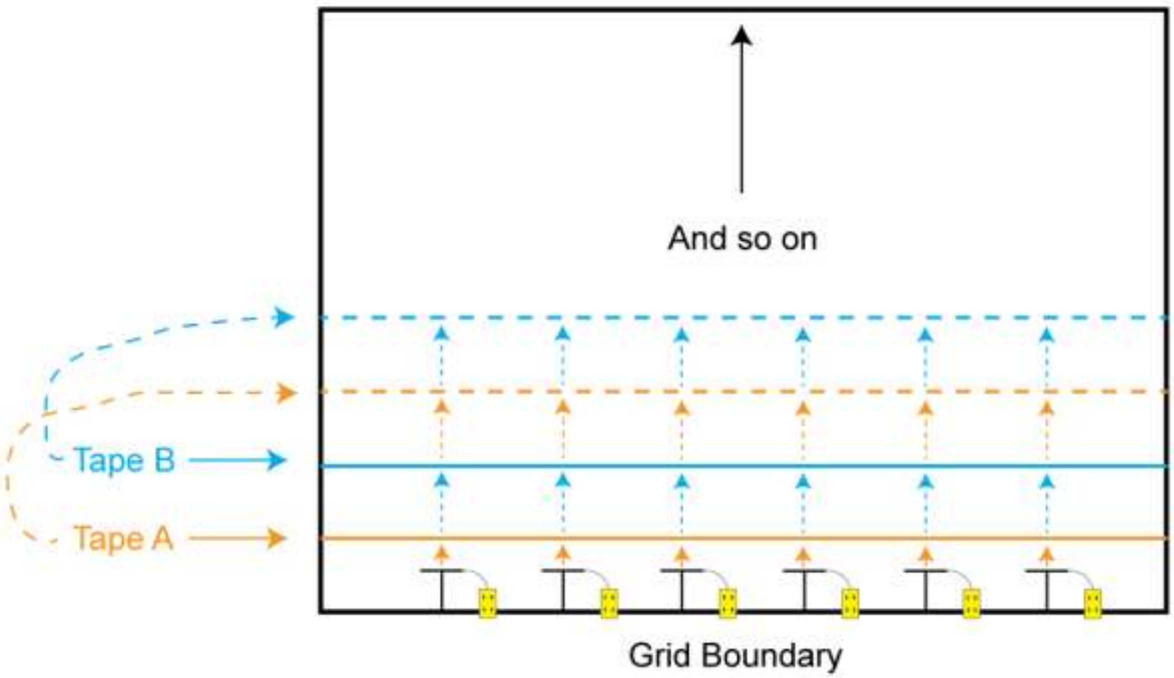

Figure 4. The rolling grid method for shallow ground temperature collection. The black T shape objects connected to yellow rectangles represent thermocouple probe and digital thermometer sets. After the temperature of a probe and thermometer set has been recorded at the boundary, that set will be moved to Tape A. After the temperature of a probe and thermometer set has been recorded on Tape A, it will be moved to Tape B. After all probe and thermometer sets are moved off of Tape A, Tape A will be rolled over Tape B to the next desired spacing interval and the process will be repeated until the grid is complete.

tapes are moved along with the thermometer and probe sets throughout the entire grid to know each ground temperature measurement location. This process will be known as "collection methods for shallow ground temperatures."

If you do not have enough thermometer and probe sets to stretch across the entire width of your grid for your desirable spacing interval, you can divide your grid into swaths and continue up one swath and down the adjacent one until the grid is complete.

The thermal spring temperatures were recorded with the highest temperature found in the thermal spring vents, while allowing time for equilibration. This method will be known as "collection methods for spring temperatures."

Before traveling to the Alvord Basin, OR, each ground temperature probe and thermal spring probe was placed in a boiling water bath and connected to a properly working digital thermometer to determine their functionalities. Then, all digital thermometers were tested with one properly functioning ground temperature probe to determine their functionalities. All digital thermometers, ground temperature probes, and thermal spring probes were working properly. This process will be known as "testing equipment functionality."

3. Data analysis and results for Alvord Basin, OR

The ground and spring temperature data were evaluated and analyzed using pscontour in Generic Mapping Tools (GMT). Pscontour contours X, Y, and Z data by direct triangulation. Figure 5 is the contoured temperature data for the main relay ramp grid, and it clearly shows linear artifacts within the data. We hypothesized these artifacts represent faulty temperatures from one or more ground temperature probes, implying some probes may not have been functioning properly.

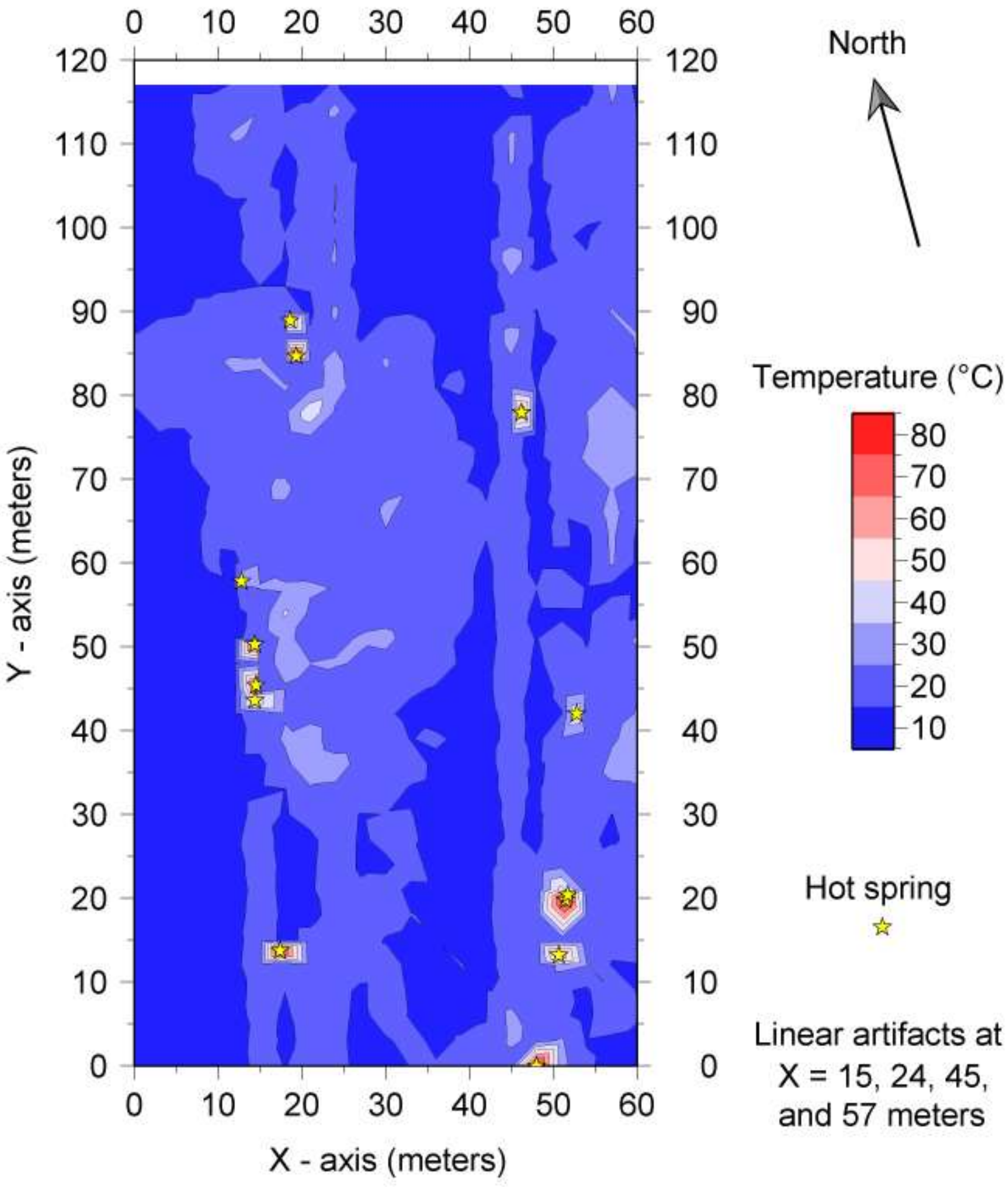

Figure 5. Temperature contour plot of the main relay ramp grid, Alvord Basin, OR. The yellow stars represent the hot springs within the grid and the temperature contour interval is 10°C. The data errors (i.e., linear artifacts) occur at X = 15, 24, 45, and 57 meters.

To determine which digital thermometers and/or ground temperature probes were not functioning correctly, the same process of "testing equipment functionality" was performed. Before data collection, all digital thermometers and ground temperature probes were functioning correctly. After returning from data collection, only one digital thermometer presented no temperature reading and five out of fifteen ground temperature probes were damaged in terms of their ability to measure temperature correctly. We used as many as thirteen ground temperature probes at one time, without any way of knowing which specific probes we used.

Even though the ground temperature probes were not functioning properly, they still measured a "temperature" for the boiling water bath. To further assess how damaged the ground temperatures probes were, we placed them in a large three liter ice bath on top of a hot plate (Figure 6). The ice bath was heated to boiling, and the ground temperature probes' measurements were recorded every 30 seconds for 9 minutes, and then every minute until 100 minutes. Figure 7 is a temperature against time plot for all the damaged probes, with probes 4, 6, 8, 10, and 11 being damaged and probe 1 being functional. Figure 7 clearly shows probes 6, 8, and 11 are not functioning correctly, probe 4 functions more or less correctly until approximately 80°C, probe 10 is functioning properly now, and probe 1 is still functioning properly.

Since probe 10 is functioning properly now with that specific digital thermometer, it was again tested with all digital thermometers in only the boiling water bath. Shortly after probe 10 was connected to a new digital thermometer, the thermometer and probe set was softly bumped and the temperature readout instantly changed from 97.2°C to 27.5°C and continued in the high 20°C's for the remainder of the digital thermometers and the previous

Figure 6. Faulty thermocouple probes in ice bath on top of hot plate to further assess damage.

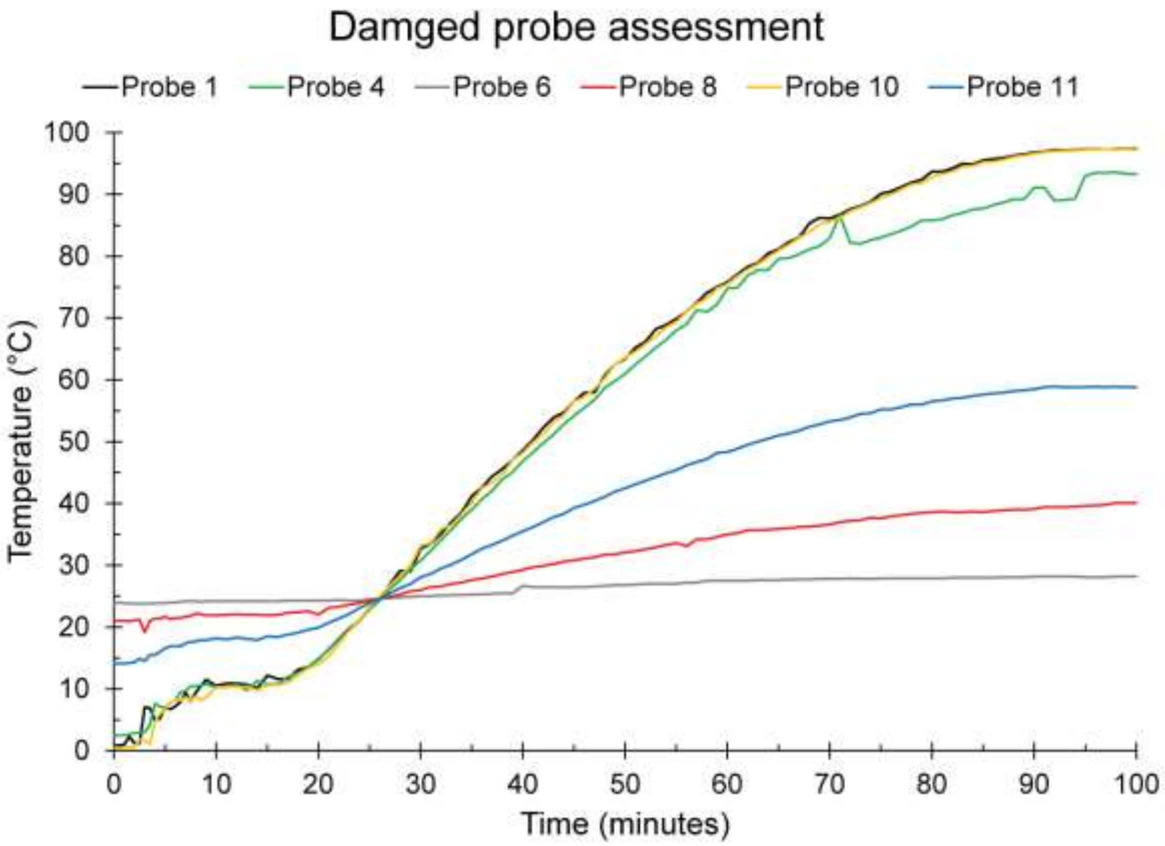

Figure 7. Temperature against time plot to further assess damaged thermocouple probes. Probe 1 is the functioning probe, while probes 4, 6, 8, 10, and 11 were the damaged probes.

digital thermometers. We hypothesized that some of the ground temperature probes are fairly sensitive, and their internal circuits may be compromised leading to faulty temperature measurements.

The ground temperature probes used for data collection in the Alvord Basin, OR were fairly old, and they were put through substantial abuse over years of data collection in harsh field conditions. However, we did not want to succumb to the idea that the faulty equipment was entirely responsible for the data errors; we recognized our methods could have been sounder to avoid these problems. As a result, it seemed appropriate to establish a new, more improved set of methodologies for conducting similar ground temperature surveys to avoid such problems in the future.

Chapter Two: Improving Shallow Ground Temperature Measurement Practices

1. Introduction

1.1 Other temperature studies

Many researchers utilize shallow ground temperature measurements within their studies. Some examples of this are to confirm the existences of archeological remains (Mori et al., 1999), to analyze heat transfer processes in a forested valley region (Kawanishi, 1983), to evaluate the development of a geothermal field following a volcanic eruption (Saba et al., 2007), to determine hydrothermal patterns on an active volcano (Miller and Mazot, 2013), to study how seismic noise heats the ground surface (Gordeev et al., 1992), to locate groundwater stream veins (Okuyama, 1992; Furuya et al., 2006), to assess slope failure due to groundwater stream veins (Furuya et al., 2006), to analyze fluid circulation patterns in hydrothermally active areas (Fairley and Hinds, 2004b), to study fault permeability in hydrothermally active areas (Anderson and Fairley, 2008), and to aid in diffusive heat flux measurements between geothermal springs in the NSF funded project mentioned earlier in the Introduction of Chapter One (Fairley, 2013).

Most of the studies listed above collected shallow ground temperature measurements by digging holes of various depths ranging from 4.5 – 100 centimeters. Therefore, these studies employed time intensive methodologies of digging holes and/or did not collect many ground temperature measurements. While Dr. Jerry Fairley’s research employed fast collection times with a much higher data collection quantity in the 100’s to 1000’s of ground temperature data points by using ground temperature probes on a set grid with high density spacing.

We believe these other shallow ground temperature studies with time intensive hole digging methodologies and/or the studies with few ground temperature measurements collected could have benefited by applying our ground temperature collection methodology to their shallower measurement depths of 25 centimeters or less. They could have performed their shallower measurement depths of 25 centimeters or less significantly faster and with a higher collection quantity to further support their research. Also, having a high density sampling interval on a set grid is superior because it allows for the development of spatial correlation relationships, and because the uncertainty of the measured temperatures decreases proportional to the square root of the total number of data points collected.

Since we believe so many shallow ground temperature applications could benefit from using ground temperature probes on a set grid with high density spacing, we developed a sounder “collection methods for shallow ground temperatures” to help further researchers, including ourselves, avoid our previous problems in the Alvord Basin, OR.

1.2 Geologic setting of Yellowstone National Park, MT and WY

The study area is located in Yellowstone National Park, northwestern WY (Figure 8). Yellowstone National Park is the nation’s first national park, established in 1872. It is located atop of the Yellowstone Plateau Volcanic Field (YPVF), which is a part of the most recent string of large calderas formed along the Snake River Plain over the past 17 million years (Pierce and Morgan, 1992; Hurwitz and Lowenstern, 2014) from the migration of the North American Plate over the Yellowstone Hot Spot (Love et al., 2007; Pierce and Morgan, 1992).

Figure 8. Google Earth image showing the location of study area in Yellowstone National Park, northwestern Wyoming, USA.

The Yellowstone Plateau is approximately 6,500 km^2 in area (Christiansen, 2001) and is surrounded by several mountain ranges: the Centennial Mountains to the west, the Gravelly, Madison, Gallatin, and Snowy Ranges to the northwest to north, respectively, the Absaroka Range to the northeast, east, and southeast, and the Red Mountains and Teton Range to the south. The only broad low land opening surrounding the plateau is the Snake River Plain to the southwest and west. These mountain ranges, valleys, and other major topographic features of the region were established before the first eruptions forming the YPVF 2.2 – 2.1 million years ago (Ma) (Christiansen, 2001). Many of these mountain ranges were formed during the Laramide Orogeny in the Late Cretaceous to Early Tertiary (Tonnsen, 1982; Love et al., 2007). The Absaroka Range, however, was formed from great volcanic eruptions in the Early Eocene, between 53 and 43 Ma. This mountain range is made up of thousands of cubic kilometers of lava, volcanic breccia, and volcanic ash eruptions (Love et al., 2007; Dickinson et al., 1988). While the Teton Range is also another Laramide Orogeny phenomenon, most of its uplift took place within the late Cenozoic (Lageson, 1992), specifically in last 5 million years along the Teton Fault (Love et al. 2007).

The YPVF is the product of three cataclysmic volcanic eruptions over the past 2.1 million years (Christiansen, 2001). The first eruption occurred 2.059 ± 0.004 Ma (Lanphere et al., 2002) and produced more than 2450 km^3 of the Huckleberry Ridge Tuff (Hurwitz and Lowenstern, 2014). The second eruption occurred 1.285 ± 0.004 Ma (Lanphere et al., 2002) and produced more than 280 km^3 of the Mesa Falls Tuff and the resulting Henrys Fork Caldera (Hurwitz and Lowenstern, 2014). The third eruption occurred 0.639 ± 0.002 Ma (Lanphere et al., 2002) and produced 1000 km^3 of the Lava Creek Tuff and the current Yellowstone Caldera (Hurwitz and Lowenstern, 2014). Throughout each eruption cycle, basaltic lavas erupted outside and around the margins of the active rhyolitic source areas, respectively (Hurwitz and Lowenstern, 2014). For more information on the geology of the Yellowstone Plateau, see Hurwitz and Lowenstern, 2014, Christiansen, 2001, and the geologic map titled, “Geologic Map of Yellowstone National Park” produced by the United States Geological Survey, 1972.

The YPVF is home to an immense hydrothermal system of over 10,000 hydrothermal features that include fumaroles, geysers, mud pots, thermal springs, and hydrothermal explosion craters (Hurwitz and Lowenstern, 2014). Almost all the heat and a considerable amount of the noncondensable gas discharged at Yellowstone Plateau are derived from the underlying magmatic source and transported through the enormous hydrothermal system (Hurwitz and Lowenstern, 2014). Among this gigantic hydrothermal system are several geyser basins. Some significant thermal areas in Yellowstone National Park are Gibbon Geyser Basin, Lower Geyser Basin, Mammoth Hot Springs area, Midway Geyser Basin, Mud Volcano area, Norris Geyser Basin, Shoshone Geyser Basin, Upper Geyser Basin, and West Thumb Geyser Basin (Yellowstone Media, 2013). To further investigate related information such as the seismicity, deformation, and chemistry of the hydrothermal system of the Yellowstone Plateau, see Hurwitz and Lowenstern, 2014.

1.3 Site description for Yellowstone National Park, WY

There are two study sites, Alpha and Bravo and three temperature surveys, Alpha, Bravo, and 2Bravo. The Bravo grid was resampled on a later day and named 2Bravo; therefore, the Bravo and 2Bravo grids were sampled at the same location.

The two study site locations of Alpha and Bravo are located just off of the western entry of the Mary Mountain Trail within the Lower Geyser Basin in Yellowstone National Park, WY

(Figure 9). The study sites Alpha and Bravo are about 85 meters and 60 meters off of the trail and 390 meters and 950 meters east of highway 287 that runs through the park, respectively. The Lower Geyser Basin has a few famous geysers and thermal areas within it. Some examples are the Great Fountain Geyser which erupts up to 46 meters into the air, White Dome Geyser whose eruption is relatively small despite it having one of the largest sinter cones in the park, and Pocket Basin which has the largest collection of mud pots in the park (Yellowstone Media, 2013).

The study sites are near the end of a small basin that drains the Nez Perce Creek; the basin is bounded by hills to the north and south with less than 65 meters of relief. The Nez Perce Creek runs about 260 meters north of the study sites. The Alpha grid is located in a relatively small opening, nestled among some trees just at the base of a large circular hill to the northwest. The Alpha grid has one main large thermal spring, named Alpha in this report (named Porcupine Hill Geyser by Yellowstone National Park), and a large thermal pool just to the east of it. The large thermal spring Alpha drains to the north/northwest towards the Nez Perce Creek.

The Bravo grid is in a large open field just to the north of a small string of hills. This large open field, which has several thermal springs discharging within it, becomes quite marshy after significant rain events. The Bravo grid contains six thermal springs and has some others in the immediate area, with the main large spring named Bravo in this report.

The large circular hill just northwest of Alpha and the string of hills just south and southeast of Bravo are made up of poorly sorted to well sorted brownish-gray sandstone and conglomerate deposited by ice-contact and ice marginal streams with clasts almost entirely composed of rhyolite and obsidian (Muffler et al., 1982). Unfortunately the hills bounding

Figure 9. Google Earth image showing the study sites within Yellowstone National Park, WY. The study sites are the Alpha and Bravo grids, located just off of the Mary Mountain Trail off of Highway 287 running through the western section of the park.

the basin to the north are just off of the geologic map produced by Muffler et al. (1982), and an adjacent geologic map was not able to be found.

The surficial geology of site Alpha is made up of white to light gray amorphous sinter, which is deposited by flowing thermal waters. The surficial geology of site Bravo is made up of white to light brownish-gray diatomaceous silt that is deposited in flat marshy areas which drain thermal waters (Muffler et al., 1982). Other surficial deposits in the basin, not near any thermal springs are composed of gray to light brown, moderately to well sorted, unconsolidated sand and gravel, with the gravel and sand being primarily composed of rhyolite and obsidian, respectively. These unconsolidated gravel and sand deposits are interpreted as outwash of the Pinedale Glaciation (i.e., a large glaciation event 55 thousand years ago (Pierce, 2004)), and this unit occurs as broad, flat, alluvial terraces (Muffler et al., 1982).

The Alpha grid is 36 x 36 meters with 1.5 x 1.5 meter spacing, and the origin was chosen so that the main thermal spring Alpha was more or less in the middle of the X baseline. The Alpha grid has one large spring with a temperature of 94.4°C and one large thermal pool (temperature not recorded). The Bravo/2Bravo grids are 72 x 72 meters with 3 x 3 meter spacing, and the origin was arbitrarily chosen to be more or less centered about the main thermal spring, Bravo. The Bravo/2Bravo grids contain six thermal springs that range from 26.3 – 76.7°C in temperature.

2. Improved shallow ground temperature collection methodology, Yellowstone National Park, WY

2.1 Introduction to improved collection methodology

Previous researchers of Montana State University documented numerous thermal springs and features in Yellowstone National Park in the late 1990's and early 2000's. They compiled a database called the Yellowstone National Park Research Coordination Network; within this database, they documented GPS measurements, temperatures, pH, conductivity, and digital photographs of the thermal springs (Montana State University, 2014). The Alpha grid and Alpha and Bravo springs were georeferenced based on the UTM measurements of the thermal springs from this research.

During our time at Yellowstone National Park, WY, we collected three shallow ground temperature surveys. The three surveys, Bravo, Alpha, and 2Bravo were conducted on June 25th, June 26th, and June 28th, 2014, respectively. The Bravo and 2Bravo grids contain 610 shallow ground and 7 spring temperature measurements and 616 shallow ground and 7 spring temperature measurements, respectively. The Alpha grid contains 519 shallow ground and 1 spring temperature measurements. Each survey was collected in four hours or less to eliminate diurnal effects.

There were significant rain events the morning and night of June 26th, the entire day of June 27th, and the morning of June 28th. These rain events amounted to total daily rainfalls of 0.89, 0.48, and 0.84 centimeters, respectively. All Yellowstone weather for our field sites was forecasted and recorded out of the Old Faithful Ranger Station, approximately 13 kilometers away from our field areas (The Weather Channel, LLC, 2014). For that reason, we took the opportunity to explore the possible effects the significant atmospheric conditions may have on the shallow ground temperatures. We investigated this by resampling the Bravo grid (i.e., collected the 2Bravo grid) to specifically determine if the rain affected the spatial correlation structures of the shallow ground temperature measurements.

Since the ground penetration thermocouple probes used in the Alvord Basin, OR were fairly old and some may have been structurally compromised, we purchased new ground penetration thermocouple probes for data collection in Yellowstone National Park, WY. The new thermocouple probes are Omega Rugged Penetration Thermocouple Probes with Extra Heavy Wall & "T" Handle. These thermocouple probes are 25 centimeters in length, have a 6.4 millimeter probe diameter (Cole-Parmer, 2014), and have a 45 second characteristic response time (personal conversation with Omega representative, Rick Dole). The same digital thermometers and thermal spring probes used in the Alvord Basin, OR were also used in Yellowstone National Park, WY.

The grids were set up arbitrarily for specific orientations about the main thermal springs as mentioned before in the site description for Yellowstone National Park, WY. The grids were set up in the same fashion as the grids in the Alvord Basin, OR, by using a plane table and alidade, sighting rod, and 100 meter measuring tapes.

Before traveling to Yellowstone National Park, WY, all digital thermometers and new ground temperature probes were deemed functioning properly by the same method of “testing equipment functionality” for the Alvord Basin, OR data collection.

The same “collection methods for shallow ground temperatures” in the Alvord Basin, OR were used in Yellowstone, WY. Also, the same “collection methods for spring temperatures” in the Alvord Basin, OR were used in Yellowstone, WY.

GPS coordinates were only collected on the main thermal springs of Alpha and Bravo with a Garmin ETrex 10, handheld GPS device, and on the corners of the Bravo grid with a Garmin ETrex Vista, handheld GPS device.

2.2 Improved collection methodology

Some crucial improvements were made to the "collection methods for shallow ground temperatures." These improvements involve keeping track of your equipment during data collection, performing several temperature checks during and after data collection, and prolonging the lifetime of your equipment.

To keep track of our equipment, each digital thermometer and ground temperature probe was numbered and noted which other piece of equipment it was tested with. Therefore, it would pair with the same equipment throughout the entire field work in Yellowstone National Park, WY. We also noted where each thermometer and probe set was in the temperature survey at all times.

Before starting the data collection process, the ground temperature probes were propped up into the air, allowed for equilibration, and air temperature measurements were recorded. Although these temperature readings were slightly different from one another, this was only done to confirm each probe was not confined to a narrow temperature range as demonstrated before during the damaged ground temperature probes assessment after data collection in the Alvord Basin, OR. These air temperature checks were performed before, after, and three other times during each data collection survey. This process will be known as an "air equilibration test."

After each day of data collection, the ground temperature probes were cleaned with baby wipes and placed in individual plastic bags with a cover over its prong connection to the digital thermometers to help ensure longevity. Then, back at the motel, each probe was again tested with an ice bath to confirm it was not confined to a narrow temperature window. The ice bath was allowed to cool for approximately five minutes after being created, and the probes were placed in the ice bath one at a time and stirred for 30 seconds each. This process will be known as conducting an “ice bath test.”

During our time at Yellowstone National Park, WY, the digital thermometers became wet and began to function improperly. To dry out our digital thermometers, we sealed them all in a bag full of rice; the rice extracts the water moisture within the digital thermometers, resulting in the thermometers functioning correctly once again.

At any time during the data collection or during the performance checks, if a ground temperature probe was suspected of functioning incorrectly, it was exchanged for a new correctly functioning probe.

3. Results for improved shallow ground temperature collection methodology in Yellowstone National Park, WY

The ground and spring temperature data were evaluated and analyzed again using pscontour in GMT. Figures 10, 11, and 12 are the temperature contour plots of the Alpha, Bravo, and 2Bravo grid, respectively. These figures clearly display no linear artifacts within the data, suggesting that our improved collection methodology and new ground temperature probes were a success.

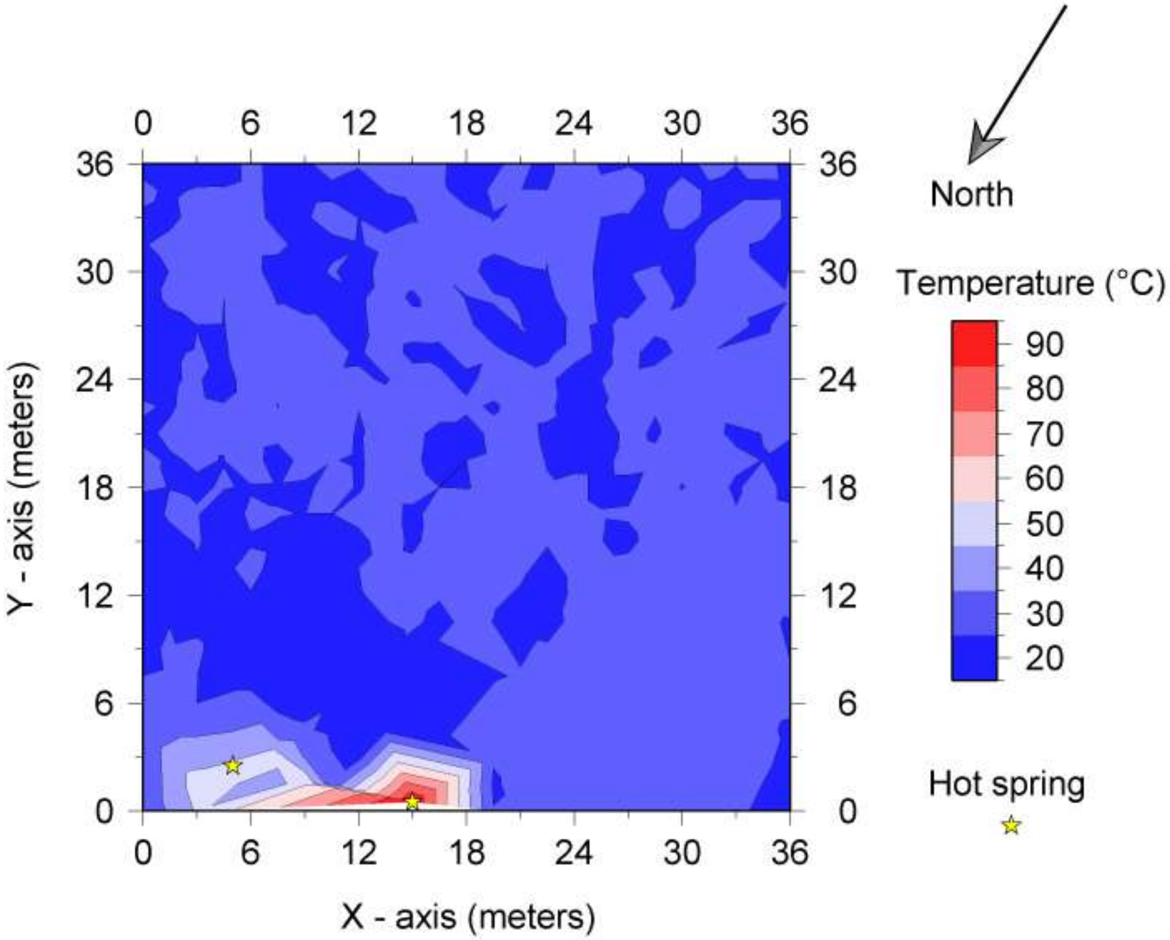

Figure 10. Temperature contour plot of the Alpha grid, Yellowstone National Park, WY. The yellow stars represent the hot springs within the grid and the temperature contour interval is 10°C.

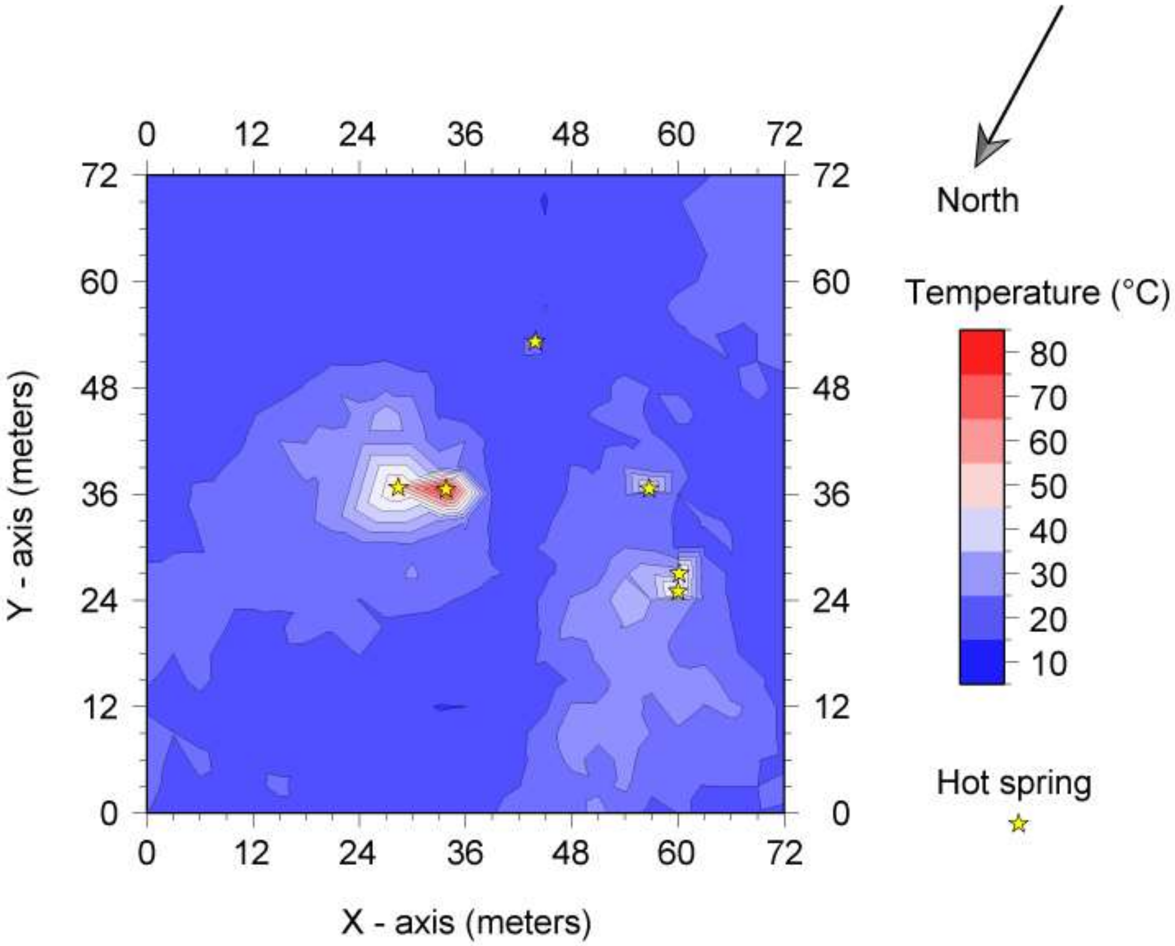

Figure 11. Temperature contour plot of the Bravo grid, Yellowstone National Park, WY. The yellow stars represent the hot springs within the grid and the temperature contour interval is 10°C.

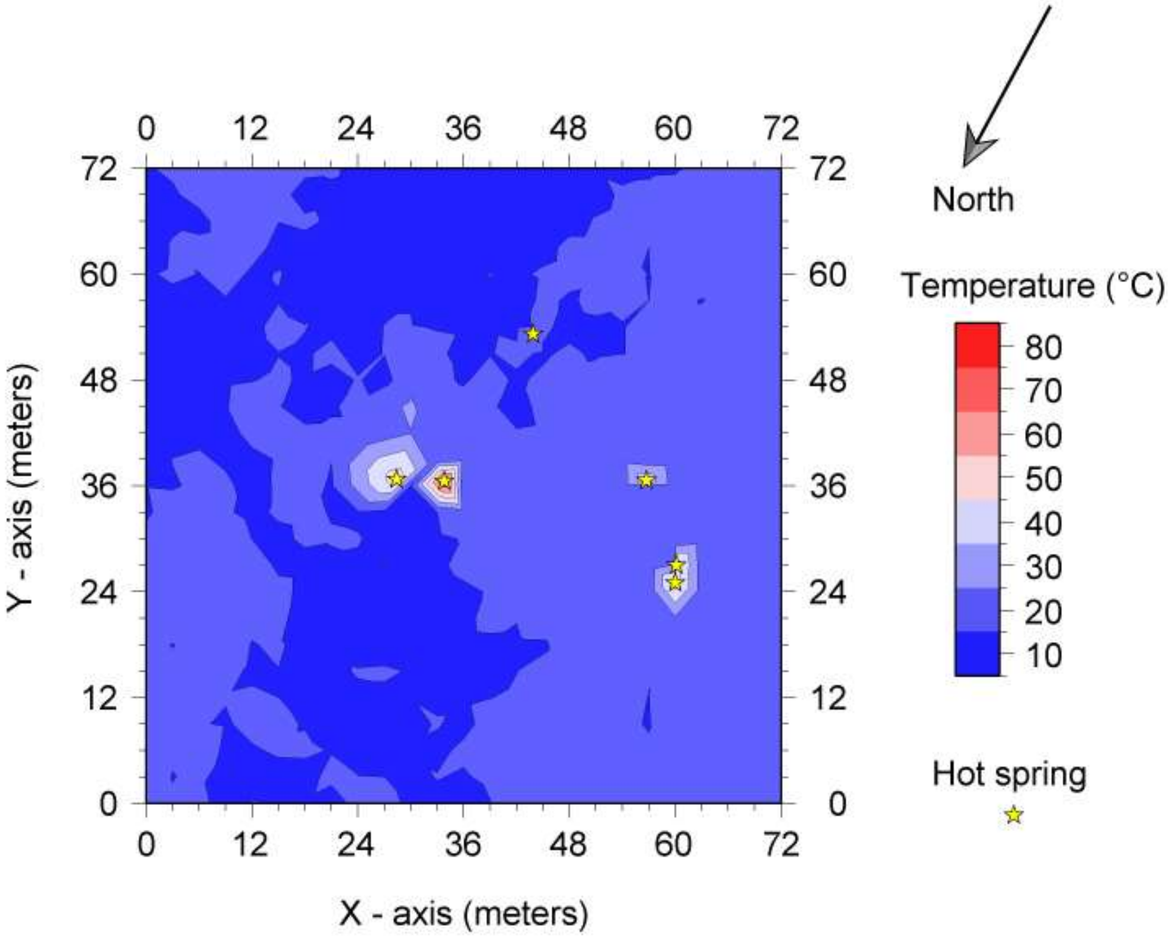

Figure 12. Temperature contour plot of the 2Bravo grid, Yellowstone National Park, WY. The yellow stars represent the hot springs within the grid and the temperature contour interval is 10°C.

4. Effects of rain on shallow ground temperatures in Yellowstone National Park, WY

4.1 Introduction to geostatistics

To determine if the rain affected the spatial correlation structures in the Bravo grids, several geostatistical analyses were performed. The geostatistical analyses performed include experimental variograms, variogram models, variogram maps, kriging and cross validation, contour plots, quantile – quantile plots (qqplots), histograms, and the mean and standard error of the mean. Each geostatistical analysis studies how a variable fluctuates in space or time using predictive statistics (Deutsch and Journel, 1998; Anderson and Fairley, 2008). In our case, the geostatistical analyses evaluate how the temperature variable is changing in time (i.e., under different atmospheric conditions) only.

A common robust geostatistical tool used is the experimental variogram, mathematically defined as:

$$\gamma(h) = \frac{1}{2N(h)}\sum(z_i - z_{i+h})^2,$$

where γ is the semivariance, h is the separation distance between data values z_i and z_{i+h}, and $N(h)$ is the number of data pairs separated by the distance h (Deutsch and Journel, 1998; Anderson and Fairley, 2008). The experimental variogram is used to quantify the dissimilarity of a variable between two data points; this dissimilarity is quantified for every pair of data points. The quantified dissimilarity (i.e., semivariance) is then plotted against the separation distance for each respective pairing of data points (McKillup and Dyar, 2010).

The experimental variogram is fitted with a model, typically an exponential, spherical, and/or nugget model in geoscience applications. These models can then predict a semivariance value for any separation distance. The purpose of variogram modeling is to capture and predict the major spatial features of the variable being modeled, rather than simply best fitting an equation to your data (Goovaerts, 1997; Anderson and Fairley, 2008). In this study, short range correlations are thought to be more significant than long range correlations due to the nature of temperature diffusion and the density of our measured temperature data.

The exponential model is mathematically defined as:

$$\gamma(h) = c * \left[1 - exp\left(\frac{-3h}{a}\right)\right],$$

where γ is the semivariance, h is the separation distance between the pairing of data points, a is the effective range (i.e., for an exponential model, the range is the separation distance when the variogram reaches 95% of maximum), *c* is the positive variance contribution or value of the sill (i.e., the maximum semivariance value not including the added nugget), and *exp* signifies *e* is raised to the following bracketed value (Deustch and Journel, 1998; Anderson and Fairley, 2008).

The spherical model is mathematically defined as:

$$\gamma(h) = \left\{ \begin{matrix} c * \left[1.5\left(\frac{h}{a}\right) - 0.5\left(\frac{h}{a}\right)^3\right], & h \leq a \\ c, & h \geq a \end{matrix} \right\},$$

where γ is the semivariance, h is the separation distance between the pairing of data points, a is the actual range (i.e., the separation distance when the variogram data reaches its maximum), and *c* is the sill (Deustch and Journel, 1998; Anderson and Fairley, 2008).

The nugget model is the Y-intercept (i.e., the discontinuity at the origin of the experimental variogram) of the variogram data. When only a nugget model is used, this means the data has already reached its outer limit of the region of influence (which is also defined as the sill for other models (McKillup and Dyar, 2010)). Therefore, when just the nugget model is used, it indicates the data has no spatial correlation structures.

With a variogram model, one can make estimates of unknown values at specific locations within the same area or, in our case, make estimates for unknown values of the same gridded locations for a different time. We applied our modeled variogram data by kriging. Kriging is an estimation method that uses linear regression techniques based on neighboring data to minimize the error-variance in its estimations (Deutsch and Journel, 1998; Anderson and Fairley, 2008). Since kriging interpolates, it has a tendency to overestimate low values and underestimate high values, producing a smooth model of the spatial variability (Goovaerts, 1997; Anderson and Fairley, 2008). The specific kriging used in this study was ordinary kriging (i.e., an expansion of simple kriging, as are all other versions of kriging (Deutsch and Journel, 1998)). Simple kriging assumes a constant trend with a known mean. Ordinary kriging, however, only assumes local means are constant for nearby data values (i.e., local neighborhoods) instead of the entire domain (Bohling, 2005).

Cross validation is good practice because so many geostatistical analyses are interdependent and subjective to the user. Cross validation is intended to uncover what could go wrong, but does not guarantee the results will be successful (Deutsch and Journel, 1998). The only reason we are using the word “validation” in this report is because of the “cross validation” analysis in the geostatistical software suite, GSLIB (Deutsch and Journel, 1998). We understand the word validate implies our model has been confirmed to be a perfect model; however, this is not the case. The cross validation analysis is only a tool to determine if your model is a good representation of your data. In cross validation, each actual data point is removed one at a time and re-estimated from some neighboring data, and each original data value is returned in the data set once it has been re-estimated (Deutsch and Journel, 1998). Residuals (i.e., the difference between actual values and their respective estimated values) are extracted from this analysis of cross validation. Therefore, to test our model's ability to re-estimate the data, we used the cross validation tool within the kt3d kriging analysis in the geostatistical software suite, GSLIB, to re-estimate the original data, and the temperature differences between the actual and re-estimated data (i.e., residuals) were extracted.

To determine the model's ability to estimate the data correctly, a series of statistical tests are performed on the residuals (Kitanidis, 1997). The statistical tests are to determine if the residuals are normally distributed about zero (Kitanidis, 1997); these tests include a histogram plot, the mean and the standard error of the mean, and a qqplot. Other statistical tests are also performed to determine if the residuals have any spatial correlation structures; these tests include a contour plot, variogram map, and a modeled experimental variogram.

A normal distribution signifies the probability of any real sample data falling between the limits as the curve approaches zero on both sides. The shape of a normal distribution curve is symmetrical about the mean, with the majority of the data near the mean. A normal distribution is mathematically defined as:

$$f(z) = \frac{1}{\sqrt{2\pi s^2}} * exp\left[\frac{(z-m)^2}{2s^2}\right],$$

where $f(z)$ is the function of z (data value), s^2 is the variance, m is the mean (in the case of a normal distribution, it is also the median and mode), and *exp* again signifies e is raised to the following bracketed value (Kitanidis, 1997).

A histogram is a graphical representation of the distribution of data (Kitanidis, 1997); it does not distinguish how your data is distributed but helps analyze the type of distribution.

The X-axis is the value of data broken up into bins of equal lengths. The number of bins is usually the square root of the total number of data points. Each data measurement is placed in its respective bin value. The Y-axis is the frequency or percentage of the total number of data points each bin has in it. A normally distributed histogram would have a symmetrical bell-shaped curve (Kitanidis, 1997).

The standard error of the mean is the standard deviation of the distribution of the sample means (McKillup and Dyar, 2010). The standard error of the mean is mathematically defined as:

$$Standard\ error\ of\ the\ mean = 1.96\left(\frac{S}{\sqrt{N}}\right),$$

where S is the standard deviation, N is the total number of data samples, and the 1.96 applies to the 95% confidence interval (McKillup and Dyar, 2010). The standard error of the mean is applied ± the sample mean. If the population mean falls within the window of the standard error of the mean about the sample mean, then the sample mean is a reasonable representation of the population mean with 95% confidence (McKillup and Dyar, 2010).

A qqplot is a graphical statistical method used to determine the type of distribution in which a data sample set belongs (Dalgaard, 2008). Q stands for quantile. A quantile is the desired division of ordered data into equal sized subsets. For example, some special quantiles are the 4-quantiles, 10-quantiles, and 100-quantiles, which are quartiles, deciles, and percentiles, respectively. For the ease of explanation, let us assume we are interested in 100-quantiles (i.e., percentiles). Therefore, the nth quantile has n% of the data falling below the nth quantile’s value. To determine an nth quantile’s value for 100-quantiles, use the mathematical expression defined as:

$$n\text{th quantile (for 100 quantiles):} \quad N * \left[\frac{n}{100}\right] = P,$$

where n is the desired quantile, N is the total number of data points, and P is the data value position in the sample population when ordered from smallest to largest. Therefore, the data value at P is the nth quantile's data value. A qqplot takes the quantiles of your sample data set and plots them against the quantiles of a theoretical data set with a specific distribution in mind. In this study, the sample quantiles are compared to a theoretical data set of a normal distribution's quantiles. When you are analyzing qqplots for the data set's distribution, focus on the middle quantiles because quantiles at the tails of the graph do not get sampled well.

A variogram map is similar to an experimental variogram, but the variogram map represents all the experimental variograms in every direction. Therefore, it performs an experimental variogram in every direction from 0-360°. The variogram map is an aerial view, looking down on the curvature of all the experimental variograms standing upright next to one another in a radial fashion from 0-360°, with the origins of all the experimental variograms located at the center of the map. Therefore, it is a two dimensional representation of the three dimensional surface (Deutsch and Journel, 1998). Values near the center of the map represent small separation distances between pairs of data points, and these separation distances increase with increasing distance from the center (Anderson and Fairley, 2008). The variogram map allows for the directions of long range correlation (i.e., the variable is correlated further out into longer separation distances) and short range correlation (i.e., the variable is only correlated to shorter separation distances) to be determined; the long and short range correlation directions are always orthogonal to one another. Variogram maps are used to determine the anisotropy (i.e., directional dependence) of your data (i.e., the long and short range correlation directions of your variable within space). If no anisotropy is present (i.e., the data is isotropic), the increasing variogram values within the variogram map are uniform about the center. Otherwise a non-uniform or elliptical pattern is displayed, representing some degree of anisotropy (Goovaerts, 1997; Isaaks and Srivastava, 1989; Anderson and Fairley, 2008).

For more information on geostatistics, consider Deutsch and Journel, 1998; Goovaerts, 1997; Isaaks and Srivastava, 1989; Kitanidis, 1997; McKillup and Dyar, 2010; and Dalgaard, 2008.

The experimental variogram, variogram mapping, and kriging geostatistical analyses mentioned in this report were performed in the geostatistical software suite, GSLIB (Deutsch and Journel, 1998), and for their input parameters, see the Appendix A. The experimental variogram model fitting was performed in Microsoft Excel, the contour mapping in GMT, and the qqplots and histograms in the statistical program R.

4.2 Geostatistical methods and results

4.2.1 Modeling 2Bravo data set

Since we are interested in whether or not the rain affected the spatial correlation structures of the shallow ground temperatures in the Bravo grids, we removed the thermal spring temperature data from the temperature survey data sets. This was done because the heat driving the thermal springs is transported by a different process than the heat in the shallow subsurface between the thermal springs. The thermal springs' heat is convectively transported by high permeability conduits, such as faults (Fairley and Hinds, 2004a), while the heat in the shallow subsurface is transported by diffusion or dispersed away from the thermal springs through relatively lower permeability pathways, such as soil matrices.

To determine the directions of anisotropy of the 2Bravo grid, a variogram map was created using varmap in GSLIB (Figure 13). The variogram map may suggest small anisotropy of long and short range correlations in the 007° and 097° directions (on the non-georeferenced grid), respectively; however, this could be an artifact of the significantly elevated shallow ground temperatures near the thermal springs. Since the anisotropy is not strong and we do not want to complicate our model more than we need to, an omnidirectional (i.e., in all directions) or isotropic experimental variogram of the 2Bravo data set was created first.

The omnidirectional variogram was created using gamv in GSLIB. The spherical model best represents the data describing the temperature spatial variability within the 2Bravo gridded area (Figure 14). The actual range, sill, and nugget of the spherical model are 33 meters, 5.6 semivariance, and 1.5 semivariance, respectively. This model was cross validated using the kt3d kriging in GSLIB, and its residuals were extracted.

4.2.2 Analyzing 2Bravo model

To determine the mean and distribution of the residuals, a histogram was created using R (Figure 15) to help understand the distribution and mean of the residuals. The number of bins used is 25 (i.e., approximately the square root of the total number of data points (616)). The histogram shows the residuals are more or less normally distributed around zero. For that reason, the standard error of the mean and qqplot were also performed.

The mean of the residuals = 3.12×10^{-4}, and the standard error of the mean for the residuals is ± 0.115. This indicates the residual mean is not significantly different than zero (i.e., the normal distribution of residuals (Kitanidis, 1997)) with 95% confidence. The qqplot was created using R (Figure 16). The qqplot clearly suggests the sample quantiles belong to a

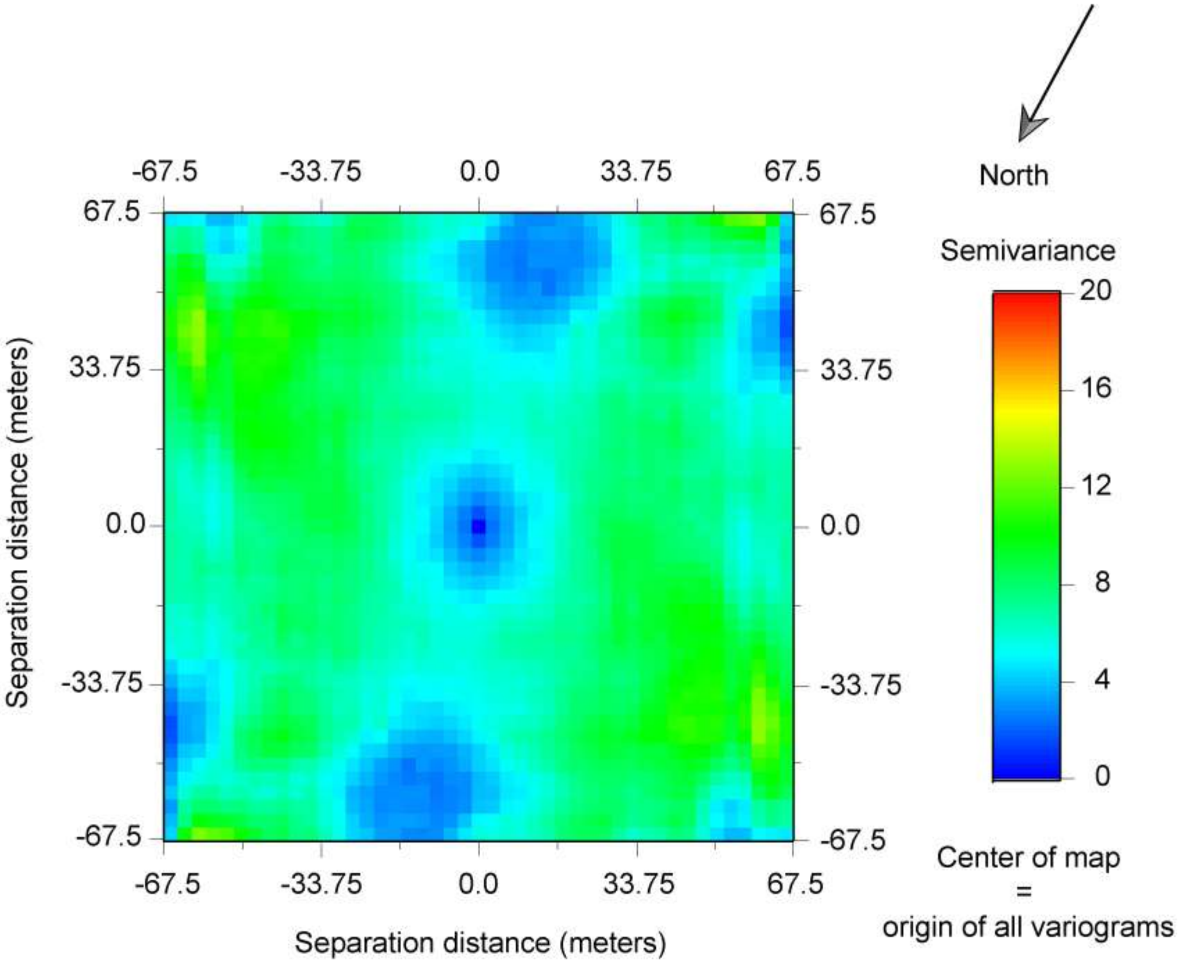

Figure 13. Variogram map of the 2Bravo grid in Yellowstone National Park, WY. The center of the map represents the origin of all experimental variograms. Values near the center of the map represent small separation distances and increase with distance from the center of the map.

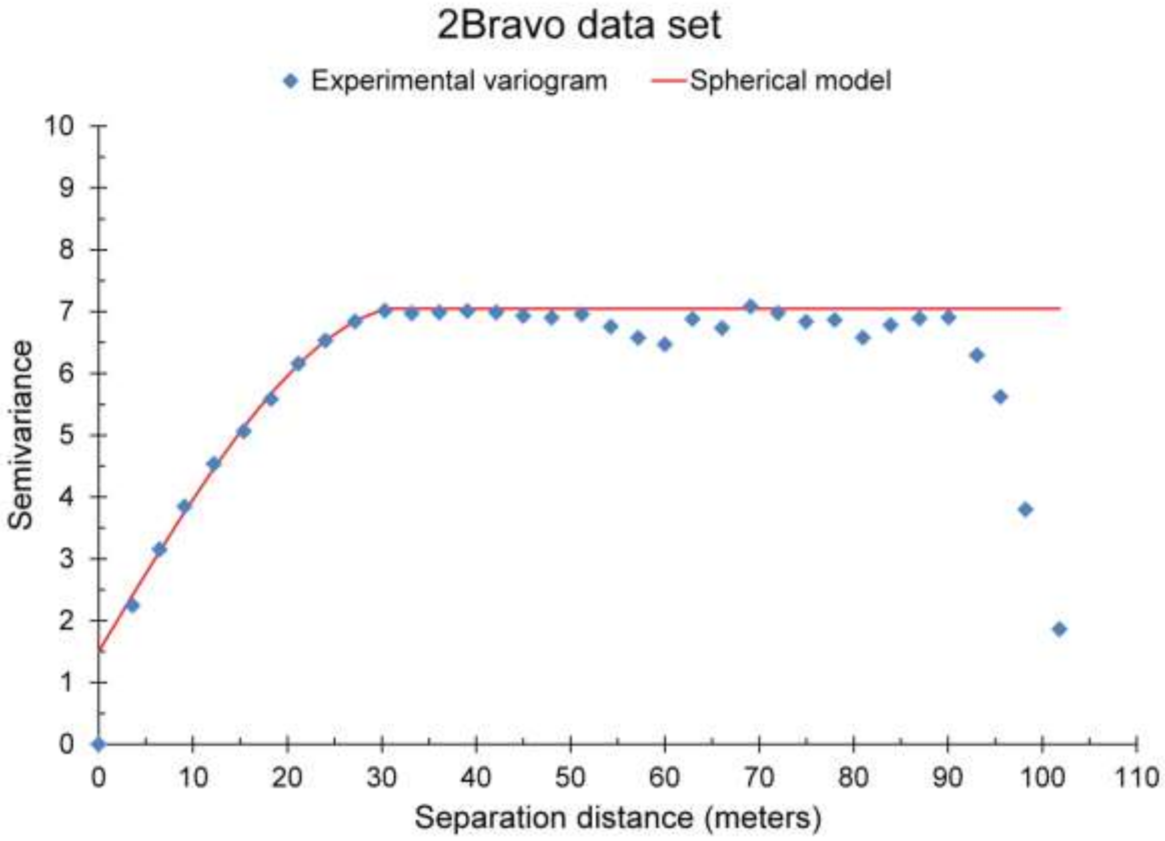

Figure 14. Modeled experimental variogram of the 2Bravo data set from Yellowstone National Park, WY. The blue diamonds represent the experimental variogram data and the red line represents the spherical model that best represents the data.

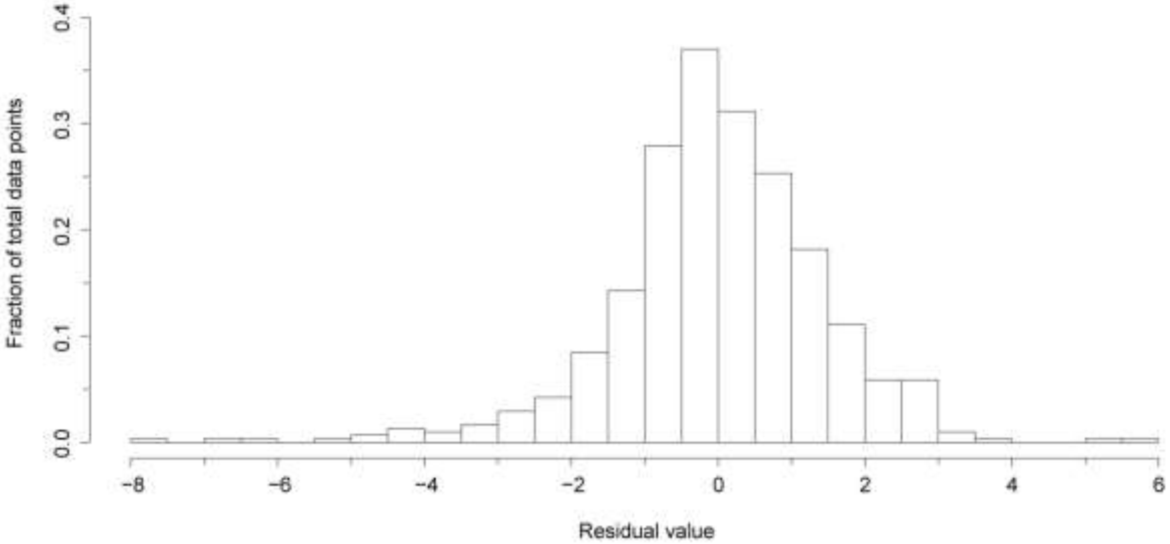

Figure 15. Histogram of the residuals after cross validating our model for the 2Bravo grid in Yellowstone National Park, WY. The X-axis is broken up into bins of 1.0 residual value and the Y-axis is the fraction of total data points (i.e., frequency).

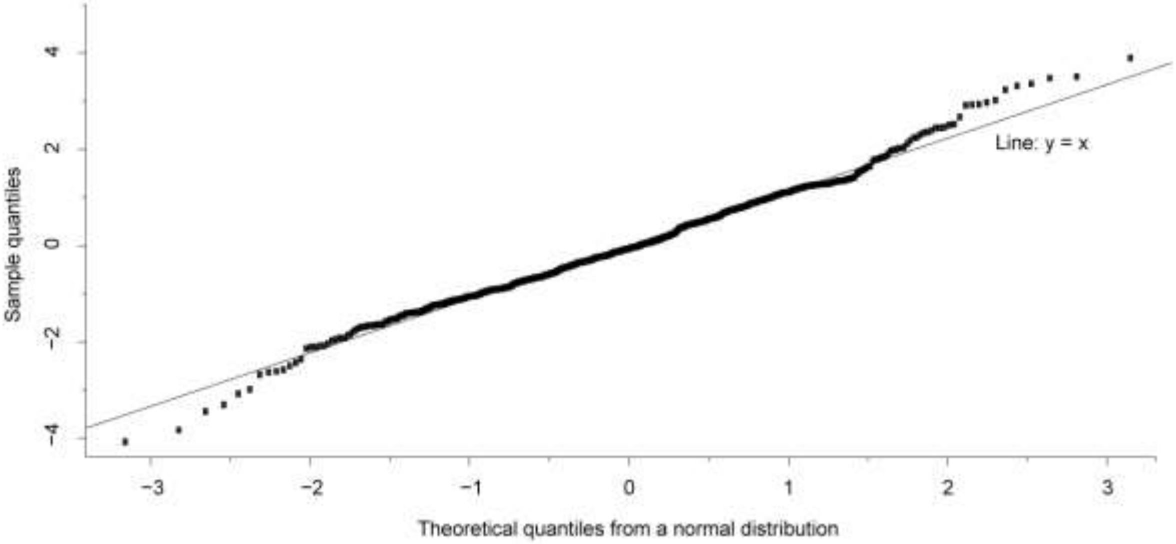

Figure 16. qqplot of the residuals after cross validating our model for the 2Bravo grid in Yellowstone National Park, WY. The X-axis is the theoretical quantiles from a normal distribution and the Y-axis is the residual quantiles. The solid black squares represent the quantile data and the black line represents the normal distribution line of y = x.

normal distribution because they fall along the theoretical normal distribution line. These three analyses strongly suggest the residuals are normally distributed about zero.

To determine if the residuals have any spatial correlation structures, a contour plot, a variogram map, and an experimental variogram of the residuals were created. The residuals were contoured using pscontour in GMT. In this contour plot (Figure 17), the contours display more or less random shapes; there are no specific patterns emerging from all of the springs or anywhere else in the grid. Then, the variogram map of the residuals (Figure 18) has no patterns emerging from the center of the map. Lastly, the omnidirectional experimental variogram of the residuals was created and modeled (Figure 19). The nugget model of 2.35 semivariance best represents the variogram data. These three analyses strongly suggest the residuals have no spatial correlation structures (i.e., the residuals are uncorrelated).

Since the residuals are normally distributed about zero and uncorrelated, it implies the variogram model of the original temperature data is a good representation of that data (i.e., all spatial correlation structures were accounted for in our model), and we can now use this model to predict the Bravo grid data set’s temperature values.

The use of an isotropic exponential model and an anisotropic spherical model to model the 2Bravo data set were explored, but neither resulted in significant improvement. Therefore, just like Ockham’s razor – “Don’t multiply entities beyond necessity (Maurer, 1978; Baker, 2010),” the simplest model is often better.

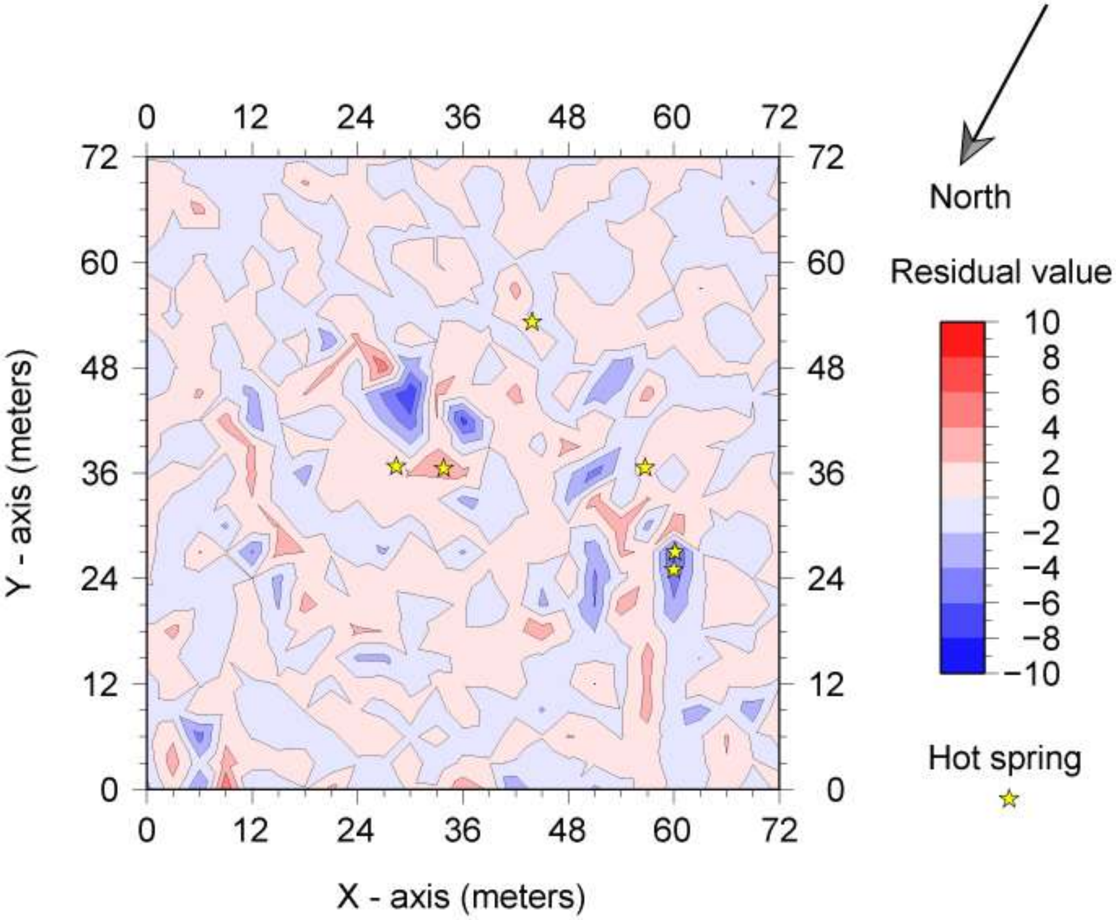

Figure 17. Contour plot of the residuals after cross validating our model for the 2Bravo grid in Yellowstone National Park, WY. The yellow stars represent the hot springs within the grid and the contour interval is 2 residual value. This contour plot is in the exact same space as the 2Bravo grid.

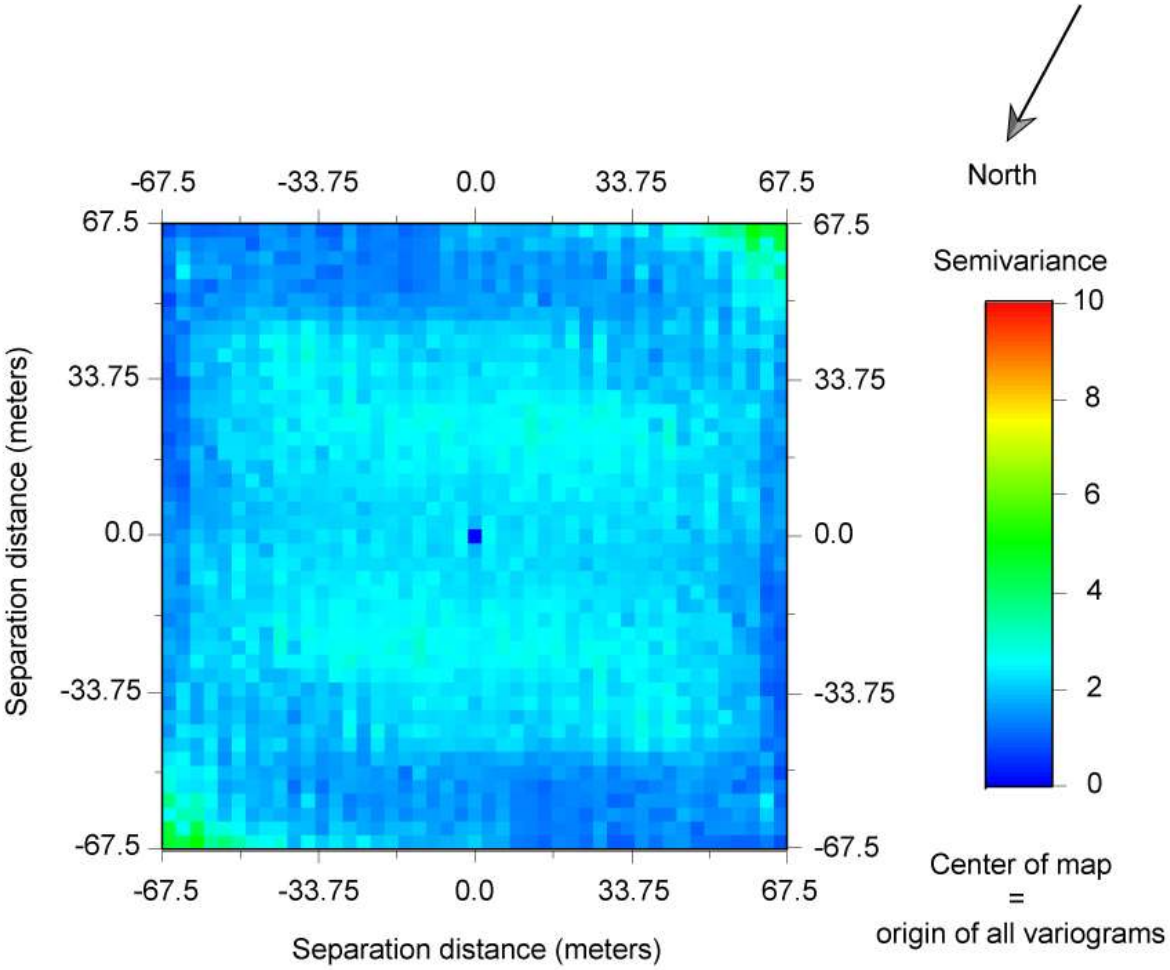

Figure 18. Variogram map of the residuals after cross validating our model for the 2Bravo grid in Yellowstone National Park, WY. The center of the map represents the origin of all experimental variograms. Values near the center of the map represent small separation distances and increase with distance from the center of the map.

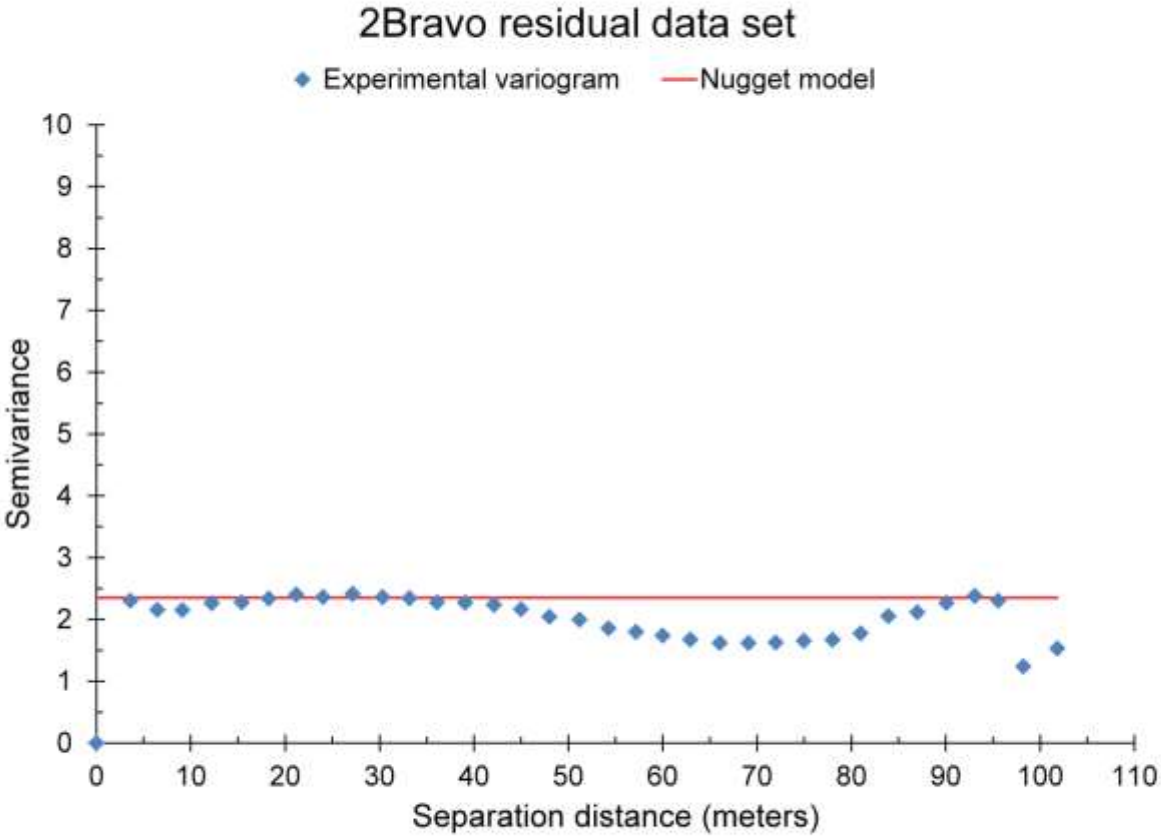

Figure 19. Modeled experimental variogram of the residuals after cross validating our model for the 2Bravo data set in Yellowstone National Park, WY. The blue diamonds represent the experimental variogram data and the red line represents the nugget model that best represents the data.

4.2.3 Using 2Bravo model to predict Bravo temperatures

To predict the Bravo grid data set's temperature values with the 2Bravo grid's experimental variogram model, we used kt3d kriging to cross validate this prediction in GSLIB; the residuals from this process were extracted.

The residuals from this process were analyzed with a histogram, the mean and standard error of the mean, and a qqplot to determine if the residuals are normally distributed about zero. Then, a contour map, a variogram map, and a modeled experimental variogram of the residuals were used to determine if the residuals have any spatial correlation structures.

The histogram of the residuals (Figure 20) suggests the data is more or less normally distributed about zero. The mean of the residuals = 8.73×10^{-3}, and the standard error of the mean for the residuals is ± 0.106, indicating the residual mean is not significantly different than zero with 95% confidence. The qqplot of the residuals (Figure 21) suggests the residuals are from a normal distribution. Therefore, these analyses strongly suggest the residuals from using the 2Bravo model to predict the temperatures of the Bravo data set are normally distributed about zero.

The contours within the contour map of the residuals (Figure 22) are randomly shaped with no specific patterns emerging around all the thermal springs. The variogram map (Figure 23) of the residuals has no pattern emerging from the center of the map. The modeled omnidirectional experimental variogram of the residuals (Figure 24) is best represented with a 1.95 semivariance nugget model. Therefore, these analyses strongly suggest the residuals from using the 2Bravo model to predict the temperatures of the Bravo data set have no spatial correlation structures.

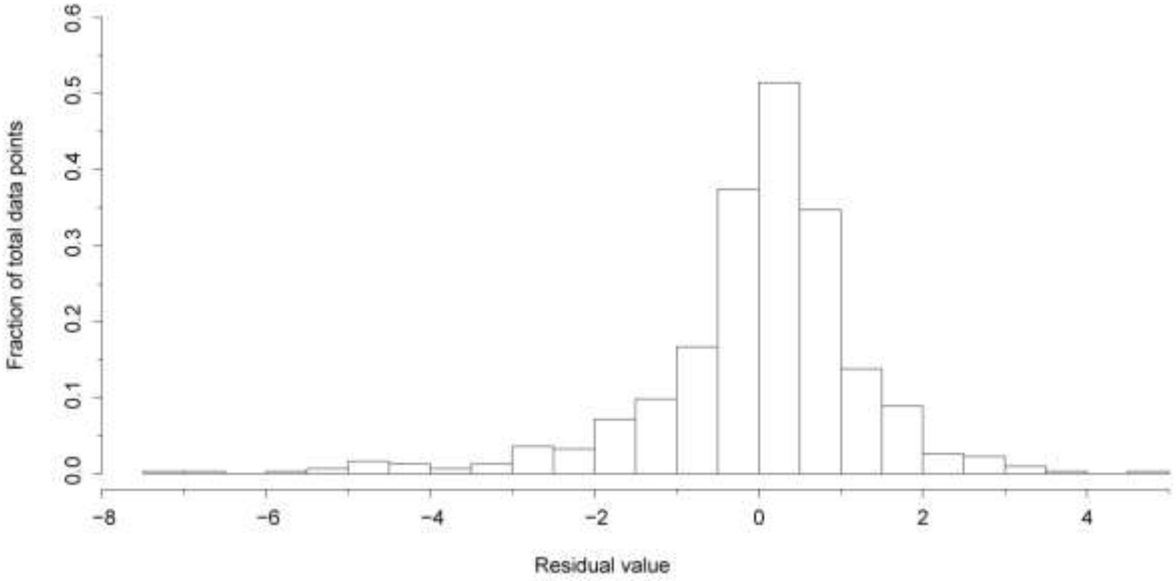

Figure 20. Histogram of the residuals after using the 2Bravo model to predict the temperatures of the Bravo grid in Yellowstone National Park, WY. The X-axis is broken up into bins of 1.0 residual value and the Y-axis is the fraction of total data points (i.e., frequency).

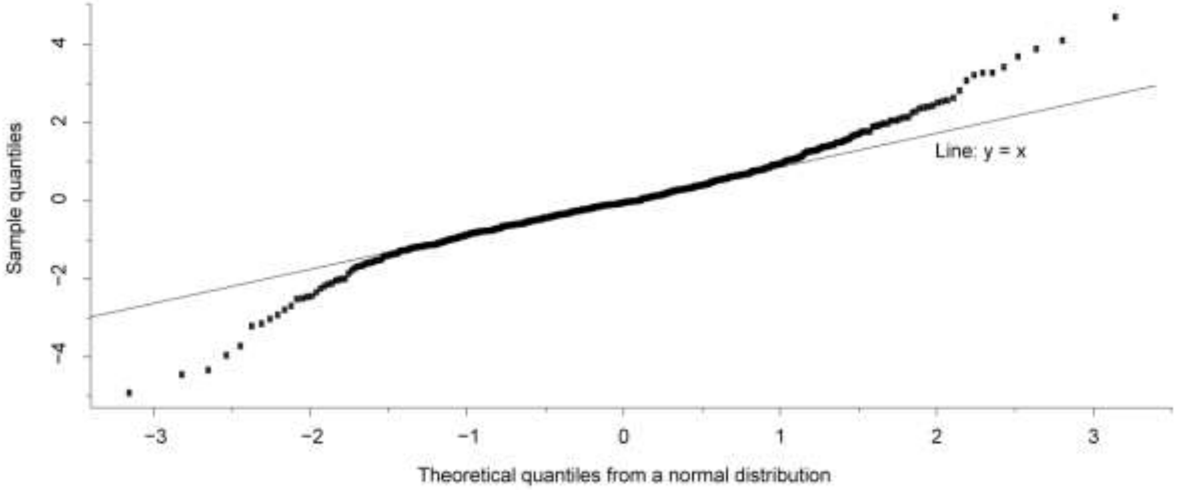

Figure 21. qqplot of the residuals after using the 2Bravo model to predict the temperatures of the Bravo grid in Yellowstone National Park, WY. The X-axis is the theoretical quantiles from a normal distribution and the Y-axis is the residual quantiles. The solid black squares represent the quantile data and the black line represents the normal distribution line of y = x.

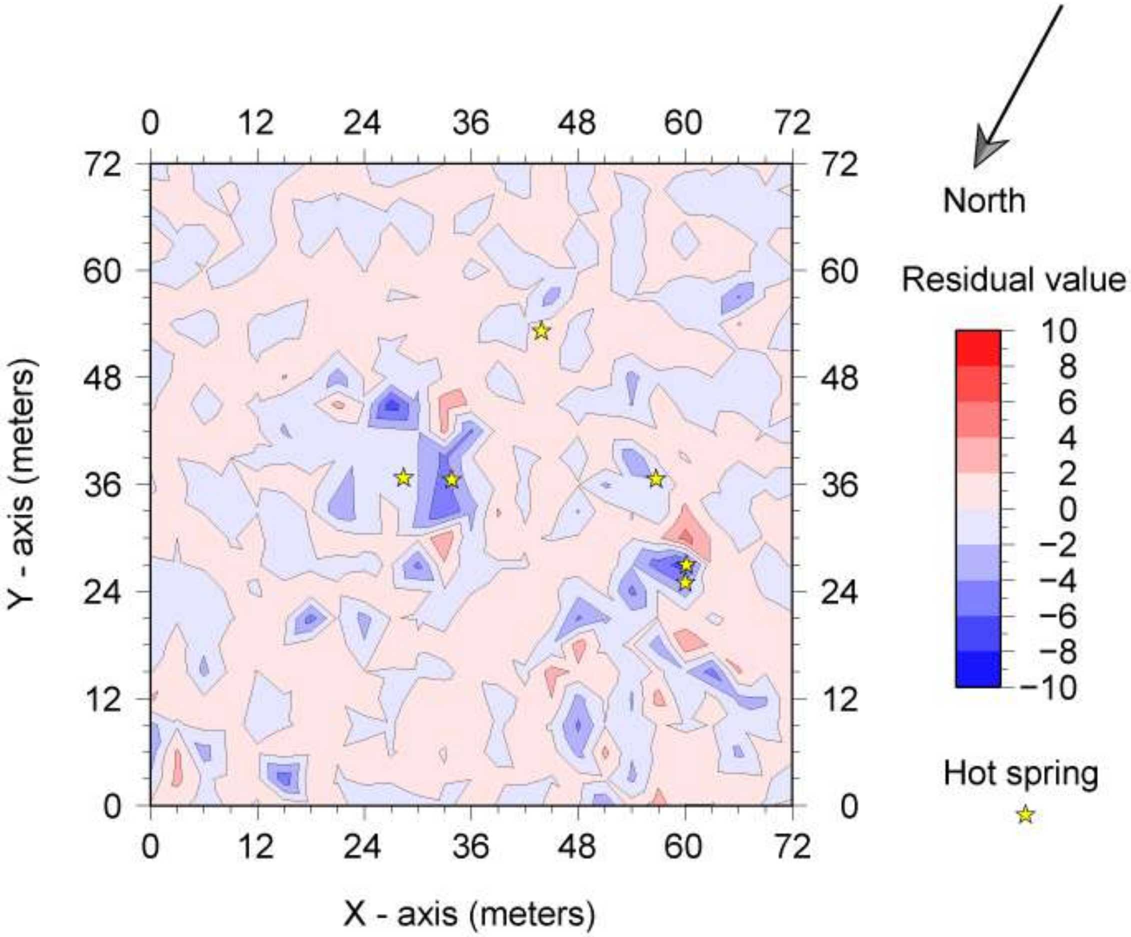

Figure 22. Contour plot of the residuals after using the 2Bravo model to predict the temperatures of the Bravo grid in Yellowstone National Park, WY. The yellow stars represent the hot springs within the grid and the contour interval is 2 residual value. This contour plot is in the exact same space as the Bravo grid.

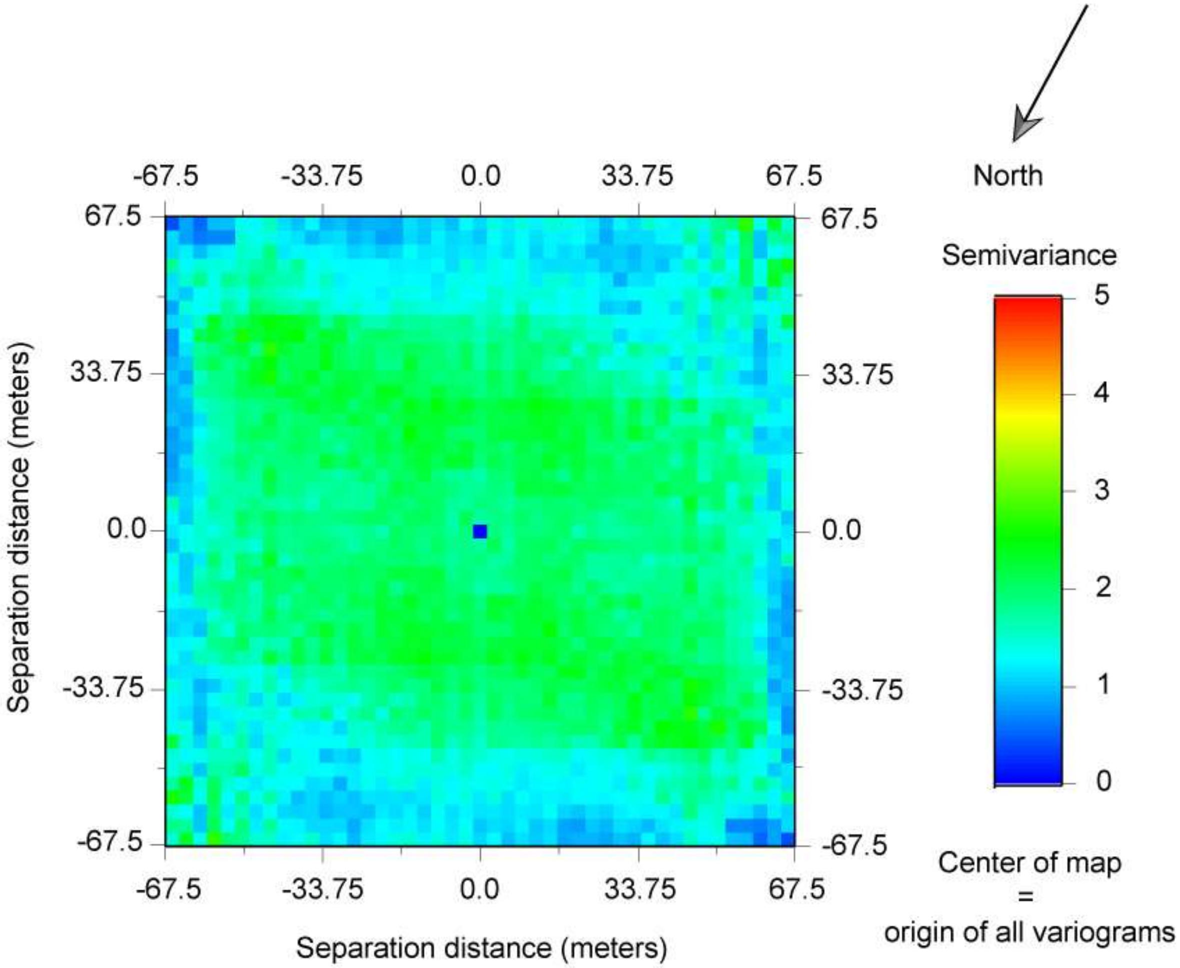

Figure 23. Variogram map of the residuals after using the 2Bravo model to predict the temperatures of the Bravo grid in Yellowstone National Park, WY. The center of the map represents the origin of all experimental variograms. Values near the center of the map represent small separation distances and increase with distance from the center of the map.

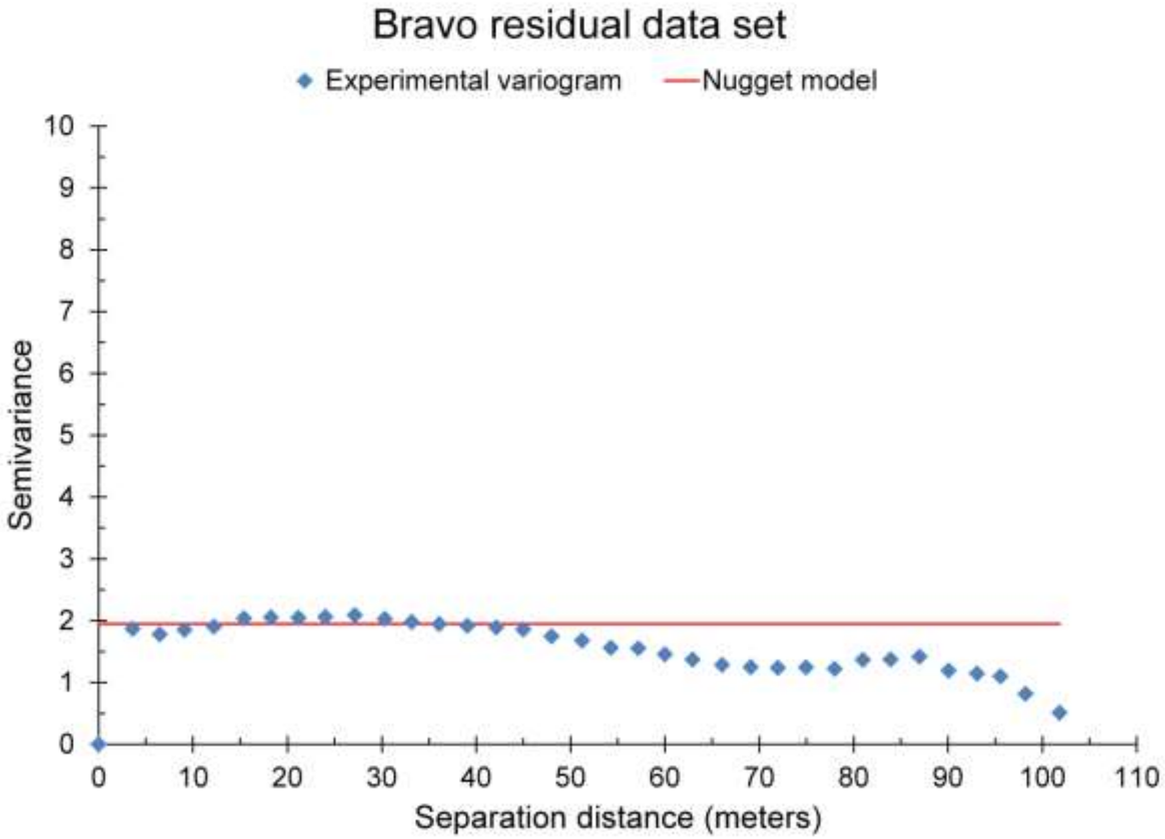

Figure 24. Modeled experimental variogram of the residuals after using the 2Bravo model to predict the temperatures of the Bravo grid in Yellowstone National Park, WY. The blue diamonds represent the experimental variogram data and the red line represents the nugget model that best represents the data.

All of these analyses strongly suggest the amount of rainfall and different atmospheric conditions for our study area between the two data collection times and during the second data collection period did not affect the spatial correlation structures of the gridded area.

5. Discussion/Conclusion

5.1 Advantages of our methodology

The advantages of using our shallow ground temperature collection methodology with ground penetrating thermocouple probes on a set grid with high density spacing in shallow ground temperature studies are as follows:

- able to collect the data significantly faster
    - able to collect higher quantities of data
- probes are less invasive to sensitive environments than digging holes
    - this also allows for research to be conducted in areas such as Yellowstone National Park and other well protected environments
- allows for the development of spatial correlation relationships
- the uncertainty of the measured temperatures decreases proportional to the square root of the total number of data points collected
- easier and faster to revisit the same locations for data collection
    - do not have to worry about the dug holes possibly equilibrating with atmospheric conditions during data collection or in between re-visitations

5.2 Our shallow ground temperature collection methodology

It is exceptionally important to have sound methodologies and be prepared to recognize and deal with equipment malfunctions. Always be prepared to make changes on the fly because your data collection will never go as planned.

From our initial data collection in the Alvord Basin, OR to our data collection in Yellowstone National Park, WY, we developed the following methodology for high resolution shallow ground temperature measurements on a set grid. For any additional information on shallow ground temperature data collection, read this report in its entirety.

5.2.1 Preparing for collecting shallow ground temperature surveys (i.e., before traveling)

- have a working knowledge of how to collect all the data needed for the study before you get in the field (i.e., visualize everything before anything else)
- have a working knowledge of using and handling your field equipment
    - be familiar with all specifications of your field equipment
- test ground temperature probes and digital thermometers in lab before traveling to collect data
    - note which ground temperature probe will go with which digital thermometer for the entire duration of data collection
    - have extra ground temperature probes and digital thermometers
        - have extra batteries
    - all field equipment will eventually quit working, make sure your field equipment is not at that point (i.e., have relatively new equipment in good shape)

- have an informative and easy to follow data collection spreadsheet setup as either hardcopy or electronic copy before traveling to collect data
- have enough field assistants for all aspects of the research to ensure data collection continues smoothly, effectively, and quickly
- have a working knowledge of the entire field area before temperature collection
    - collect GPS data and describe significant features before temperature collection

5.2.2 Setting up shallow ground temperature survey grids

- record weather information each day and if it changes throughout your data collection
- determine origin of temperature survey grids and set up with accurate surveying equipment (i.e., Brunton compass, plane table and alidade, sighting rod, and 100 meter measuring tapes)
    - collect GPS data on grid corners before temperature collection
    - collect GPS data on thermal springs within grid before temperature collection
- collect thermal spring temperatures within grid before ground temperature collection
    - find hottest temperature in thermal spring vents, may have to probe around
        - wait three characteristic response time units (i.e., 95% of the way to equilibrium) between each thermal spring temperature measurement

5.2.3 Collecting shallow ground temperature measurements

- set up ground temperature probes with their respective digital thermometers for entire duration of field work
- perform an “air equilibration test”

  - this is done to help assess if the temperature readings are confined to a narrow temperature range
    - be sure the air temperature readings are relatively the same
  - do this before, after, and at least three other times throughout each temperature survey and aim for tests to be equally spaced apart from one another
- insert ground temperature probes into ground and allow for equilibration
  - wait three characteristic response time units (i.e., 95% of the way to equilibrium) between each probe's temperature measurement
- collect temperature data with a rolling grid system explained in Figure 4
  - if it is not possible to lay out ground temperature probes throughout the entire width of grid for your desired spacing interval, collect data up one swath and down the adjacent, add additional swaths when necessary
- note the grid coordinates of all thermal springs in your grid by referencing your 100 meter tapes
- record notes on each probes' penetration depth into the subsurface
- record any additional notes you feel necessary
- replace any ground temperature probe and/or digital thermometer with suspected behavior of malfunctioning

5.2.4 Proper care of field equipment after data collection

- clean field equipment after day of usage in the field
  - wipe down the ground temperature probes with baby wipes

    - cover ground temperature probes’ connection pieces to the digital thermometers if available
    - store ground temperature probes in separate plastic bags
        - store other field equipment properly so that sensitive components do not become damaged
- if digital thermometers become considerably wet, seal them in bag of rice to dry out

5.2.5 Assessments after a day of data collection

- perform an “ice bath test” on the ground temperature probes and digital thermometers
    - this ensures the temperature readings are not confined to a narrow temperature range
- preliminarily plot temperature surveys to help determine if data errors exists
    - it is always easier to recollect the data when you are still near your study area
- look up weather stations nearest to study site and record relevant information

5.3 Recognizing data errors

It is helpful to be able to recognize data errors. Some indications for possible data errors are as follows:

- linear artifacts within your contour plots (i.e., hardly anything in the nature is straight)
- ground temperature readings are never equilibrating
    - temperature readings are slowly increasing or decreasing and never equilibrating
    - temperature readings are varying rapidly over several degrees Celsius

- some ground temperature values seem abnormally high or low relative to the adjacent area
    - you can always verify that ground temperature measurement with a different thermometer and probe set
- it never hurts to err on the side of caution

5.4 Other conclusions

- The amount of rain experienced on the Bravo grid between the two sampling days did not affect the spatial correlation structures for the shallow ground temperature measurements.
- It is safe to say this shallow ground temperature collection methodology is robust and reproducible.
    - However, with that said, larger amounts of rainfall than experienced in this report may result a different outcome.
- All shallow ground temperature data used in this report is available in Appendix B.

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Appendix A

Input parameters for GSLIB's geostatistical analyses

Using "varmap" to determine anisotropy for 2Bravo temperature data set

2Bravo data set without thermal springs	:file with data
1, 3	:number of variables, columns numbers
-1.0e21 and 1.0e21	:trimming limits
0	:1=regular grid, 0=scattered values
50, 50, 1	:if=1: nx, ny, nz
1, 1, 1	:xsiz, ysiz, zsiz
1, 2, 0	:if=0: columns for x, y, z, coordinates
Variogram map output for 2Bravo data set	:file for variogram output
22, 22, 0	:nxlag, nylag, nzlag
3, 3, 1	:dxlag, dylag, dzlag
5	:minimum number of pairs
0	:standardize sill? (0=no, 1=yes)
1	:number of variograms
1, 1, 1	:tail, head, variogram type

Using "pixelplt" to plot variogram map of 2Bravo data set

2Bravo temperature data set with no springs	:file with gridded data
1	:column number for variable
-1.0e21 and 1.0e21	:data trimming limits
Output file name	:file with PostScript output
1	:realization number
45, -66, 3	:nx, xmn, xsiz
45, -66, 3	:ny, ymn, ysiz
1, 0.0, 1.0	:nz, zmn, zsiz
1	:slice orientation: 1=XY, 2=XZ, 3=YZ
1	:slice number
0	:0=arithmetic, 1=log scaling
1	:0=gray scale, 1=color scale
0	:0=continuous, 1=categorical
0, 20, 4	:continuous: min, max, increm.

Using "gamv" to create experimental variogram of 2Bravo temperature data set

2Bravo temperature data set with no springs	:file with data
1, 2, 0	:columns for X, Y, Z coordinates
1, 3	:number of variables, col numbers
-1.0e21 and 1.0e21	:trimming limits
Variogram output file name	:file for variogram output
34	:number of lags
3	:lag separation distance
1.5	:lag tolerance
2	:number of directions
0, 90, 110, 0, 90, 50.0	:azm, atol, bandh, dip, dtol, bandv
90, 90, 110, 0, 90, 50.0	:azm, atol, bandh, dip, dtol, bandv
0	:standardize sill? (0=no, 1=yes)
2	:number of variograms
1, 1, 1	:tail var., head var., variogram type
2, 2, 1	:tail var., head var., variogram type

type 1 = traditional semivariogram
type 2 = traditional cross semivariogram
type 5 = general relative semivariogram
type 7 = semivariogram of logarithms
type 9 = indicator semivariogram - continuous

type 3 = covariance
type 4 = correlogram
type 6 =pairwise relative semivariogram
type 8 = semimadorgram
type 10 = indicator semivariogram - categorical

Note: only did 2 variogram directions to make sure they were the same

Using "kt3d" to determine if experimental variogram model is a good representation of 2Bravo temperature data

2Bravo temperatue data set with no springs	:file with data
1, 2, 0, 3, 0	:columns for X, Y, Z, var, sec var
-1.0e21 and 1.0e21	:trimming limits
1	:option: 0=grid, 1=cross validation, 2=jackknife
xvk.dat	:file with jackknife data
1, 2, 0, 3, 0	:columns for X, Y, Z, var, and sec var
1	:debugging level: 0, 1, 2, 3
Debugging output file name	:file for debugging output
Kriged file output name	:file for kriged output
25, 0, 3.0	:nx, xmn, xsiz
25, 0, 3.0	:ny, ymn, ysiz
1, 0.5, 1.0	:nz, zmn, zsiz
1, 1, 1	:x, y, and z block discretization
4, 8	:min, max, data for kriging

Using "kt3d" to determine if experimental variogram model is a good representation of 2Bravo temperature data

0	:max per octant (0 = not used)
50, 50, 50	:maximum search radii
0, 0 ,0	:angles for search ellipsoid
1, 2.302	:0=SK, 1=OK, 2=non-st SK, 3=exdrift
0, 0, 0, 0, 0, 0, 0, 0, 0	:drift: x, y, z, xx, yy ,zz, xy, xz, zy
0	:0, variable; 1, estimate trend
extdrift.dat	:gridded file with drift/mean
4	:column number in gridded file
1, 1.5	:nst, nugget effect
1, 5.6, 0, 0, 0	:it, cc, ang1, ang2, ang3
33, 33, 10	:a_hmax, a_hmin, a_vert

Using "varmap" to determine anisotropy of 2Bravo residuals after using experimental variogram model to predict 2Bravo temperatures

2Bravo residual data set	:file with data
1, 3	:number of variables, columns numbers
-1.0e21 and 1.0e21	:trimming limits
0	:1=regular grid, 0=scattered values
50, 50, 1	:if=1: nx, ny, nz
1, 1, 1	:xsiz, ysiz, zsiz
1, 2, 0	:if=0: columns for x, y, z, coordinates
Variogram map output for 2Bravo data set	:file for variogram output
25, 25, 0	:nxlag, nylag, nzlag
3, 3, 1	:dxlag, dylag, dzlag
5	:minimum number of pairs
0	:standardize sill? (0=no, 1=yes)
1	:number of variograms
1, 1, 1	:tail, head, variogram type

Using "pixelplt" to plot variogram map of 2Bravo residual data set

2Bravo residual data set	:file with gridded data
1	:column number for variable
-1.0e21 and 1.0e21	:data trimming limits
Output file name	:file with PostScript output
1	:realization number
51, -75, 3	:nx, xmn, xsiz
51, -75, 3	:ny, ymn, ysiz
1, 0.0, 1.0	:nz, zmn, zsiz
1	:slice orientation: 1=XY, 2=XZ, 3=YZ
1	:slice number
0	:0=arithmetic, 1=log scaling
1	:0=gray scale, 1=color scale
0	:0=continuous, 1=categorical
0, 10, 2	:continuous: min, max, increm.

Using "gamv" to create experimental variogram of 2Bravo residual data set

2Bravo residual data set	:file with data
1, 2, 0	:columns for X, Y, Z coordinates
1, 3	:number of variables, col numbers
-1.0e21 and 1.0e21	:trimming limits
Variogram output file name	:file for variogram output
34	:number of lags
3	:lag separation distance
1.5	:lag tolerance
2	:number of directions
0, 90, 110, 0, 90, 50.0	:azm, atol, bandh, dip, dtol, bandv
90, 90, 110, 0, 90, 50.0	:azm, atol, bandh, dip, dtol, bandv
0	:standardize sill? (0=no, 1=yes)
2	:number of variograms
1, 1, 1	:tail var., head var., variogram type
2, 2, 1	:tail var., head var., variogram type

type 1 = traditional semivariogram
type 2 = traditional cross semivariogram
type 5 = general relative semivariogram
type 7 = semivariogram of logarithms
type 9 = indicator semivariogram - continuous
type 3 = covariance
type 4 = correlogram
type 6 =pairwise relative semivariogram
type 8 = semimadorgram
type 10 = indicator semivariogram - categorical

Note: only did 2 variogram directions to make sure they were the same

Using "kt3d" to predict the Bravo temperatures with 2Bravo experimental variogram model and determining if the 2Bravo experimental variogram model is a good representation of the Bravo temperatures

Bravo temperatue data set with no springs	:file with data
1, 2, 0, 3, 0	:columns for X, Y, Z, var, sec var
-1.0e21 and 1.0e21	:trimming limits
1	:option: 0=grid, 1=cross validation, 2=jackknife
xvk.dat	:file with jackknife data
1, 2, 0, 3, 0	:columns for X, Y, Z, var, and sec var
1	:debugging level: 0, 1, 2, 3
Debugging output file name	:file for debugging output
Kriged file output name	:file for kriged output
25, 0, 3.0	:nx, xmn, xsiz
25, 0, 3.0	:ny, ymn, ysiz
1, 0.5, 1.0	:nz, zmn, zsiz
1, 1, 1	:x, y, and z block discretization
4, 8	:min, max, data for kriging
0	:max per octant (0 = not used)
50, 50, 50	:maximum search radii
0, 0 ,0	:angles for search ellipsoid
1, 2.302	:0=SK, 1=OK, 2=non-st SK, 3=exdrift
0, 0, 0, 0, 0, 0, 0, 0, 0	:drift: x, y, z, xx, yy ,zz, xy, xz, zy
0	:0, variable; 1, estimate trend
extdrift.dat	:gridded file with drift/mean
4	:column number in gridded file
1, 1.5	:nst, nugget effect
1, 5.6, 0, 0, 0	:it, cc, ang1, ang2, ang3
33, 33, 10	:a_hmax, a_hmin, a_vert

Using "varmap" to determine the anisotropy of the Bravo residuals variogram map

Bravo residual data set	:file with data
1, 3	:number of variables, columns numbers
-1.0e21 and 1.0e21	:trimming limits
0	:1=regular grid, 0=scattered values
50, 50, 1	:if=1: nx, ny, nz
1, 1, 1	:xsiz, ysiz, zsiz
1, 2, 0	:if=0: columns for x, y, z, coordinates
Variogram map output for 2Bravo data set	:file for variogram output
25, 25, 0	:nxlag, nylag, nzlag
3, 3, 1	:dxlag, dylag, dzlag
5	:minimum number of pairs
0	:standardize sill? (0=no, 1=yes)
1	:number of variograms
1, 1, 1	:tail, head, variogram type

Using "pixelplt" to plot variogram map of Bravo residual data set

Bravo residual data set	:file with gridded data
1	:column number for variable
-1.0e21 and 1.0e21	:data trimming limits
Output file name	:file with PostScript output
1	:realization number
51, -75, 3	:nx, xmn, xsiz
51, -75, 3	:ny, ymn, ysiz
1, 0.0, 1.0	:nz, zmn, zsiz
1	:slice orientation: 1=XY, 2=XZ, 3=YZ
1	:slice number
0	:0=arithmetic, 1=log scaling
1	:0=gray scale, 1=color scale
0	:0=continuous, 1=categorical
0, 5, 1	:continuous: min, max, increm.

Using "gamv" to create experimental variogram of Bravo residual data set

Bravo residual data set	:file with data
1, 2, 0	:columns for X, Y, Z coordinates
1, 3	:number of variables, col numbers
-1.0e21 and 1.0e21	:trimming limits
Variogram output file name	:file for variogram output
34	:number of lags
3	:lag separation distance
1.5	:lag tolerance
2	:number of directions
0, 90, 110, 0, 90, 50.0	:azm, atol, bandh, dip, dtol, bandv
90, 90, 110, 0, 90, 50.0	:azm, atol, bandh, dip, dtol, bandv
0	:standardize sill? (0=no, 1=yes)
2	:number of variograms
1, 1, 1	:tail var., head var., variogram type
2, 2, 1	:tail var., head var., variogram type

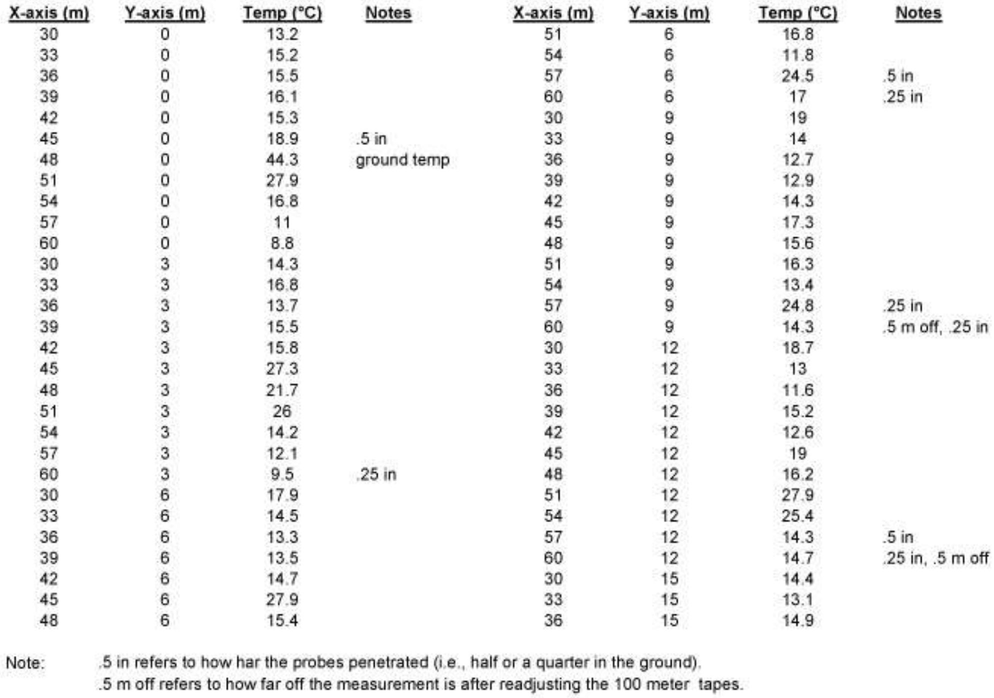
type 1 = traditional semivariogram
type 2 = traditional cross semivariogram
type 5 = general relative semivariogram
type 7 = semivariogram of logarithms
type 9 = indicator semivariogram - continuous

type 3 = covariance
type 4 = correlogram
type 6 =pairwise relative semivariogram
type 8 = semimadorgram
type 10 = indicator semivariogram - categorical

Note: only did 2 variogram directions to make sure they were the same

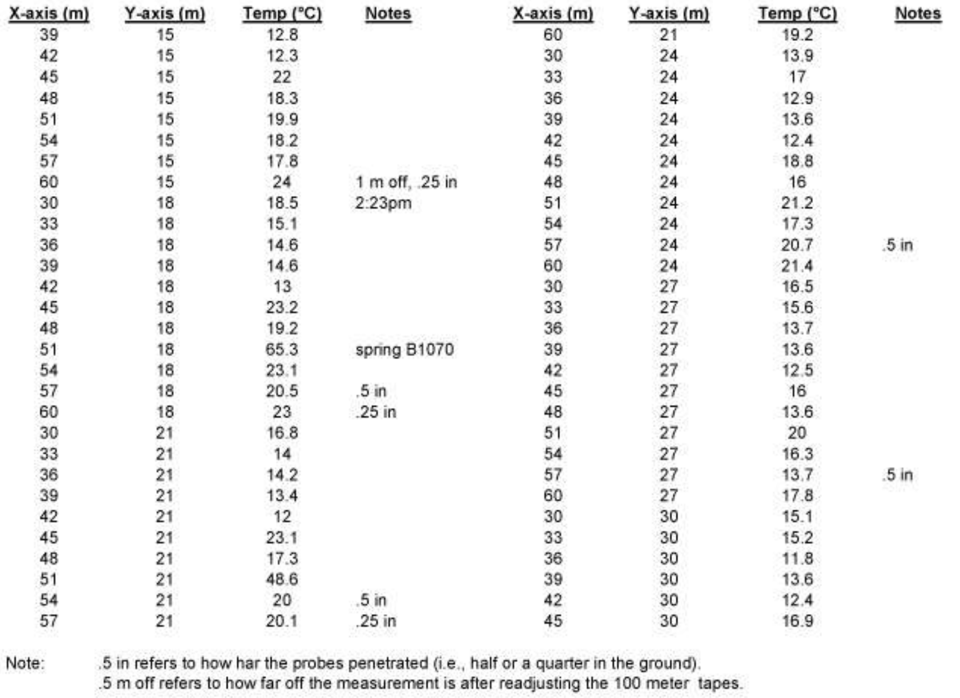
Appendix B

Temperature survey data for Main relay ramp grid, Alvord Basin, OR



X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
30	0	13.2		51	6	16.8	
33	0	15.2		54	6	11.8	
36	0	15.5		57	6	24.5	.5 in
39	0	16.1		60	6	17	.25 in
42	0	15.3		30	9	19	
45	0	18.9	.5 in	33	9	14	
48	0	44.3	ground temp	36	9	12.7	
51	0	27.9		39	9	12.9	
54	0	16.8		42	9	14.3	
57	0	11		45	9	17.3	
60	0	8.8		48	9	15.6	
30	3	14.3		51	9	16.3	
33	3	16.8		54	9	13.4	
36	3	13.7		57	9	24.8	.25 in
39	3	15.5		60	9	14.3	.5 m off, .25 in
42	3	15.8		30	12	18.7	
45	3	27.3		33	12	13	
48	3	21.7		36	12	11.6	
51	3	26		39	12	15.2	
54	3	14.2		42	12	12.6	
57	3	12.1		45	12	19	
60	3	9.5	.25 in	48	12	16.2	
30	6	17.9		51	12	27.9	
33	6	14.5		54	12	25.4	
36	6	13.3		57	12	14.3	.5 in
39	6	13.5		60	12	14.7	.25 in, .5 m off
42	6	14.7		30	15	14.4	
45	6	27.9		33	15	13.1	
48	6	15.4		36	15	14.9	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.



X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
39	15	12.8		60	21	19.2	
42	15	12.3		30	24	13.9	
45	15	22		33	24	17	
48	15	18.3		36	24	12.9	
51	15	19.9		39	24	13.6	
54	15	18.2		42	24	12.4	
57	15	17.8		45	24	18.8	
60	15	24	1 m off, .25 in	48	24	16	
30	18	18.5	2:23pm	51	24	21.2	
33	18	15.1		54	24	17.3	
36	18	14.6		57	24	20.7	.5 in
39	18	14.6		60	24	21.4	
42	18	13		30	27	16.5	
45	18	23.2		33	27	15.6	
48	18	19.2		36	27	13.7	
51	18	65.3	spring B1070	39	27	13.6	
54	18	23.1		42	27	12.5	
57	18	20.5	.5 in	45	27	16	
60	18	23	.25 in	48	27	13.6	
30	21	16.8		51	27	20	
33	21	14		54	27	16.3	
36	21	14.2		57	27	13.7	.5 in
39	21	13.4		60	27	17.8	
42	21	12		30	30	15.1	
45	21	23.1		33	30	15.2	
48	21	17.3		36	30	11.8	
51	21	48.6		39	30	13.6	
54	21	20	.5 in	42	30	12.4	
57	21	20.1	.25 in	45	30	16.9	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
48	30	13.5	
51	30	19	
54	30	17.6	
57	30	14.9	
60	30	17.2	.5 m off
30	33	17.7	
33	33	14.4	
36	33	13.3	
39	33	13.3	
42	33	11.8	
45	33	18.5	
48	33	13.6	
51	33	22.8	
54	33	20.5	
57	33	23.6	
60	33	23.9	
30	36	22	2:38pm
33	36	17.9	
36	36	13.5	
39	36	13.3	
42	36	11.6	
45	36	20.7	
48	36	13.1	
51	36	18.7	
54	36	17.5	
57	36	27.5	
60	36	29.8	
30	39	17.6	
33	39	14.8	
36	39	16	
39	39	13.7	
42	39	11.5	
45	39	18.2	
48	39	12.2	
51	39	23.5	
54	39	17.5	
57	39	23.8	
60	39	28.6	
30	42	15.7	
33	42	13.8	
36	42	12.5	
39	42	14.2	
42	42	12.7	
45	42	17.8	
48	42	12.6	
51	42	14.8	
54	42	15.9	
57	42	22.6	
60	42	25.3	
30	45	19.4	
33	45	15.7	
36	45	14.6	
39	45	13	
42	45	13.4	
45	45	19.6	
48	45	12.4	
51	45	16.3	
54	45	20.8	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
57	45	25	
60	45	24.6	
30	48	22.8	
33	48	19.6	
36	48	17.2	
39	48	14.5	
42	48	13.3	
45	48	18.9	
48	48	13.9	
51	48	17.8	
54	48	16.1	
57	48	20.5	
60	48	22	
30	51	26.7	
33	51	22.4	
36	51	17.8	
39	51	14.2	
42	51	12.5	
45	51	18.4	
48	51	14.7	
51	51	18.6	
54	51	14.3	
57	51	20.6	
60	51	26	
30	54	22.4	2:54pm
33	54	21	
36	54	16.4	
39	54	16.9	
42	54	12.8	
45	54	19.1	
48	54	13.1	
51	54	13.3	
54	54	13.5	
57	54	21.1	
60	54	12.5	
30	57	19.5	
33	57	20.3	
36	57	16.8	
39	57	16.6	
42	57	13.4	
45	57	19.3	
48	57	15.2	
51	57	22.2	
54	57	14.3	
57	57	11.8	
60	57	13	
30	60	18.9	
33	60	17.3	
36	60	16.8	
39	60	17.7	
42	60	13.5	
45	60	19.4	
48	60	12.8	
51	60	12.8	
54	60	12.5	
57	60	26.4	
60	60	13.6	
30	63	23.7	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
33	63	20.3		54	69	20	
36	63	19.6		57	69	25.8	
39	63	17.6		60	69	20.6	
42	63	15.2		30	72	22.1	3:11pm
45	63	21.8		33	72	21.6	
48	63	12.6		36	72	17.8	
51	63	16.4		39	72	18.3	
54	63	12.4		42	72	12	
57	63	26.8		45	72	17.6	
60	63	13.7		48	72	12.3	
30	66	27.1		51	72	17.2	
33	66	20.4		54	72	25.6	
36	66	17.8		57	72	30.6	
39	66	17.9		60	72	29.2	
42	66	15.4		30	75	19	
45	66	19.2		33	75	19.3	
48	66	13		36	75	18.4	
51	66	15.8		39	75	14.6	
54	66	18.1		42	75	12.3	
57	66	29.1		45	75	18.5	
60	66	15.6		48	75	11.7	
30	69	22.6		51	75	22.5	
33	69	24.1		54	75	24.8	
36	69	18.7		57	75	28.3	
39	69	16		60	75	27.2	
42	69	14.5		30	78	19.6	
45	69	20.6		33	78	16.9	
48	69	11.5		36	78	17	
51	69	17.6		39	78	14	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
42	78	12.2		30	87	19.7	
45	78	24		33	87	18	
48	78	12.3		36	87	15	
51	78	21		39	87	13.8	
54	78	25		42	87	13.2	
57	78	28		45	87	30.3	
60	78	25.2		48	87	13.9	
30	81	22.1		51	87	15.5	
33	81	18.8		54	87	19.8	
36	81	14.9		57	87	18.8	
39	81	15.5		60	87	26.1	
42	81	12.5		30	90	13.7	3:26pm
45	81	23		33	90	14.6	
48	81	14.6		36	90	13.2	
51	81	22.6		39	90	14.8	
54	81	23.8		42	90	12.1	
57	81	25.1		45	90	16.3	
60	81	20.8		48	90	14.8	
30	84	26		51	90	18.5	
33	84	19.2		54	90	15.9	
36	84	14.5		57	90	25.6	
39	84	14.8		60	90	19.3	
42	84	12.6		30	93	13.8	
45	84	23		33	93	14	
48	84	12.9		36	93	13.3	
51	84	18.3		39	93	14.1	
54	84	19.6		42	93	11.7	
57	84	22.3		45	93	19.5	
60	84	24.8		48	93	17.2	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
51	93	17.8		39	102	13	
54	93	19.2		42	102	10.5	
57	93	21.2		45	102	19.5	
60	93	20.2		48	102	14.1	
30	96	14.4		51	102	16.7	
33	96	14.2		54	102	16.9	
36	96	13.9		57	102	16.1	
39	96	14		60	102	16.9	
42	96	11.5		30	105	13	
45	96	33.4		33	105	12.1	
48	96	13.5		36	105	10.5	
51	96	15.3		39	105	12.9	
54	96	16.1		42	105	11.8	
57	96	16.8		45	105	18.6	
60	96	19.2		48	105	13.4	
30	99	13.8		51	105	16.1	
33	99	11.4		54	105	20.6	
36	99	11.5		57	105	19.5	
39	99	12.4		60	105	22.8	
42	99	11.3		30	108	13.8	3:44pm
45	99	18.6		33	108	13	
48	99	13.2		36	108	10.9	
51	99	16.3		39	108	10.6	
54	99	13.5		42	108	10.1	
57	99	24.9		45	108	26.4	
60	99	16.2		48	108	13.6	
30	102	12.9		51	108	19.8	
33	102	12		54	108	20.9	
36	102	11		57	108	22.8	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
60	108	24.4		45	117	17.9	
30	111	13.9		48	117	10.1	
33	111	12.3		51	117	12.7	
36	111	11.7		54	117	11.7	
39	111	11.9		57	117	27.7	
42	111	11.1		60	117	11.8	
45	111	27.2		0	117	11	4:00pm
48	111	12.9		3	117	13.5	
51	111	18.2		6	117	13.4	
54	111	20.6		9	117	13.2	
57	111	22.9		12	117	15.6	
60	111	20.2		15	117	21.3	.25 in, road
30	114	13.5		18	117	13.9	
33	114	13		21	117	13.8	
36	114	13		24	117	15.4	
39	114	11.5		27	117	12.5	
42	114	10.8		0	114	10.6	
45	114	12	not 100% sure	3	114	12.1	
48	114	12.5		6	114	13.8	
51	114	13.2		9	114	18.3	
54	114	15.7		12	114	20	.5 in
57	114	24.2		15	114	24.6	.25 in, road
60	114	14.6		18	114	14.9	
30	117	13.2		21	114	15.5	
33	117	13		24	114	28	
36	117	13.2		27	114	13	
39	117	11.6		0	111	10.9	
42	117	10.8		3	111	12	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.
Road refers to the measurement is taken within the somewhat compacted road through the study area.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
6	111	12.5		0	102	10.1	
9	111	19.7		3	102	11	
12	111	26.5	.5 in, high temp?	6	102	11.3	
15	111	23.2		9	102	11.9	
18	111	15.9		12	102	13.4	
21	111	16.3		15	102	23.2	
24	111	16.6		18	102	13.6	.5 in
27	111	12.3		21	102	17	
0	108	10.5		24	102	25.1	
3	108	11.6		27	102	12.1	
6	108	13.5		0	99	10.3	4:30pm
9	108	18.4		3	99	10.9	
12	108	20.8		6	99	10.6	
15	108	18.6		9	99	11.7	
18	108	13.3	.5 in	12	99	11.8	
21	108	17.1		15	99	21	
24	108	17.4		18	99	15.3	
27	108	13.6		21	99	24	
0	105	10.8		24	99	24.9	
3	105	11.6		27	99	11.9	
6	105	11.9		0	96	10	
9	105	13.9		3	96	11	
12	105	16.9		6	96	12.1	
15	105	16.7		9	96	11.8	
18	105	12.9		12	96	12.1	
21	105	18.1		15	96	23.8	
24	105	25.2		18	96	13.8	
27	105	12.6		21	96	22	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.
Road refers to the measurement is taken within the somewhat compacted road through the study area.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
24	96	25.6		18	87	16.9	.5 in
27	96	12.6		21	87	16.4	
0	93	11.8		24	87	22.5	near spring 1.5 ft
3	93	12.5		27	87	13.7	
6	93	13		0	84	17.3	
9	93	13.2		3	84	22	
12	93	13.8		6	84	21.1	
15	93	15	.5 in	9	84	23.5	
18	93	15		12	84	26.2	
21	93	15.5		15	84	25.9	road
24	93	19.6		18	84	19.4	
27	93	12.2		21	84	22.5	
0	90	14		24	84	27.5	
3	90	13.6		27	84	19.4	
6	90	14.3		0	81	16.9	4:50pm
9	90	17.3		3	81	19	
12	90	19.8		6	81	18.6	
15	90	22.8		9	81	21.3	
18	90	19.6		12	81	23.3	
21	90	13.2		15	81	23.1	road
24	90	26.5		18	81	25.5	
27	90	14.9		21	81	21.8	
0	87	15.2		24	81	28	
3	87	18.5		27	81	21.2	
6	87	19.3		0	78	14.5	
9	87	19.4		3	78	16.5	
12	87	18.8		6	78	15.8	
15	87	22	road	9	78	18.1	

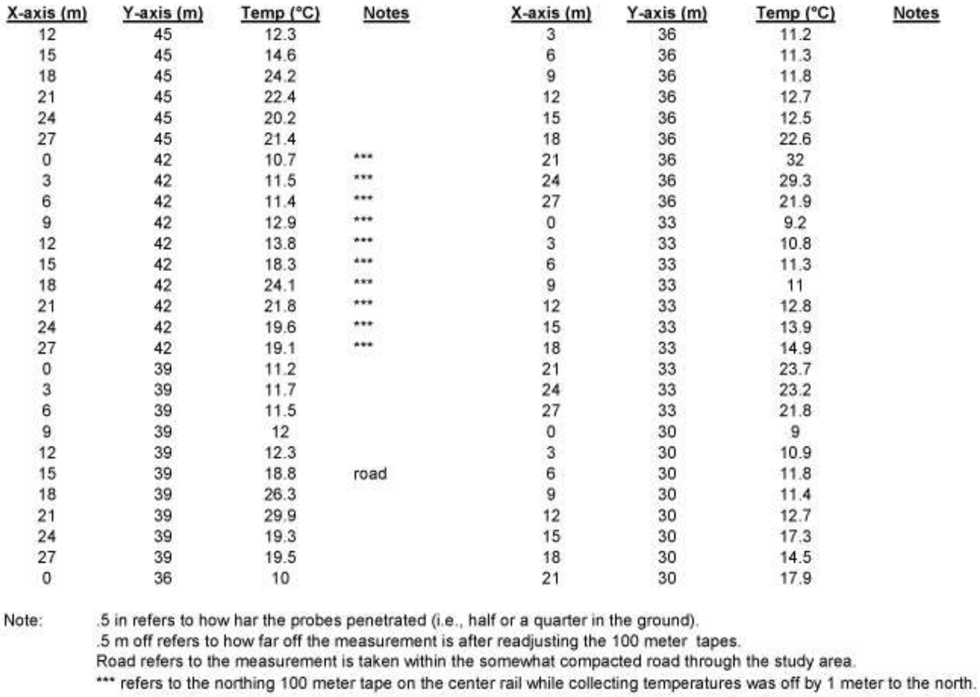
Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.
Road refers to the measurement is taken within the somewhat compacted road through the study area.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
12	78	20	
15	78	19.6	road
18	78	22.7	
21	78	42.5	
24	78	23.8	
27	78	18.3	
0	75	11.2	
3	75	14.6	
6	75	14.6	
9	75	16	
12	75	18.6	
15	75	20.2	road
18	75	20	
21	75	23.8	
24	75	24.9	
27	75	16.7	
0	72	9.9	
3	72	12.5	
6	72	14.3	
9	72	17.2	
12	72	19.5	
15	72	21.5	
18	72	21.7	
21	72	16.4	
24	72	22.4	
27	72	15.9	
0	69	10.3	
3	69	12.7	
6	69	13.6	
9	69	15	
12	69	20.2	
15	69	23.3	
18	69	27.1	
21	69	18.8	
24	69	17.6	
27	69	16.4	
0	66	10.5	
3	66	11.4	
6	66	13.2	
9	66	15.3	
12	66	16.8	.5 in
15	66	23	.5 in, temp hold?
18	66	23	
21	66	16.5	
24	66	18.3	
27	66	17.9	
0	63	10.9	5:07pm
3	63	12.7	
6	63	13.1	
9	63	16	
12	63	16.5	
15	63	23	.5 in, temp hold?
18	63	22.5	
21	63	20.5	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.
Road refers to the measurement is taken within the somewhat compacted road through the study area.
Temp hold refers to the thermometer reading accidently being held.

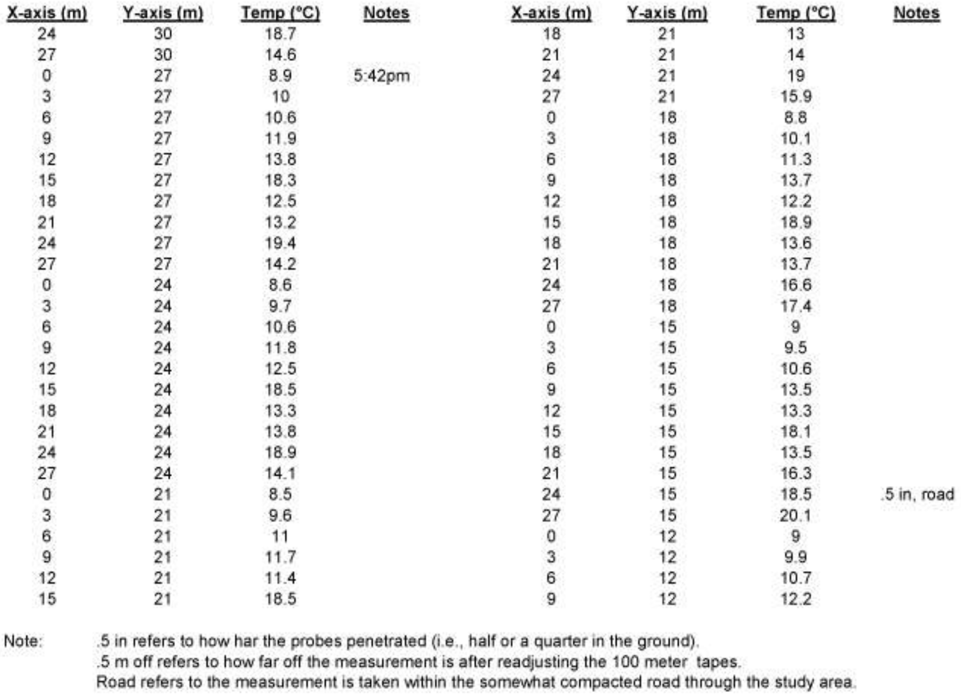
X-axis (m)	Y-axis (m)	Temp (°C)	Notes
24	63	23.8	
27	63	21	
0	60	10.6	
3	60	12.5	
6	60	12.6	
9	60	15.9	
12	60	13.7	.5 in, road
15	60	23.3	
18	60	21.6	
21	60	21.1	
24	60	23	
27	60	20.6	
0	57	10.8	
3	57	11.5	
6	57	12.4	
9	57	13.3	
12	57	14.2	.25 in
15	57	25.3	.5 in
18	57	26.1	
21	57	26.3	
24	57	24.6	
27	57	22.7	
0	54	11.2	
3	54	11.8	
6	54	12.7	
9	54	13.5	
12	54	12.5	.5 in, road
15	54	17.9	
18	54	36.3	
21	54	23.1	
24	54	22.5	
27	54	20	
0	51	11.3	
3	51	11.4	
6	51	11.9	
9	51	13.6	
12	51	12.7	
15	51	19.9	.25 in
18	51	26.6	
21	51	22.4	
24	51	22.6	
27	51	25.9	
0	48	10.7	
3	48	11.4	
6	48	11.8	
9	48	11.8	
12	48	13.4	
15	48	20.4	.5 m off, .5 in
18	48	28.3	
21	48	25.1	
24	48	25.8	
27	48	24.1	
0	45	10.1	5:23pm
3	45	11	
6	45	11.5	
9	45	13	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.
Road refers to the measurement is taken within the somewhat compacted road through the study area.



X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
12	45	12.3		3	36	11.2	
15	45	14.6		6	36	11.3	
18	45	24.2		9	36	11.8	
21	45	22.4		12	36	12.7	
24	45	20.2		15	36	12.5	
27	45	21.4		18	36	22.6	
0	42	10.7	***	21	36	32	
3	42	11.5	***	24	36	29.3	
6	42	11.4	***	27	36	21.9	
9	42	12.9	***	0	33	9.2	
12	42	13.8	***	3	33	10.8	
15	42	18.3	***	6	33	11.3	
18	42	24.1	***	9	33	11	
21	42	21.8	***	12	33	12.8	
24	42	19.6	***	15	33	13.9	
27	42	19.1	***	18	33	14.9	
0	39	11.2		21	33	23.7	
3	39	11.7		24	33	23.2	
6	39	11.5		27	33	21.8	
9	39	12		0	30	9	
12	39	12.3		3	30	10.9	
15	39	18.8	road	6	30	11.8	
18	39	26.3		9	30	11.4	
21	39	29.9		12	30	12.7	
24	39	19.3		15	30	17.3	
27	39	19.5		18	30	14.5	
0	36	10		21	30	17.9	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.
Road refers to the measurement is taken within the somewhat compacted road through the study area.
*** refers to the northing 100 meter tape on the center rail while collecting temperatures was off by 1 meter to the north.



X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
24	30	18.7		18	21	13	
27	30	14.6		21	21	14	
0	27	8.9	5:42pm	24	21	19	
3	27	10		27	21	15.9	
6	27	10.6		0	18	8.8	
9	27	11.9		3	18	10.1	
12	27	13.8		6	18	11.3	
15	27	18.3		9	18	13.7	
18	27	12.5		12	18	12.2	
21	27	13.2		15	18	18.9	
24	27	19.4		18	18	13.6	
27	27	14.2		21	18	13.7	
0	24	8.6		24	18	16.6	
3	24	9.7		27	18	17.4	
6	24	10.6		0	15	9	
9	24	11.8		3	15	9.5	
12	24	12.5		6	15	10.6	
15	24	18.5		9	15	13.5	
18	24	13.3		12	15	13.3	
21	24	13.8		15	15	18.1	
24	24	18.9		18	15	13.5	
27	24	14.1		21	15	16.3	
0	21	8.5		24	15	18.5	.5 in, road
3	21	9.6		27	15	20.1	
6	21	11		0	12	9	
9	21	11.7		3	12	9.9	
12	21	11.4		6	12	10.7	
15	21	18.5		9	12	12.2	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.
Road refers to the measurement is taken within the somewhat compacted road through the study area.

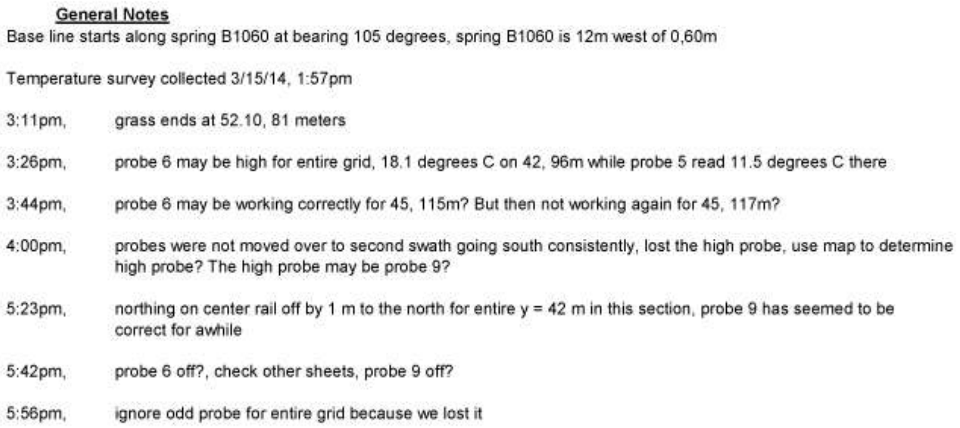
X-axis (m)	Y-axis (m)	Temp (°C)	Notes
12	12	13.8	
15	12	18.2	
18	12	15.1	
21	12	19.5	
24	12	18.2	
27	12	18.9	
0	9	8.9	5:56pm
3	9	10.1	
6	9	11.4	
9	9	11.1	
12	9	12.2	
15	9	18	
18	9	15.1	
21	9	15.5	
24	9	17.9	
27	9	13.5	
0	6	9.4	
3	6	10.8	
6	6	12	
9	6	13.1	
12	6	12.8	
15	6	17.4	
18	6	14.1	
21	6	17.7	
24	6	17.4	
27	6	13.3	
0	3	9.2	
3	3	11	
6	3	12	
9	3	14.1	
12	3	11.4	
15	3	18.2	
18	3	13.8	
21	3	16.7	
24	3	16.8	
27	3	13	
0	0	9.8	
3	0	11	
6	0	12.7	
9	0	12.2	
12	0	11.6	
15	0	17.4	
18	0	14.8	
21	0	17.2	
24	0	17.3	
27	0	13.2	

Note: .5 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
.5 m off refers to how far off the measurement is after readjusting the 100 meter tapes.
Road refers to the measurement is taken within the somewhat compacted road through the study area.

Spring names	x (m)	y (m)	Spring temps (°C)
B1060	48	0	84.2
B1070	51	18	65.3
B1080	Didn't record	Didn't record	86.2
B1090	Didn't record	Didn't record	82.9
B1100	Didn't record	Didn't record	45.1
B1110	Didn't record	Didn't record	66.2
B1120	Didn't record	Didn't record	80.8
B1130	Didn't record	Didn't record	53.2
B1140	Didn't record	Didn't record	72.1
B1150	Didn't record	Didn't record	77.9
B1160	Didn't record	Didn't record	36
B1170	Didn't record	Didn't record	84.5
B1180	Didn't record	Didn't record	64

Estimated based on spring UTM measurements

Spring names	x (m)	y (m)	Spring temps (°C)
B1060	48	0.0	84.2
B1070	50.7	13.2	65.3
B1080	51.5	19.8	86.2
B1090	51.7	20.4	82.9
B1100	52.8	42	45.1
B1110	46.2	77.9	66.2
B1120	17.4	13.7	80.8
B1130	14.4	43.6	53.2
B1140	14.5	45.4	72.1
B1150	14.4	50.3	77.9
B1160	12.8	57.8	36
B1170	19.3	84.7	84.5
B1180	18.6	88.9	64



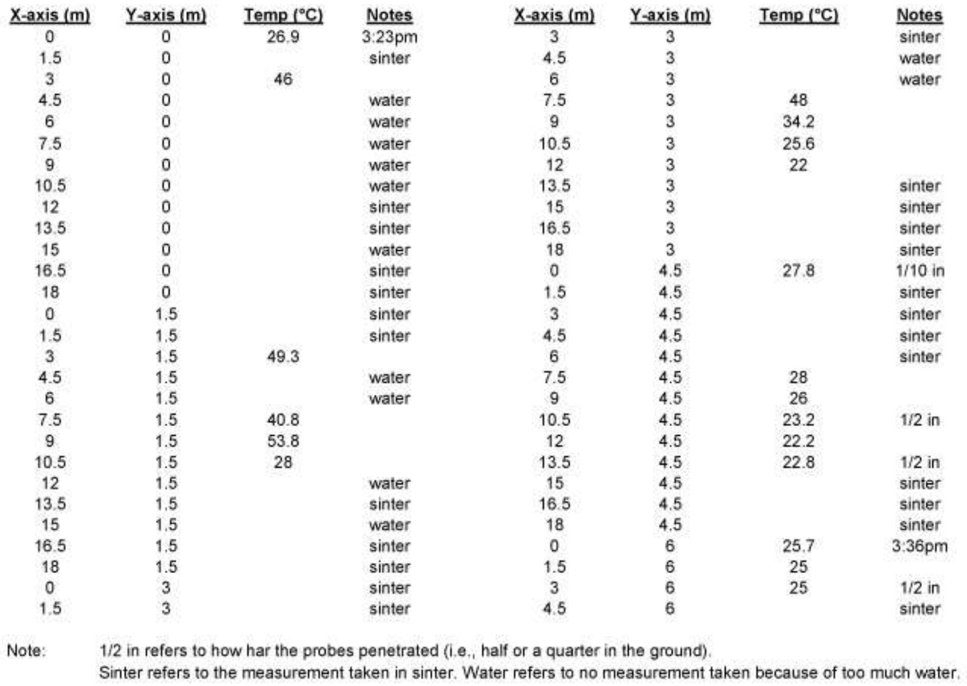
General Notes

Base line starts along spring B1060 at bearing 105 degrees, spring B1060 is 12m west of 0,60m

Temperature survey collected 3/15/14, 1:57pm

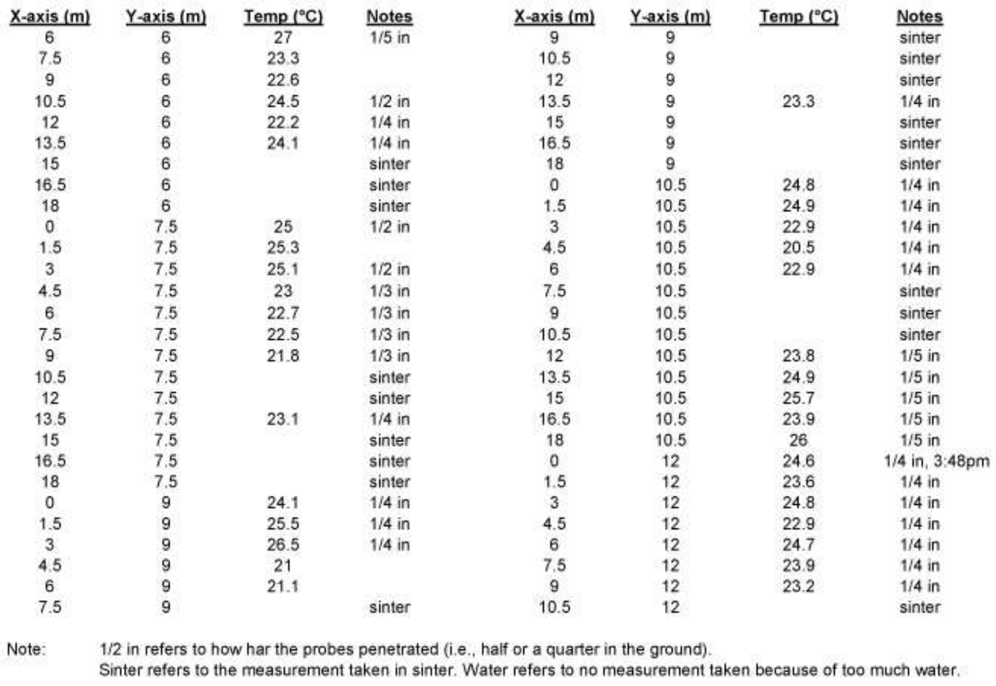
3:11pm,	grass ends at 52.10, 81 meters
3:26pm,	probe 6 may be high for entire grid, 18.1 degrees C on 42, 96m while probe 5 read 11.5 degrees C there
3:44pm,	probe 6 may be working correctly for 45, 115m? But then not working again for 45, 117m?
4:00pm,	probes were not moved over to second swath going south consistently, lost the high probe, use map to determine high probe? The high probe may be probe 9?
5:23pm,	northing on center rail off by 1 m to the north for entire y = 42 m in this section, probe 9 has seemed to be correct for awhile
5:42pm,	probe 6 off?, check other sheets, probe 9 off?
5:56pm,	ignore odd probe for entire grid because we lost it

Temperature survey data for Alpha grid, Yellowstone National Park, WY



X-axis (m)	Y-axis (m)	Temp (°C)	Notes
0	0	26.9	3:23pm
1.5	0		sinter
3	0	46	
4.5	0		water
6	0		water
7.5	0		water
9	0		water
10.5	0		water
12	0		sinter
13.5	0		sinter
15	0		water
16.5	0		sinter
18	0		sinter
0	1.5		sinter
1.5	1.5		sinter
3	1.5	49.3	
4.5	1.5		water
6	1.5		water
7.5	1.5	40.8	
9	1.5	53.8	
10.5	1.5	28	
12	1.5		water
13.5	1.5		sinter
15	1.5		water
16.5	1.5		sinter
18	1.5		sinter
0	3		sinter
1.5	3		sinter
3	3		sinter
4.5	3		water
6	3		water
7.5	3	48	
9	3	34.2	
10.5	3	25.6	
12	3	22	
13.5	3		sinter
15	3		sinter
16.5	3		sinter
18	3		sinter
0	4.5	27.8	1/10 in
1.5	4.5		sinter
3	4.5		sinter
4.5	4.5		sinter
6	4.5		sinter
7.5	4.5	28	
9	4.5	26	
10.5	4.5	23.2	1/2 in
12	4.5	22.2	
13.5	4.5	22.8	1/2 in
15	4.5		sinter
16.5	4.5		sinter
18	4.5		sinter
0	6	25.7	3:36pm
1.5	6	25	
3	6	25	1/2 in
4.5	6		sinter

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.



X-axis (m)	Y-axis (m)	Temp (°C)	Notes
6	6	27	1/5 in
7.5	6	23.3	
9	6	22.6	
10.5	6	24.5	1/2 in
12	6	22.2	1/4 in
13.5	6	24.1	1/4 in
15	6		sinter
16.5	6		sinter
18	6		sinter
0	7.5	25	1/2 in
1.5	7.5	25.3	
3	7.5	25.1	1/2 in
4.5	7.5	23	1/3 in
6	7.5	22.7	1/3 in
7.5	7.5	22.5	1/3 in
9	7.5	21.8	1/3 in
10.5	7.5		sinter
12	7.5		sinter
13.5	7.5	23.1	1/4 in
15	7.5		sinter
16.5	7.5		sinter
18	7.5		sinter
0	9	24.1	1/4 in
1.5	9	25.5	1/4 in
3	9	26.5	1/4 in
4.5	9	21	
6	9	21.1	
7.5	9		sinter
9	9		sinter
10.5	9		sinter
12	9		sinter
13.5	9	23.3	1/4 in
15	9		sinter
16.5	9		sinter
18	9		sinter
0	10.5	24.8	1/4 in
1.5	10.5	24.9	1/4 in
3	10.5	22.9	1/4 in
4.5	10.5	20.5	1/4 in
6	10.5	22.9	1/4 in
7.5	10.5		sinter
9	10.5		sinter
10.5	10.5		sinter
12	10.5	23.8	1/5 in
13.5	10.5	24.9	1/5 in
15	10.5	25.7	1/5 in
16.5	10.5	23.9	1/5 in
18	10.5	26	1/5 in
0	12	24.6	1/4 in, 3:48pm
1.5	12	23.6	1/4 in
3	12	24.8	1/4 in
4.5	12	22.9	1/4 in
6	12	24.7	1/4 in
7.5	12	23.9	1/4 in
9	12	23.2	1/4 in
10.5	12		sinter

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
12	12	24.8	1/5 in	15	15	24.3	1/4 in
13.5	12		sinter	16.5	15	26.6	1/4 in
15	12	26.4	1/5 in	18	15	27.6	1/4 in
16.5	12	25.3	1/5 in	0	16.5	21	1/4 in
18	12	26.3	1/5 in	1.5	16.5	26.1	1/4 in
0	13.5	21.6	1/3 in	3	16.5	25.3	1/4 in
1.5	13.5	20.3		4.5	16.5	22.2	1/4 in
3	13.5	24.4	1/4 in	6	16.5	25.9	1/4 in
4.5	13.5	24	1/4 in	7.5	16.5	25.2	1/4 in
6	13.5	26.5	1/4 in	9	16.5	24.9	1/4 in
7.5	13.5	23.3	1/4 in	10.5	16.5	24.9	1/4 in
9	13.5	23.1	1/4 in	12	16.5	26.3	1/4 in
10.5	13.5	23.2	1/4 in	13.5	16.5		sinter
12	13.5	25	1/4 in	15	16.5	23.9	1/4 in
13.5	13.5	26.3	1/4 in	16.5	16.5	27	1/4 in
15	13.5	25.9	1/4 in	18	16.5	25.8	1/4 in
16.5	13.5		sinter	0	18	25.8	1/4 in, 3:59pm
18	13.5		sinter	1.5	18	24.9	1/4 in
0	15	24	1/4 in	3	18	24.5	1/4 in
1.5	15	22.6	1/4 in	4.5	18	25.3	1/4 in
3	15	25.5	1/4 in	6	18	24.6	1/4 in
4.5	15	22.5	1/4 in	7.5	18	24.5	1/4 in
6	15	24.5	1/4 in	9	18	24	1/2 in
7.5	15	24	1/4 in	10.5	18	26.8	1/5 in
9	15	22.8	1/4 in	12	18	24.6	1/5 in
10.5	15	24.2	1/4 in	13.5	18	26.9	1/5 in
12	15	23.8	1/4 in	15	18	27	1/5 in
13.5	15	26.8	1/4 in	16.5	18	25	1/5 in

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
18	18	24.9	1/5 in	1.5	22.5	24.5	1/4 in
0	19.5	25.8	1/4 in	3	22.5	26.8	1/4 in
1.5	19.5	24.6	1/4 in	4.5	22.5	25.6	1/4 in
3	19.5	25.4	1/4 in	6	22.5	29.2	1/4 in
4.5	19.5	24.9	1/4 in	7.5	22.5	24.9	1/4 in
6	19.5	28.3	1/6 in	9	22.5	27.9	1/4 in
7.5	19.5	21.3		10.5	22.5	27.8	1/4 in
9	19.5	27.7	1/4 in	12	22.5	25.1	1/4 in
10.5	19.5	25.2	1/4 in	13.5	22.5	26.6	1/4 in
12	19.5	24.5	1/4 in	15	22.5		sinter
13.5	19.5	27.1	1/4 in	16.5	22.5	27.6	1/4 in
15	19.5	26.1	1/4 in	18	22.5	25.8	1/4 in
16.5	19.5	22.9	1/4 in	0	24	23.2	1/2 in, 4:14pm
18	19.5	25	1/4 in	1.5	24	24.3	1/3 in
0	21	24.2	1/4 in	3	24	25.9	1/4 in
1.5	21	25.7	1/4 in	4.5	24	21.2	1/2 in
3	21	25.5	1/4 in	6	24	29.8	1/4 in
4.5	21	25.5	1/4 in	7.5	24	25.8	1/4 in
6	21	28.9	1/4 in	9	24	25.3	1/4 in
7.5	21	27.5	1/4 in	10.5	24	25.5	1/4 in
9	21	25.3	1/4 in	12	24	25.6	1/4 in
10.5	21	26.8	1/4 in	13.5	24	24.6	1/4 in
12	21	24.6	1/4 in	15	24	27	1/4 in
13.5	21	26.4	1/4 in	16.5	24	25.9	1/4 in
15	21	26.6	1/4 in	18	24	23.8	1/3 in
16.5	21	23.2	1/2 in	0	25.5	22.7	1/4 in
18	21	23.3	1/4 in	1.5	25.5	24.4	1/2 in
0	22.5	25.5	1/4 in	3	25.5	25.4	1/4 in

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
4.5	25.5	24	1/4 in
6	25.5	29.9	1/4 in
7.5	25.5	26.3	1/4 in
9	25.5	28.6	1/4 in
10.5	25.5	26.2	1/4 in
12	25.5	24.4	1/4 in
13.5	25.5	27.4	1/4 in
15	25.5	23.7	1/4 in
16.5	25.5	23.9	1/4 in
18	25.5	26.9	1/4 in
0	27	21.1	
1.5	27	21.9	
3	27	24.9	1/4 in
4.5	27	24.8	1/4 in
6	27	29.7	1/2 in
7.5	27	26.9	1/4 in
9	27	27.6	1/4 in
10.5	27	24.5	1/4 in
12	27	23.5	1/4 in
13.5	27	28	1/4 in
15	27	27.2	1/4 in
16.5	27	26.9	1/4 in
18	27	25.8	1/4 in
0	28.5	20.9	
1.5	28.5	26.8	1/4 in
3	28.5	28.6	1/4 in
4.5	28.5	25	1/4 in
6	28.5	29.8	1/4 in
7.5	28.5	24.4	1/4 in
9	28.5	21.5	1/4 in
10.5	28.5	21.5	1/4 in
12	28.5	23.9	1/4 in
13.5	28.5	27.9	1/4 in
15	28.5	24.1	1/4 in
16.5	28.5	27.6	1/4 in
18	28.5	24.8	1/4 in
0	30	21.3	1/4 in, 4:23pm
1.5	30	25.2	1/4 in
3	30	27	1/4 in
4.5	30	25.8	1/4 in
6	30	28	1/4 in
7.5	30	20.9	
9	30	20.9	
10.5	30	25.9	1/4 in
12	30	20.9	
13.5	30	28.8	1/4 in
15	30	26.9	1/4 in
16.5	30	25.2	1/4 in
18	30	26.6	1/4 in
0	31.5	24.4	1/4 in
1.5	31.5	27.5	1/4 in
3	31.5	28.7	1/4 in
4.5	31.5	27.4	1/4 in
6	31.5	28	1/4 in
7.5	31.5	27.5	1/4 in
9	31.5	21.3	1/2 in

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
10.5	31.5	23	1/2 in
12	31.5	24.6	1/4 in
13.5	31.5	26.6	1/4 in
15	31.5	28.3	1/4 in
16.5	31.5	27.6	1/4 in
18	31.5	27.8	1/4 in
0	33	23.9	1/4 in
1.5	33	22.8	1/2 in
3	33	28.3	1/4 in
4.5	33	27	1/4 in
6	33	29.1	1/4 in
7.5	33	21.5	1/4 in
9	33	24.1	1/4 in
10.5	33	28.2	1/4 in
12	33	24.9	1/4 in
13.5	33	22.9	1/4 in
15	33	24.4	1/4 in
16.5	33	28.7	1/4 in
18	33	26.9	1/4 in
0	34.5	26.6	1/4 in
1.5	34.5	23.7	1/4 in
3	34.5	25.8	1/4 in
4.5	34.5	26	1/4 in
6	34.5	28.8	1/4 in
7.5	34.5	20.1	1/4 in
9	34.5	22.6	1/4 in
10.5	34.5	22.9	1/4 in
12	34.5	20.4	1/4 in
13.5	34.5	25.2	1/4 in
15	34.5	25.8	1/4 in
16.5	34.5	26.3	1/4 in
18	34.5	22.5	1/4 in
0	36	22.7	1/4 in
1.5	36	20	1/2 in
3	36	19.7	
4.5	36	18.2	1/4 in
6	36	29.2	1/4 in
7.5	36	19.3	1/4 in
9	36	23.7	1/4 in
10.5	36	28.3	1/4 in
12	36	26	1/4 in
13.5	36	26.2	1/4 in
15	36	28.3	1/4 in
16.5	36	26.8	1/4 in
18	36	20.3	1/4 in
19.5	36		tree, 4:45pm
21	36	27	1/4 in
22.5	36	22.3	1/4 in
24	36	33	1/4 in
25.5	36	23.3	1/2 in
27	36	24.5	1/2 in
28.5	36	22.2	1/2 in
30	36	22.2	1/2 in
31.5	36	27.1	1/2 in
33	36	25.1	1/4 in
34.5	36	28	1/4 in

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
36	36	22.1		24	31.5	33.5	1/4 in
19.5	34.5	25.8	1/4 in	25.5	31.5	23.1	1/2 in
21	34.5	25.2	1/4 in	27	31.5	24.1	1/2 in
22.5	34.5	25.1	1/4 in	28.5	31.5	22.7	1/2 in
24	34.5	32.8	1/4 in	30	31.5	22.7	1/2 in
25.5	34.5	27.5	1/4 in	31.5	31.5	27.9	1/4 in
27	34.5	29	1/4 in	33	31.5		sinter
28.5	34.5	22.7	1/4 in	34.5	31.5	24	1/4 in
30	34.5	27.8	1/4 in	36	31.5	24.9	1/4 in
31.5	34.5	23.8	1/4 in	19.5	30	23	1/4 in, 4:55pm
33	34.5	22.8	1/4 in	21	30	23.9	1/4 in
34.5	34.5		sinter	22.5	30	24.8	1/4 in
36	34.5	23	1/4 in	24	30	32.9	1/4 in
19.5	33	24.8	1/4 in	25.5	30	21.5	1/4 in
21	33	25.9	1/4 in	27	30	24.7	1/4 in
22.5	33	26.4	1/4 in	28.5	30	25.7	1/4 in
24	33	33.3	1/4 in	30	30	22.3	1/4 in
25.5	33	25	1/4 in	31.5	30		sinter
27	33	24.5	1/4 in	33	30		sinter
28.5	33	24	1/4 in	34.5	30		sinter
30	33	26.8	1/4 in	36	30		sinter
31.5	33	24	1/4 in	19.5	28.5	25.5	1/4 in
33	33		sinter	21	28.5	24.7	1/4 in
34.5	33	29.4	1/4 in	22.5	28.5	22.1	1/4 in
36	33	23.1	1/4 in	24	28.5	32.5	1/4 in
19.5	31.5	26.1	1/4 in	25.5	28.5	22.5	1/4 in
21	31.5	28.8	1/4 in	27	28.5	21.5	
22.5	31.5	25.5	1/4 in	28.5	28.5	26.8	1/4 in

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
30	28.5	24.4	1/4 in	36	25.5	28.9	1/4 in
31.5	28.5	28.2	1/4 in	19.5	24	26.9	1/4 , 5:04pm
33	28.5		sinter	21	24	28	1/4 in
34.5	28.5		sinter	22.5	24	25.8	1/4 in
36	28.5	25.2	1/4 in	24	24	23.2	1/4 in
19.5	27	23	1/4 in	25.5	24	25	1/4 in
21	27	25.2	1/4 in	27	24	25.8	1/4 in
22.5	27	22.3	1/4 in	28.5	24	26.4	1/4 in
24	27	26.2	1/4 in	30	24	26.4	1/4 in
25.5	27	24.1	1/4 in	31.5	24	28	1/4 in
27	27	26.3	1/4 in	33	24	27.3	1/4 in
28.5	27	25.8	1/4 in	34.5	24	25.2	1/4 in
30	27	26.6	1/4 in	36	24	26.8	1/4 in
31.5	27	28.6	1/4 in	19.5	22.5	24.5	1/4 in
33	27		sinter	21	22.5	26.6	1/4 in
34.5	27	23.8	1/4 in	22.5	22.5	26.2	1/4 in
36	27	27.8	1/4 in	24	22.5	22.2	1/4 in
19.5	25.5	25.9	1/4 in	25.5	22.5	24.7	1/4 in
21	25.5	24	1/4 in	27	22.5	26.6	1/4 in
22.5	25.5	24.5	1/4 in	28.5	22.5	25.3	1/4 in
24	25.5	26.2	1/4 in	30	22.5	27	1/4 in
25.5	25.5	24.4	1/4 in	31.5	22.5	26.7	1/4 in
27	25.5	26	1/4 in	33	22.5	27.6	1/4 in
28.5	25.5	23.8	1/4 in	34.5	22.5	27.9	1/4 in
30	25.5	25.7	1/4 in	36	22.5	28	1/4 in
31.5	25.5	25.2	1/4 in	19.5	21	26	1/4 in
33	25.5		sinter	21	21	27	1/4 in
34.5	25.5	27.5	1/4 in	22.5	21	24.1	1/4 in

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
24	21	22.8	1/4 in	30	18	24.8	1/4 in
25.5	21	22.8	1/4 in	31.5	18	27	1/4 in
27	21	26.1	1/4 in	33	18	24.3	1/4 in
28.5	21	24.5	1/4 in	34.5	18	27.9	1/4 in
30	21	27	1/4 in	36	18	22.5	1/2 in
31.5	21	26.3	1/4 in	19.5	16.5	27.1	1/4 in
33	21	24	1/4 in	21	16.5		sinter
34.5	21	25.1	1/4 in	22.5	16.5		sinter
36	21	25.3	1/4 in	24	16.5	26.2	1/4 in
19.5	19.5	25.6	1/4 in	25.5	16.5	25.3	1/4 in
21	19.5	27.3	1/4 in	27	16.5	25.5	1/4 in
22.5	19.5		sinter	28.5	16.5	27.6	1/4 in
24	19.5	23.9	1/4 in	30	16.5	28.2	1/4 in
25.5	19.5	23.9	1/4 in	31.5	16.5	28.4	1/4 in
27	19.5	26.4	1/4 in	33	16.5		sinter
28.5	19.5	25.9	1/4 in	34.5	16.5	27.8	1/4 in
30	19.5	26.4	1/4 in	36	16.5	26.8	1/4 in
31.5	19.5	28.5	1/4 in	19.5	15		sinter
33	19.5	26	1/4 in	21	15	25.9	1/4 in
34.5	19.5	24.9	1/4 in	22.5	15	25.2	1/4 in
36	19.5		sinter	24	15	26.1	1/4 in
19.5	18	25.5	1/4 in, 5:11pm	25.5	15	25.1	1/4 in
21	18	26	1/4 in	27	15	23.7	1/4 in
22.5	18	25.4	1/4 in	28.5	15	27.2	1/4 in
24	18	26.2	1/4 in	30	15	27.7	1/4 in
25.5	18	23.8	1/4 in	31.5	15	28.3	1/4 in
27	18	23.9	1/4 in	33	15	26.4	1/4 in
28.5	18	27	1/4 in	34.5	15	27.3	1/4 in

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
36	15	26.6	1/4 in	24	10.5	26.3	1/4 in
19.5	13.5		sinter	25.5	10.5	26.4	1/4 in
21	13.5	25.5	1/4 in	27	10.5	25.3	1/4 in
22.5	13.5		sinter	28.5	10.5	26.9	1/4 in
24	13.5	25.7	1/4 in	30	10.5	27.6	1/4 in
25.5	13.5	26.1	1/4 in	31.5	10.5	28.6	1/4 in
27	13.5	26.7	1/4 in	33	10.5	27.9	1/4 in
28.5	13.5	27.2	1/4 in	34.5	10.5	26.3	1/4 in
30	13.5	26.6	1/4 in	36	10.5	24.3	1/4 in
31.5	13.5	28.2	1/4 in	19.5	9		sinter
33	13.5		sinter	21	9	24.6	1/4 in
34.5	13.5	25	1/4 in	22.5	9	25.6	1/4 in
36	13.5	28.5	1/4 in	24	9		sinter
19.5	12		sinter, 5:20pm	25.5	9	26.4	1/4 in
21	12		sinter	27	9		sinter
22.5	12	23.3	1/4 in	28.5	9		sinter
24	12	25.6	1/4 in	30	9	27.9	1/4 in
25.5	12	26.1	1/4 in	31.5	9	27.5	1/4 in
27	12	26.4	1/4 in	33	9	28.3	1/4 in
28.5	12	27.7	1/4 in	34.5	9		sinter
30	12	28.1	1/4 in	36	9		sinter
31.5	12	28.2	1/4 in	19.5	7.5		sinter
33	12	28.1	1/4 in	21	7.5	25.2	1/4 in
34.5	12	27.4	1/4 in	22.5	7.5		sinter
36	12	29.2	1/4 in	24	7.5	26.9	1/4 in
19.5	10.5		sinter	25.5	7.5	27.3	1/4 in
21	10.5	23.9	1/4 in	27	7.5	26.4	1/4 in
22.5	10.5	23.1	1/4 in	28.5	7.5		sinter

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
30	7.5	26.7	1/4 in
31.5	7.5	28.4	1/4 in
33	7.5	28.3	1/4 in
34.5	7.5	26.8	1/4 in
36	7.5	25.3	1/4 in
19.5	6		sinter, 5:26pm
21	6		sinter
22.5	6	25.9	1/4 in
24	6	26.5	1/4 in
25.5	6	27.3	1/4 in
27	6	26.9	1/4 in
28.5	6	27.7	1/4 in
30	6	27	1/4 in
31.5	6	27.9	1/4 in
33	6	27.9	1/4 in
34.5	6	26.4	1/4 in
36	6	26	1/4 in
19.5	4.5		sinter
21	4.5		sinter
22.5	4.5	25.7	1/4 in
24	4.5	27.2	1/4 in
25.5	4.5	27.4	1/4 in
27	4.5	27.6	1/4 in
28.5	4.5	27.6	1/4 in
30	4.5	27.7	1/4 in
31.5	4.5	27.9	1/4 in
33	4.5	27.5	1/4 in
34.5	4.5		sinter
36	4.5	24.3	1/4 in, shade
19.5	3	25.6	1/4 in
21	3	27.1	1/4 in
22.5	3	26	1/4 in
24	3	27.1	1/4 in
25.5	3	27.3	1/4 in
27	3	26.8	1/4 in
28.5	3	27	1/4 in
30	3		sinter
31.5	3		sinter
33	3		sinter
34.5	3	26.3	1/4 in
36	3		sinter
19.5	1.5	24.2	1/4 in
21	1.5	26.9	1/4 in
22.5	1.5	26.9	1/4 in
24	1.5	27.3	1/4 in
25.5	1.5	26.8	1/4 in
27	1.5	26.7	1/4 in
28.5	1.5	27	1/4 in
30	1.5		sinter
31.5	1.5	26.4	1/4 in
33	1.5		sinter
34.5	1.5		sinter
36	1.5	22.3	1/4 in, shade
19.5	0	25.2	1/4 in
21	0	26.1	1/4 in
22.5	0	26.1	1/4 in

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
24	0	26.5	1/4 in
25.5	0	25.7	1/4 in
27	0	26.6	1/4 in
28.5	0	25.8	1/4 in
30	0	26.4	1/4 in
31.5	0	26.5	1/4 in
33	0	26.5	1/4 in
34.5	0	23.5	1/4 in, shade
36	0	20.6	1/2 in, shade

Spring names	x (m)	y (m)	Spring temps (°C)
Main Alpha	15	0.5	94.4
Large pool	5	2.5	Not recorded

General Notes

Alpha - Yellowstone on Mary Mountain Trail, 6/26/14 at 3:10pm, Workers are Erika, Alex, Ben, Jenny, Brady, Alayne, Keegan, 1st array, starting at 0,0 (m) at the north east corner and going up, 1st measurement location description = 0, 0 (m), weather is cloudy, windy, and rained in the morning, Alpha is spaced 1.5 m x 1.5 m and is only 36 m x 36 m, probe 6 wasn't working as of the night before, replaced with probe 5

At x = 36 meters and y = 28.5 meters with temperature = 25.2°C the Y-axis was off by half a meter on the west side

Air checks

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
3:10pm	13	19		Didn't record first air check
	1	3		
	2	7		
	4	4		
	3	6		
	8	2		
	7	8		
	6	17		
	5	6		
	9	18		
	10	1		
	11	16		
	12	10		

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
3:59pm	13	was 19, now 12	29	replacing probe 19 with probe 12 because when 19 is turned upside down it reads 6 degrees C higher than right side up
	1	3	21/7	
	2	7	21.3	
	4	4	21.5	
	3	6	22.1	
	8	2	22.7	
	7	8	23.5	
	5	5	23.5	
	6	17	23.6	
	9	18	24.5	
	10	1	25.2	
	11	16	24.6	
	12	10	23.6	

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
4:45pm	13	12	28.5	
	1	3	24.8	
	2	7	25.2	
	4	4	25.6	
	3	6	28.2	Broken?
	8	2	28.6	
	7	8	29.6	
	5	5	29.4	
	6	17	28.8	
	9	18	30.1	
	10	1	30.2	
	11	16	30.1	
	12	10	28.2	

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
5:11pm	13	12	Didn't use	
	1	3	25.2	
	2	7	25.2	
	4	4	24.4	
	3	6	24	
	8	2	24.2	
	7	8	24.2	
	5	5	25.5	
	6	17	25.9	
	9	18	26.5	
	10	1	25.2	
	11	16	25.5	
	12	10	26.4	

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
After data collection	13	1	1.7	Ice bath check after field work on all probes with Thermometer #13
	13	9	1.7	
	13	6	1.2	
	13	18	0.8	
	13	2	1.2	
	13	12	0.8	
	13	17	0.7	
	13	16	0.6	
	13	10	0.8	
	13	7	0.7	
	13	3	0.5	
	13	5	Not working from previous night	
	13	4	0.7	
	13	19	Broken, 22.5 - 22.9	
	13	8	0.6	
	13	11	0.7	

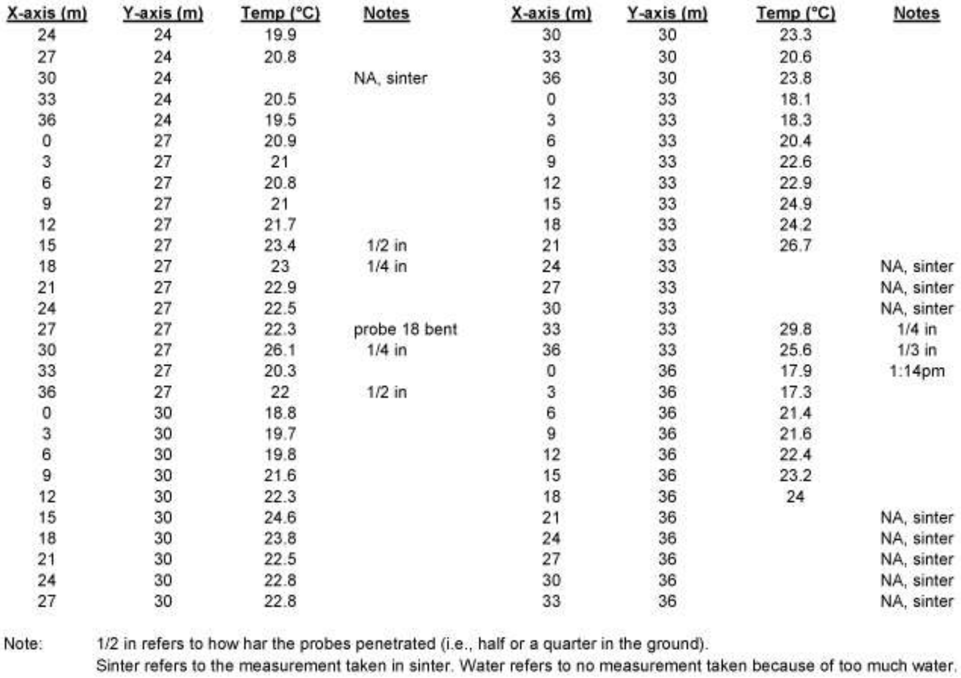
Temperature survey data for Bravo grid, Yellowstone National Park, WY

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
0	0	20.2	11:56am	6	6	21.3	
3	0	18.9		9	6	17.8	
6	0	19.9		12	6	17.6	
9	0	18.2		15	6	16.4	
12	0	18.2		18	6	15.9	
15	0	16.3		21	6	15.8	
18	0	16.2		24	6	15.8	
21	0	16.2		27	6	16.2	
24	0	18.8		30	6	15.9	
27	0	19.3		33	6	16.4	
30	0	18.7		36	6	16.7	
33	0	18.4		0	9	23.1	
36	0	18.2		3	9	20.1	
0	3	22.3		6	9	18.2	
3	3	17.7	3/4 in	9	9	17.3	
6	3	19.3		12	9	18	
9	3	18.2	3/4 in, water	15	9	16.9	
12	3	17.8	3/4 in	18	9	15.6	
15	3	22.2	1/4 in	21	9	15.2	
18	3	15.6		24	9	16.3	
21	3	16.6		27	9	16.1	
24	3	16.5		30	9	15.2	
27	3	16.8		33	9	15.5	
30	3	16		36	9	15.9	
33	3	17.2		0	12	18.7	12:10pm
36	3	17.9		3	12	18.5	
0	6	23.7		6	12	18.3	
3	6	18.3		9	12	16.9	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

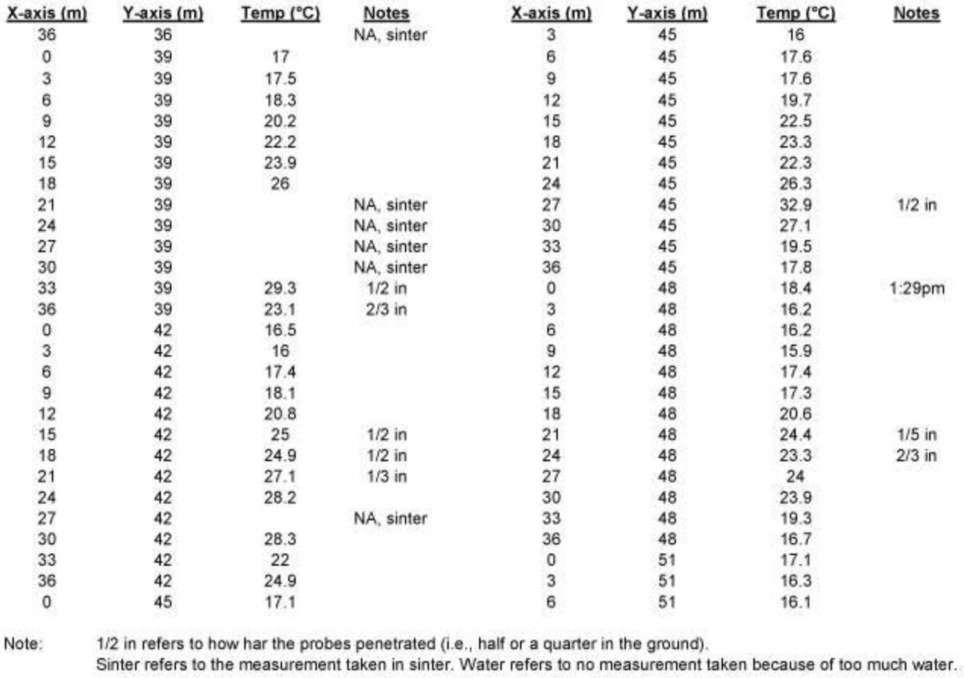
X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
12	12	17.4		18	18	17.2	1/2 in
15	12	16.6		21	18	18	
18	12	15.3		24	18	20.3	1/3 in
21	12	15.6		27	18	16.8	
24	12	15.5		30	18	17.6	
27	12	17		33	18	16.8	
30	12	15.4		36	18	16.4	
33	12	14.9		0	21	22.1	
36	12	15		3	21	21.8	
0	15	20.4		6	21	21.6	
3	15	18.7		9	21	20	
6	15	21.4		12	21	18.6	
9	15	17.8		15	21	19.1	
12	15	17		18	21	24.4	1/4 in
15	15	15.4		21	21	20.6	1/3 in
18	15	15.8		24	21	22.5	1/4 in
21	15	16.1		27	21	19.6	
24	15	17.1		30	21	19.4	
27	15	17.3		33	21	18.9	
30	15	16.9		36	21	16.8	
33	15	16.5		0	24	21.8	1:02pm
36	15	15.5		3	24	22.6	
0	18	22		6	24	22.2	
3	18	20		9	24	20.6	
6	18	21.6		12	24	20.7	
9	18	17.8		15	24	20.6	
12	18	16.3		18	24	20.8	
15	18	17.7		21	24	21.2	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.



X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
24	24	19.9		30	30	23.3	
27	24	20.8		33	30	20.6	
30	24		NA, sinter	36	30	23.8	
33	24	20.5		0	33	18.1	
36	24	19.5		3	33	18.3	
0	27	20.9		6	33	20.4	
3	27	21		9	33	22.6	
6	27	20.8		12	33	22.9	
9	27	21		15	33	24.9	
12	27	21.7		18	33	24.2	
15	27	23.4	1/2 in	21	33	26.7	
18	27	23	1/4 in	24	33		NA, sinter
21	27	22.9		27	33		NA, sinter
24	27	22.5		30	33		NA, sinter
27	27	22.3	probe 18 bent	33	33	29.8	1/4 in
30	27	26.1	1/4 in	36	33	25.6	1/3 in
33	27	20.3		0	36	17.9	1:14pm
36	27	22	1/2 in	3	36	17.3	
0	30	18.8		6	36	21.4	
3	30	19.7		9	36	21.6	
6	30	19.8		12	36	22.4	
9	30	21.6		15	36	23.2	
12	30	22.3		18	36	24	
15	30	24.6		21	36		NA, sinter
18	30	23.8		24	36		NA, sinter
21	30	22.5		27	36		NA, sinter
24	30	22.8		30	36		NA, sinter
27	30	22.8		33	36		NA, sinter

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.



X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
36	36		NA, sinter	3	45	16	
0	39	17		6	45	17.6	
3	39	17.5		9	45	17.6	
6	39	18.3		12	45	19.7	
9	39	20.2		15	45	22.5	
12	39	22.2		18	45	23.3	
15	39	23.9		21	45	22.3	
18	39	26		24	45	26.3	
21	39		NA, sinter	27	45	32.9	1/2 in
24	39		NA, sinter	30	45	27.1	
27	39		NA, sinter	33	45	19.5	
30	39		NA, sinter	36	45	17.8	
33	39	29.3	1/2 in	0	48	18.4	1:29pm
36	39	23.1	2/3 in	3	48	16.2	
0	42	16.5		6	48	16.2	
3	42	16		9	48	15.9	
6	42	17.4		12	48	17.4	
9	42	18.1		15	48	17.3	
12	42	20.8		18	48	20.6	
15	42	25	1/2 in	21	48	24.4	1/5 in
18	42	24.9	1/2 in	24	48	23.3	2/3 in
21	42	27.1	1/3 in	27	48	24	
24	42	28.2		30	48	23.9	
27	42		NA, sinter	33	48	19.3	
30	42	28.3		36	48	16.7	
33	42	22		0	51	17.1	
36	42	24.9		3	51	16.3	
0	45	17.1		6	51	16.1	

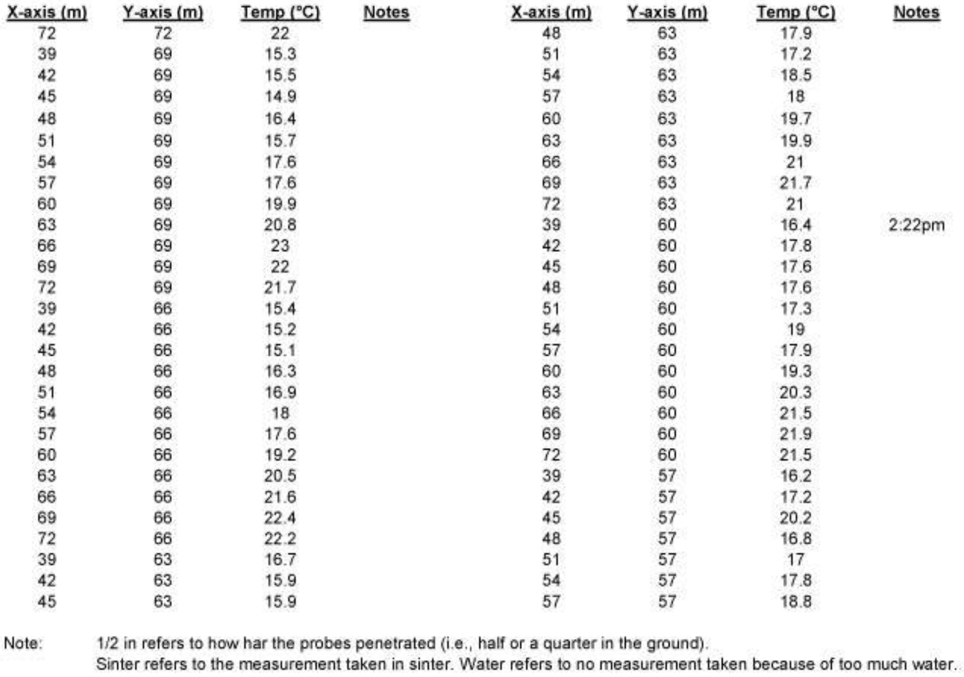
Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
9	51	15.8	
12	51	16.9	
15	51	16.9	
18	51	17.8	
21	51	19.4	
24	51	19.4	
27	51	20.1	
30	51	17.8	
33	51	17.1	
36	51	16.5	
0	54	16.2	
3	54	16.4	
6	54	16.6	
9	54	15.6	
12	54	16.6	
15	54	17.6	
18	54	16.6	
21	54	16.5	
24	54	16.9	
27	54	16.7	
30	54	16.8	
33	54	16.4	
36	54	15.9	
0	57	15.7	
3	57	16	
6	57	15.9	
9	57	15.4	
12	57	15.8	
15	57	15.8	
18	57	16.1	
21	57	15.7	
24	57	15.6	
27	57	16.2	
30	57	16	
33	57	15.4	
36	57	15.8	
0	60	16.9	1:43pm
3	60	17.8	
6	60	16.9	
9	60	17.8	
12	60	16.5	
15	60	16	
18	60	16	
21	60	15.8	
24	60	16.1	
27	60	15.8	
30	60	15.5	
33	60	15.3	
36	60	16	
0	63	15.4	
3	63	17.2	
6	63	18.1	
9	63	16.9	
12	63	17.8	
15	63	16.7	
18	63	16.9	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

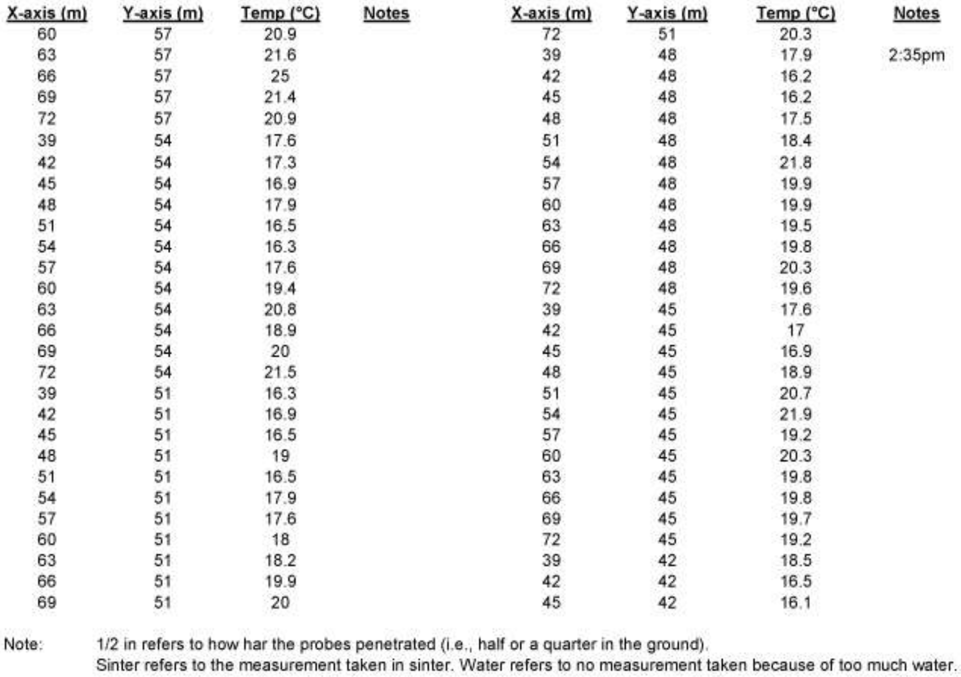
X-axis (m)	Y-axis (m)	Temp (°C)	Notes
21	63	16.5	
24	63	17	
27	63	15.9	
30	63	16	
33	63	15.4	
36	63	15.6	
0	66	17	
3	66	16.7	
6	66	17.1	
9	66	17.7	
12	66	18.1	
15	66	17	
18	66	17.7	
21	66	17.1	
24	66	17.4	
27	66	16.6	
30	66	16.2	
33	66	15.4	
36	66	15.9	
0	69	16.5	
3	69	16.9	
6	69	17.9	
9	69	18	
12	69	18.8	
15	69	17.5	
18	69	16.7	
21	69	16.9	
24	69	16.5	
27	69	16.6	
30	69	15.8	
33	69	15	
36	69	15	
0	72	17.9	
3	72	17.3	
6	72	18.4	
9	72	18.9	
12	72	19.3	
15	72	18.7	
18	72	17.4	
21	72	16.9	
24	72	17	
27	72	18.1	
30	72	16.8	
33	72	15.9	
36	72	15.3	
39	72	15.5	2:00pm
42	72	15.6	
45	72	15.2	
48	72	16.3	
51	72	15.8	
54	72	16	
57	72	16.3	
60	72	18.2	
63	72	19.7	
66	72	21	
69	72	20.9	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.



X-axis (m)	Y-axis (m)	Temp (°C)	Notes
72	72	22	
39	69	15.3	
42	69	15.5	
45	69	14.9	
48	69	16.4	
51	69	15.7	
54	69	17.6	
57	69	17.6	
60	69	19.9	
63	69	20.8	
66	69	23	
69	69	22	
72	69	21.7	
39	66	15.4	
42	66	15.2	
45	66	15.1	
48	66	16.3	
51	66	16.9	
54	66	18	
57	66	17.6	
60	66	19.2	
63	66	20.5	
66	66	21.6	
69	66	22.4	
72	66	22.2	
39	63	16.7	
42	63	15.9	
45	63	15.9	
48	63	17.9	
51	63	17.2	
54	63	18.5	
57	63	18	
60	63	19.7	
63	63	19.9	
66	63	21	
69	63	21.7	
72	63	21	
39	60	16.4	2:22pm
42	60	17.8	
45	60	17.6	
48	60	17.6	
51	60	17.3	
54	60	19	
57	60	17.9	
60	60	19.3	
63	60	20.3	
66	60	21.5	
69	60	21.9	
72	60	21.5	
39	57	16.2	
42	57	17.2	
45	57	20.2	
48	57	16.8	
51	57	17	
54	57	17.8	
57	57	18.8	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.



X-axis (m)	Y-axis (m)	Temp (°C)	Notes
60	57	20.9	
63	57	21.6	
66	57	25	
69	57	21.4	
72	57	20.9	
39	54	17.6	
42	54	17.3	
45	54	16.9	
48	54	17.9	
51	54	16.5	
54	54	16.3	
57	54	17.6	
60	54	19.4	
63	54	20.8	
66	54	18.9	
69	54	20	
72	54	21.5	
39	51	16.3	
42	51	16.9	
45	51	16.5	
48	51	19	
51	51	16.5	
54	51	17.9	
57	51	17.6	
60	51	18	
63	51	18.2	
66	51	19.9	
69	51	20	
72	51	20.3	
39	48	17.9	2:35pm
42	48	16.2	
45	48	16.2	
48	48	17.5	
51	48	18.4	
54	48	21.8	
57	48	19.9	
60	48	19.9	
63	48	19.5	
66	48	19.8	
69	48	20.3	
72	48	19.6	
39	45	17.6	
42	45	17	
45	45	16.9	
48	45	18.9	
51	45	20.7	
54	45	21.9	
57	45	19.2	
60	45	20.3	
63	45	19.8	
66	45	19.8	
69	45	19.7	
72	45	19.2	
39	42	18.5	
42	42	16.5	
45	42	16.1	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
48	42	18.3	
51	42	18.3	
54	42	19.4	
57	42	20.4	
60	42	19.5	
63	42	19.5	
66	42	18.9	
69	42	19.2	
72	42	19.5	
39	39	19	
42	39	18.9	
45	39	18	
48	39	20.2	
51	39	19.8	
54	39	25.2	
57	39	21.4	
60	39	20.4	
63	39	18.8	
66	39	19	
69	39	18.4	
72	39	18.3	
39	36	20	2:46pm
42	36	19.3	
45	36	18	
48	36	20.6	
51	36	24.3	
54	36	24	
57	36	23.7	
60	36	20	
63	36	19.4	
66	36	20	
69	36	19	
72	36	19.2	
39	33	19.3	
42	33	19.7	
45	33	19.1	
48	33	22.9	
51	33	21.6	
54	33	23.4	
57	33	23.8	
60	33	18.9	
63	33	20.2	
66	33	19.9	
69	33	18.1	
72	33	16.7	
39	30	19.6	
42	30	19.4	
45	30	20.3	
48	30	21.2	
51	30	21.5	
54	30	24.9	
57	30	23.8	
60	30	19.2	
63	30	19.4	
66	30	20.1	
69	30	18.8	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
72	30	17.9	
39	27	20.2	
42	27	19.7	
45	27	19.2	
48	27	21.5	
51	27	23.6	
54	27	29.5	1/4 in
57	27	33.1	1/2 in
60	27	32.1	
63	27	21.4	
66	27	19.7	
69	27	19.8	
72	27	18.8	
39	24	18.3	3:03pm
42	24	18.1	
45	24	20.8	
48	24	25.5	
51	24	27.2	
54	24	33.5	1/4 in
57	24	30	1/4 in
60	24	29.9	1/2 in
63	24	22.3	
66	24	19.7	
69	24	19.7	
72	24	20	
39	21	17.5	
42	21	18.3	
45	21	20.7	
48	21	28.1	
51	21	29.6	
54	21	30.1	1/3 in
57	21	28.5	1/4 in
60	21	24.9	
63	21	23	
66	21	20.1	
69	21	18.7	
72	21	18.7	
39	18	16.3	
42	18	16.9	
45	18	21.3	
48	18	20.4	
51	18	26.3	
54	18	27.2	1/2 in
57	18	29.9	1/4 in
60	18	22.9	
63	18	22	
66	18	20.4	
69	18	18.9	
72	18	18.1	
39	15	15.8	
42	15	18	
45	15	17	
48	15	20.7	
51	15	23.2	1/2 in
54	15	27.6	1/4 in
57	15	26.2	1/3 in

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
60	15	27.5	1/3 in	72	9	18.6	
63	15	28.8	1/4 in	39	6	18.8	
66	15	21.1		42	6	19.2	
69	15	20.5		45	6	21.6	
72	15	18.9		48	6	26.5	1/5 in
39	12	17.9	Finished ~ 3:30pm	51	6	23.3	
42	12	18.1		54	6	26.3	
45	12	19.1		57	6	23	
48	12	25.6	1/2 in	60	6	21.7	
51	12	25.5	1/2 in	63	6	21.2	
54	12	27.9	1/4 in	66	6	23.9	
57	12	23.7	1/3 in	69	6	20.1	
60	12	27.2	1/4 in	72	6	19.2	
63	12	24.8	1/3 in	39	3	18.6	
66	12	26		42	3	19.9	
69	12	23.6	1/3 in	45	3	22	
72	12	18.4		48	3	23	
39	9	17.9	Y-axis off a meter	51	3	24.1	
42	9	18.8	Y-axis off a meter	54	3	25.7	
45	9	22.3	Y-axis off a meter	57	3	20.7	
48	9	28.5	1/3 in	60	3	20.5	
51	9	26.2	1/3 in	63	3	19.9	
54	9	27.3	1/4 in	66	3	20	
57	9	24.9	1/3 in	69	3	20	
60	9	24.3	1/4 in	72	3	20.8	
63	9	23.8		39	0	19.7	
66	9	23.8		42	0	21.9	
69	9	23		45	0	21.5	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
48	0	23.1					
51	0	26.6					
54	0	22					
57	0	18.8					
60	0	20.1					
63	0	19.9					
66	0	19.4					
69	0	19.9					
72	0	19.6					

Spring names	x (m)	y (m)	Spring temps (°C)
Bravo	33.8	36.5	76.7
	28.4	36.75	51.2
	43.9	53.2	26.3
	56.7	36.6	42.3
	60.15	27	49.8
	60	25	49.8

General Notes

Bravo - Yellowstone on Mary Mountain Trail, 6/25/14 at 11:56am, Workers are Erika, Alex, Ben, Jay, Brady, Jerry, 1st array, starting at 0,0 (m) in the north east corner and going up, 1st measurement location description = 0, 0 (m), weather sunny and a little breezy, didn't rain for days

At 1:14pm, air checks not developed fully, probes close to ground still, some may have been reading radiation from ground surface

At 2:46pm, developed air check procedure

Air checks

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
11:56am	13	19		Didn't record first air check
	1	3		
	2	7		
	4	4		
	3	6		
	8	2		
	7	8		
	5	5		
	6	17		
	9	18		
	10	1		
	11	16		
	12	10		

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
1:14pm	13	19	25.3	
	1	3	25.7	
	2	7	27.5	
	4	4	27.7	
	3	6	27.3	
	8	2	29.3	
	7	8	29.4	
	5	5	29.3	
	6	17	32.6	
	9	18	33.4	
	10	1	33.7	
	11	16	29.8	
	12	10	31.8	

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
2:00pm	13	19	Didn't use	
	1	3	28.3	
	2	7	27.9	
	4	4	27.1	
	3	6	27.9	
	8	2	28.1	
	7	8	27.5	
	5	5	27.5	
	6	17	25.5	
	9	18	28.9	
	10	1	29.7	
	11	16	27.9	
	12	10	28.5	

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
2:46pm	13	19	Didn't use	
	1	3	24.6	
	2	7	24.7	
	4	4	23.5	
	3	6	24.4	
	8	2	25	
	7	8	24.6	
	5	5	24.7	
	6	17	23.4	
	9	18	23.6	
	10	1	24.5	
	11	16	24.2	
	12	10	24.3	

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
After data collection	6	10	1.3	Ice bath check after field work on all probes with Thermometer #6
	6	16	1	
	6	17	1.1	
	6	7	0.9	
	6	3	0.9	
	6	4	0.8	
	6	19	0.9	
	6	6	1	
	6	2	0.7	
	6	1	0.9	
	6	18	1.9	
	6	8	1.2	
	6	5	Broken?	Not working with any thermometers
	6	9	0.8	
	6	12	0.9	
	6	11	0.7	

Temperature survey data for 2Bravo grid, Yellowstone National Park, WY

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
0	0	19.7	8:14am
3	0	16.1	
6	0	18.6	
9	0	9.5	
12	0	15.3	
15	0	14.6	
18	0	14.4	
21	0	12.8	
24	0	16.5	
27	0	16.2	
30	0	14.3	
33	0	13.8	
36	0	11.8	
0	3	19.1	
3	3	14.7	
6	3	16.6	
9	3	11.7	
12	3	12.9	
15	3	13.6	
18	3	13.7	
21	3	16	
24	3	15.1	
27	3	15	
30	3	13.6	
33	3	15.2	
36	3	14.5	
0	6	18.8	
3	6	16	
6	6	20.1	
9	6	13.6	
12	6	14.6	
15	6	15.5	
18	6	15.6	
21	6	14.8	
24	6	13.7	
27	6	13.1	
30	6	14.5	
33	6	14	
36	6	15.9	
0	9	19.2	
3	9	18.1	
6	9	15.3	
9	9	14.6	
12	9	16.1	
15	9	15.6	
18	9	14.8	
21	9	13.5	
24	9	13.8	
27	9	14.4	
30	9	13.9	
33	9	15.3	
36	9	13.8	
0	12	18.7	8:25am
3	12	15.3	
6	12	16.2	
9	12	15.2	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
12	12	15.5	
15	12	15	
18	12	14.3	
21	12	14.3	
24	12	13.5	
27	12	13.5	
30	12	14.9	
33	12	14.3	
36	12	14.4	
0	15	15.8	
3	15	16.2	
6	15	17.8	
9	15	16.1	
12	15	14.4	
15	15	14.9	
18	15	14.5	
21	15	13.3	
24	15	15.6	
27	15	16	
30	15	14.5	
33	15	14.3	
36	15	13.9	
0	18	16.6	
3	18	14.8	1/2 in
6	18	18.2	
9	18	17.4	
12	18	14.8	
15	18	15.6	
18	18	13.3	
21	18	12.7	
24	18	10.3	
27	18	11.1	
30	18	14.5	
33	18	13.3	
36	18	13.7	
0	21	18.5	
3	21	18.9	
6	21	18.9	
9	21	18.6	
12	21	16.1	
15	21	17.1	
18	21	11.2	
21	21	10.9	
24	21	11.1	
27	21	10.4	
30	21	13.3	
33	21	13.7	
36	21	13.9	
0	24	17.8	8:37am
3	24	20	
6	24	19.4	
9	24	18.8	
12	24	17.7	
15	24	17.8	
18	24	12.5	1/2 in
21	24	12.8	1/2 in

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
24	24	11.8	1/2 in	30	30	14	
27	24	11.2	1/4 in	33	30	14.2	
30	24	11	1/4 in	36	30	15.3	
33	24	11.8	1/2 in	0	33	14.5	
36	24	13.7		3	33	16.6	
0	27	16.9		6	33	17.9	
3	27	19.5		9	33	15.7	1/2 in
6	27	16.8		12	33	13.5	
9	27	18.3		15	33	15.9	
12	27	20.6		18	33	16.7	
15	27	13.2	1/2 in	21	33	14.6	
18	27	12.5	1/2 in	24	33	14.1	
21	27	13.8	1/2 in	27	33	12.6	
24	27	14.4		30	33	13.2	
27	27	15.1		33	33	15	
30	27	11.3	1/4 in	36	33	19.2	
33	27	13.6		0	36	14.9	8:53am
36	27	17		3	36	14.7	
0	30	15.9		6	36	15.6	
3	30	18.6		9	36	16.2	probe switch
6	30	18.4		12	36	12.6	1/2 in
9	30	19.2		15	36	15.9	
12	30	14.9	1/4 in	18	36	18.3	
15	30	13.3	1/4 in	21	36	14	1/2 in
18	30	16.2		24	36		NA, sinter
21	30	15.5		27	36		NA, sinter
24	30	15.3		30	36	14	1/2 in
27	30	13.6	1/2 in	33	36		NA, sinter

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
36	36	15.6		3	45	12.8	
0	39	13.1		6	45	11.2	
3	39	15.1		9	45	14.7	
6	39	15.8		12	45	17.7	
9	39	14		15	45	15.2	
12	39	12.8		18	45	12.9	1/2 in
15	39	15.6		21	45	14.2	1/2 in
18	39	15.2		24	45	16.9	1/2 in
21	39	15.2		27	45		NA, sinter
24	39		NA, sinter	30	45	26.7	
27	39		NA, sinter	33	45	17.6	
30	39		NA, sinter	36	45	17.1	
33	39	16.8		0	48	14.6	9:15am
36	39	19.8		3	48	13.2	
0	42	12.6		6	48	12.6	
3	42	13.2		9	48	14.3	
6	42	13.6		12	48	14.8	
9	42	11.9		15	48	15.7	
12	42	17.8		18	48	14.3	
15	42	15.7		21	48	12.3	1/4 in
18	42	16		24	48	15.5	
21	42	16.2		27	48	12.3	1/6 in
24	42	16.2	1/4 in	30	48	20.7	
27	42		NA, sinter	33	48	16.2	
30	42	24.8		36	48	14.4	
33	42	18.8		0	51	13.8	
36	42	24.6		3	51	12.9	
0	45	13.7		6	51	12.2	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
9	51	14.1		15	57	14.8	
12	51	13.5		18	57	12.9	
15	51	14.9		21	57	14.2	
18	51	14.2		24	57	14.3	
21	51	16.8		27	57	14.1	
24	51	12.2		30	57	14.9	
27	51	15.2		33	57	13.5	
30	51	15.3		36	57	13.8	
33	51	15.5		0	60	14.4	9:28am
36	51	14.2		3	60	15.8	
0	54	13		6	60	14.9	
3	54	13.3		9	60	17	
6	54	12.6		12	60	14.3	
9	54	13.3		15	60	15.2	
12	54	14		18	60	13.8	
15	54	16.3		21	60	14	
18	54	15.2		24	60	13.3	
21	54	13.2		27	60	14.1	
24	54	13		30	60	13	
27	54	15.1		33	60	13.5	
30	54	15.1		36	60	12.1	
33	54	14.9		0	63	12	Y-axis off 1 meter
36	54	14.8		3	63	15.5	Y-axis off 1 meter
0	57	12.2		6	63	16.4	Y-axis off 1 meter
3	57	13.7		9	63	17.1	Y-axis off 1 meter
6	57	12.5		12	63	16.5	Y-axis off 1 meter
9	57	14.6		15	63	13.8	Y-axis off 1 meter
12	57	14.4		18	63	13.7	Y-axis off 1 meter

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
21	63	14.3	Y-axis off 1 meter	27	69	14.8	
24	63	13.4	Y-axis off 1 meter	30	69	13.8	
27	63	13.9	Y-axis off 1 meter	33	69	12.6	
30	63	13.6	Y-axis off 1 meter	36	69	13.3	
33	63	13.4	Y-axis off 1 meter	0	72	14.7	
36	63	13.6	Y-axis off 1 meter	3	72	15.7	
0	66	12.2		6	72	17.2	
3	66	14.2		9	72	18.3	
6	66	13.5		12	72	17.9	
9	66	17.3		15	72	17.4	
12	66	17.3		18	72	16	
15	66	15.1		21	72	15.8	
18	66	15.7		24	72	13.6	
21	66	14.5		27	72	13.4	
24	66	12.8		30	72	13.6	
27	66	12.8		33	72	14	
30	66	13.3		36	72	12.6	
33	66	13.6		39	72	12.4	9:45am
36	66	13.2		42	72	11.9	
0	69	13.2		45	72	14.3	
3	69	14.4		48	72	14.3	
6	69	16.6		51	72	14.6	
9	69	17.8		54	72	13.9	
12	69	17.6		57	72	14.5	
15	69	16.5		60	72	14.6	
18	69	13.3		63	72	16	
21	69	13.9		66	72	18.8	
24	69	13.2		69	72	19.4	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
72	72	19.3		48	63	16.2	
39	69	13.8		51	63	16.2	
42	69	12.6		54	63	15.3	
45	69	14		57	63	15	
48	69	13.2		60	63	16.9	
51	69	13.7		63	63	18	
54	69	15.6		66	63	18.4	
57	69	15.7		69	63	18.5	
60	69	16.3		72	63	17	
63	69	19.3		39	60	15.1	10:09am
66	69	19.4		42	60	14.2	
69	69	21.3		45	60	15.6	
72	69	18.9		48	60	16.5	
39	66	13.9		51	60	16	
42	66	13		54	60	16.4	
45	66	13.7		57	60	14.9	
48	66	13.4		60	60	17.1	
51	66	15.3		63	60	17.4	
54	66	16		66	60	17.8	
57	66	16		69	60	18.8	
60	66	17.7		72	60	18.6	
63	66	19.3		39	57	14.4	
66	66	18.9		42	57	12.1	
69	66	19.7		45	57	16.2	
72	66	19		48	57	14.3	
39	63	13.8		51	57	16.4	
42	63	12.9		54	57	15.8	
45	63	13.5		57	57	15	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes	X-axis (m)	Y-axis (m)	Temp (°C)	Notes
60	57	16		72	51	17.3	
63	57	14.8		39	48	16.8	10:20am
66	57	16.3		42	48	14.3	
69	57	18.6		45	48	15.9	
72	57	16.9		48	48	16.9	
39	54	14.5		51	48	17.8	
42	54	13.7		54	48	21	
45	54	16		57	48	18.3	
48	54	13.4		60	48	19.5	
51	54	14		63	48	17.8	
54	54	14.8		66	48	18	
57	54	16.2		69	48	18	
60	54	16.4		72	48	18.2	
63	54	16.6		39	45	15.6	
66	54	18.3		42	45	13.3	
69	54	17.6		45	45	16.4	
72	54	16.6		48	45	16	
39	51	14.8		51	45	20.9	
42	51	16.1		54	45	20.4	
45	51	14.3		57	45	16.1	
48	51	16		60	45	18.9	
51	51	14.1		63	45	19.2	
54	51	14.8		66	45	19	
57	51	16.6		69	45	18.4	
60	51	17		72	45	18.4	
63	51	17.2		39	42	17.9	
66	51	19.1		42	42	15.3	
69	51	18.2		45	42	15.7	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
48	42	17.6	
51	42	16.8	
54	42	19.4	
57	42	18.6	
60	42	16.8	
63	42	17.3	
66	42	17.4	
69	42	18.3	
72	42	19.4	
39	39	18.2	
42	39	16.5	
45	39	17.3	
48	39	15.6	
51	39	17.9	
54	39	20.8	
57	39	18	
60	39	17	
63	39	17.4	
66	39	17.8	
69	39	18.6	
72	39	18.6	
39	36	18.8	10:31am
42	36	17.5	
45	36	16.8	
48	36	19.9	
51	36	23.8	
54	36	20.2	
57	36	17.8	1/4 in
60	36	18.9	
63	36	16.4	
66	36	18.1	
69	36	16.4	
72	36	18.2	
39	33	19.2	
42	33	18.2	
45	33	16.4	
48	33	20.9	
51	33	17.3	
54	33	20.4	
57	33	16.3	1/4 in
60	33	17.2	
63	33	17.4	
66	33	16.7	
69	33	15.7	
72	33	16.9	
39	30	17.8	
42	30	16.7	
45	30	16.9	
48	30	18.3	
51	30	19	
54	30	15.5	1/2 in
57	30	20.6	
60	30	16.4	
63	30	18.5	
66	30	18.4	
69	30	18.6	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
72	30	16.7	
39	27	15.5	
42	27	15.2	
45	27	16.5	
48	27	19.3	
51	27	22.9	
54	27	17.3	1/2 in
57	27	18.3	1/2 in
60	27	25.7	
63	27	20.2	
66	27	19.6	
69	27	19.6	
72	27	17.2	
39	24	15.5	10:48am
42	24	15.2	
45	24	19.5	
48	24	18.9	
51	24	24.9	
54	24	20.5	1/4 in
57	24	18.8	
60	24		NA, sinter
63	24	20.8	
66	24	17.8	
69	24	18	
72	24	17.2	
39	21	16.4	
42	21	15.3	
45	21	19.5	
48	21	20.8	1/3 in
51	21	24.5	1/2 in
54	21	17.5	1/6 in
57	21	18.5	1/5 in
60	21	23.6	
63	21	20.3	
66	21	17.8	
69	21	17	
72	21	17.6	
39	18	14	
42	18	13.8	
45	18	14	1/3 in
48	18	18.4	
51	18	21.2	
54	18	18.1	1/2 in
57	18	17.3	1/2 in
60	18	20.9	
63	18	20.2	
66	18	19.1	
69	18	17.9	
72	18	16.4	
39	15	13.5	
42	15	14.9	
45	15	16.7	
48	15	18.3	
51	15	18.3	
54	15	18.1	
57	15	15.2	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
60	15	19.8	
63	15	21.3	
66	15	18.6	
69	15	17.9	
72	15	16.8	
39	12	14.9	11:03am
42	12	15.7	
45	12	18	
48	12	17.6	1/2 in
51	12	15.4	1/2 in
54	12	17	1/4 in
57	12	14.9	1/2 in
60	12	20	1/4 in
63	12	18.2	
66	12	19	
69	12	18	
72	12	17.8	
39	9	16.7	
42	9	17.5	
45	9	19.5	
48	9	17.4	1/4 in
51	9	17	1/4 in
54	9	16.2	1/2 in
57	9	14.6	1/2 in
60	9	19.8	1/2 in
63	9	21.9	
66	9	19.8	
69	9	21.4	
72	9	16.5	
39	6	17.2	
42	6	16.8	
45	6	17.9	
48	6	15.7	
51	6	15.3	1/2 in
54	6	16.4	1/2 in
57	6	15.8	1/4 in
60	6	19.4	
63	6	19	
66	6	16.6	
69	6	18.4	
72	6	17.7	
39	3	16.1	
42	3	18.3	
45	3	20.2	
48	3	18.8	
51	3	17.7	
54	3	16.4	
57	3	16.6	
60	3	19	
63	3	18.5	
66	3	15.9	
69	3	17.5	
72	3	17.8	
39	0	14.8	
42	0	21.3	
45	0	19.6	

Note: 1/2 in refers to how har the probes penetrated (i.e., half or a quarter in the ground).
Sinter refers to the measurement taken in sinter. Water refers to no measurement taken because of too much water.

X-axis (m)	Y-axis (m)	Temp (°C)	Notes
48	0	19.9	
51	0	21	
54	0	19.1	
57	0	17.6	
60	0	18.3	
63	0	18	
66	0	16.9	
69	0	18.2	
72	0	17.4	

Spring names	x (m)	y (m)	Spring temps (°C)
Bravo	33.8	36.5	76.7
	28.4	36.75	51.2
	43.9	53.2	26.3
	56.7	36.6	42.3
	60.15	27	49.8
	60	25	49.8

General Notes

2Bravo- 6/28/14, started at 8:14am. Brady, Alex, Jenny, Ben, and Keegan worked on this grid. 1st array, starting at 0, 0 (m) and going up (NE corner), 1st measurement location description 0, 0 (m). Cloudy, just rained before we got here and most of yesterday, field has some standing water in it.

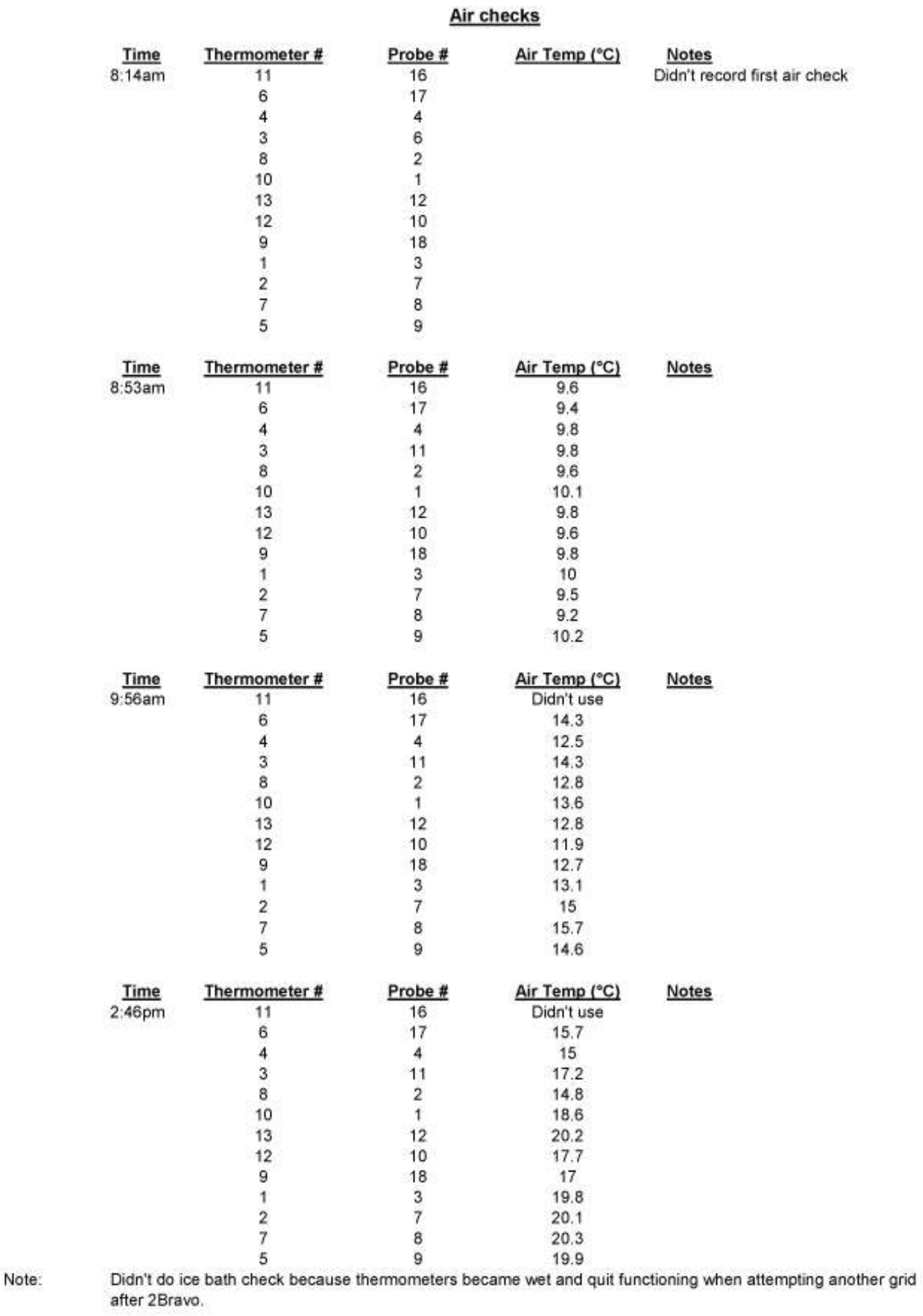
8:25am, water at about 18 m base line, water 0,15 m - a lot, water at about 12, 24 m

8:37am - cool temperature morning

At 9, 33 (m) with temp = 15.7 deg C, reading slowly counted down from 18.9 deg C over 3 mins, called it.

Changed probe 6 for probe 11 at 8:53am, at 9, 36 (m)

At 8:53am - sprinkling



Air checks

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
8:14am	11	16		Didn't record first air check
	6	17		
	4	4		
	3	6		
	8	2		
	10	1		
	13	12		
	12	10		
	9	18		
	1	3		
	2	7		
	7	8		
	5	9		

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
8:53am	11	16	9.6	
	6	17	9.4	
	4	4	9.8	
	3	11	9.8	
	8	2	9.6	
	10	1	10.1	
	13	12	9.8	
	12	10	9.6	
	9	18	9.8	
	1	3	10	
	2	7	9.5	
	7	8	9.2	
	5	9	10.2	

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
9:56am	11	16	Didn't use	
	6	17	14.3	
	4	4	12.5	
	3	11	14.3	
	8	2	12.8	
	10	1	13.6	
	13	12	12.8	
	12	10	11.9	
	9	18	12.7	
	1	3	13.1	
	2	7	15	
	7	8	15.7	
	5	9	14.6	

Time	Thermometer #	Probe #	Air Temp (°C)	Notes
2:46pm	11	16	Didn't use	
	6	17	15.7	
	4	4	15	
	3	11	17.2	
	8	2	14.8	
	10	1	18.6	
	13	12	20.2	
	12	10	17.7	
	9	18	17	
	1	3	19.8	
	2	7	20.1	
	7	8	20.3	
	5	9	19.9	

Note: Didn't do ice bath check because thermometers became wet and quit functioning when attempting another grid after 2Bravo.