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Development of shallow (2-m) temperature survey standard operating procedures and interpretation workbook

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ABSTRACT

Shallow (1-2 m) temperature surveys have been deployed in the Great Basin region of the western United States to identify and characterize geothermal resources for over 40 years. The physiographic characteristics of low rainfall (that can suppress or conceal shallow thermal anomalies) and basins with low-thermal-conductivity alluvial fan sediments make shallow temperature survey techniques especially effective in this region. Since the mid-2000s, a group centered at the Great Basin Center for Geothermal Energy (GBCGE) modernized the technique and deployed it for greenfield exploration and mapping of shallow thermal outflow plumes. Since then, several industry and research groups (including the Navy Geothermal Program Office) developed their own systems and methodologies for the collection and interpretation of shallow temperature surveys. Growing interest in geothermal exploration, and the 2-m temperature survey technique in particular, has prompted a review and re-evaluation of best practices and interpretation techniques for shallow temperature surveys and the need to standardize procedures to allow for comparison between surveys conducted by different organizations. Here, we present an equipment inventory as well as standard operating procedures for 2-m survey data collection using the GBCGE 2-m temperature survey rig. In addition, we present progress on a Python notebook that is intended to assist with data processing and interpretation of 2-m temperature survey results. This workbook walks through various data processing tasks such as multi-survey normalization, removal of seasonal temperature effects through establishment of background temperatures, identification and removal of non-geothermal anomalies due to surface albedo and elevation, calculation of estimated heat loss, and geostatistical analyses for interpolation and simulation.

1. INTRODUCTION

The goal of shallow (2-m) temperature surveys are to identify and map the extent of shallow thermal anomalies to infer characteristics and geometries of subsurface fluid flow. This information can be utilized in well targeting and conceptual modeling, estimation of shallow heat loss through conduction, and as a surface constraint on thermal models. The first shallow temperature surveys performed in the Great Basin region of the western United States occurred in the late 1970s-early 1980s (Olmsted, 1977; Trexler et al., 1981, 1982; Lange et al., 1982; LeSchack and Lewis, 1983, Olmsted and Ingebritsen, 1986) and these focused primarily on mapping the subsurface extent of known thermal anomalies. Since then, the technique has been updated and deployed for greenfield exploration by a group centered around the Great Basin Center for Geothermal Energy (GBCGE) in the mid 2000's (Coolbaugh et al., 2007; Sladek et al., 2007; Sladek et al., 2009) and has been key for the discovery of at least 6 previously unknown thermal anomalies in Nevada: Teels Marsh, Rhodes Marsh, Columbus Marsh, East Hawthorne, Emerson Pass, and Petrified Springs (Kratt et al., 2008, 2009, 2010, Shevenell et al., 2014; Craig et al., 2021), as well as mapping the extent of subsurface shallow thermal outflow plumes at dozens of other sites.

In addition to modernizing the equipment, several studies were published in conference literature regarding data processing and interpretation, such as multi-survey corrections (Sladek et al., 2009, 2013), removal of background annual temperature fluctuations (Sladek et al., 2013), corrections for the effects of albedo (Sladek et al., 2009), investigations of the role of thermal diffusivity (Coolbaugh et al., 2009), weather and rainfall on shallow temperatures (Sladek et al., 2012), and estimates of shallow conductive heat loss (Coolbaugh et al., 2013, 2014).

This document intends to provide all the required information regarding equipment, survey design, data collection, and data interpretation to begin performing shallow (2-m) temperature surveys for geothermal exploration in the Great Basin or analogous geologic environments. Future work will include a detailed review of methods for shallow temperature surveys, a review of case studies and use in conceptual modeling of geothermal resources, and a Python-based notebook to guide data processing, interpretation, and interpolation using geostatistical techniques. The notebook is intended to serve as a chapter in a “Hidden Systems Playbook”, a joint-deliverable from two DOE-GTO funded projects, INGENIOUS (led by UNR), and BRIDGE (led by SNL) expected to be released in 2025.

2.0 EQUIPMENT

The following list of equipment is intended to document the inventory of the GBCGE's 2-m Temperature Survey rig to facilitate interested parties in constructing their own 2-m temperature setups. Development of methodologies and equipment have been presented previously

(Coolbaugh et al., 2007; Sladek et al., 2007), and here we update the equipment list based on several documents (in appendices) prepared by Chris Sladek. The authors do not endorse any specific brands or products. Brand/product names are intended for informational purposes only.

2.1 2-m Probes

The probes utilized by the GBCGE are 1/4" extra-heavy schedule 80 pipe, ASTM A53, Type F, Grade B. Suppliers utilized by the GBCGE include Sharon Tube and Wheatland Tube. To build the probes, cut the schedule 80 pipe to 7'. Using and oxygen acetylene torch weld one end closed with mild steel filler rod and hard face with Stoody Acetylene Tube Borium 10227100 to form a pointed tip. The pointed tip is formed by applying an initial layer or a bead of the Acetylene Tube Borium to the welded end and playing or sweeping the bead down with the flame to form a point. This usually takes about 4 applications of a 1/8 to 3/16" bead and then playing it down. Use a slightly reducing flame with the Acetylene Tube Borium. GBCGE utilizes a Victor aircraft torch with a #1 tip, or a model 100FC with a #0, but the aircraft torch is lighter and easier for controlling. The open end of the probe is threaded to accept ¼" pipe cap to protect end from mushrooming (Mcmaster Carr 44605K172).

2.2 Hammer and Rock Drill

The probe hammer utilized by the GBCGE is a Milwaukee 3/4" hex demolition hammer 5337-21 (Kango 900K) equipped with a ground rod driver (48-62-3070). Make sure the ground rod driver for the hammer you chose has a bore that will fit the cap you use on the end of the 2m probes. A generator is required to power the demolition hammer. At least a 2kW generator is recommended. The demolition hammer is effective for driving rods into moderately rocky soils but is not effective for use in especially rocky areas or in bedrock.

Figure 1: Example of GBCGE personnel driving a hollow steel probe into the ground using a demolition hammer.

The GBCGE has also deployed a rock drill to collect 2-m temperature measurements in bedrock, or more difficult ground conditions. This technique is effective, although more time is required to deploy each probe. The following equipment has been utilized: the Cobra Combi gas powered pavement breaker/rock drill made by Atlas Copco (see Sladek et al., 2009 for additional information regarding the rock drill methods and application).

2.3 Temperature Meter and Sensors

Thermistors or Pt RTD's are recommended for temperature measurements. Thermocouples are not recommended because cold junction compensation on thermocouple meters may be sensitive to ambient temperature changes, and we have seen up to 2 °C drift related to ambient temperature change while making measurements in the field using thermocouples. The GBCGE is currently using a Omega HH804 RTD meter. Amprobe has a similar meter (Amprobe RTD-10). Recommended RTDs are: TE NBPTC-110 or Omega F2020-100-A-100 thin film RTD's attached to 26 AWG 4 wire cable (Omega EXTT-4CU-26S). The RTD's are protected with adhesive lined heat shrink tubing. The wires for the lower RTD's pass through the heat shrink tube of the 1m and 1.5m RTD's. The overall length is 9' and terminated with a 15 pin D connector. The RTD string is connected to an Omega HH804 meter through a switch box to select between the 1, 1.5 and 2m depth RTD's. Switch box details and schematic are shown below in the supplemental text.

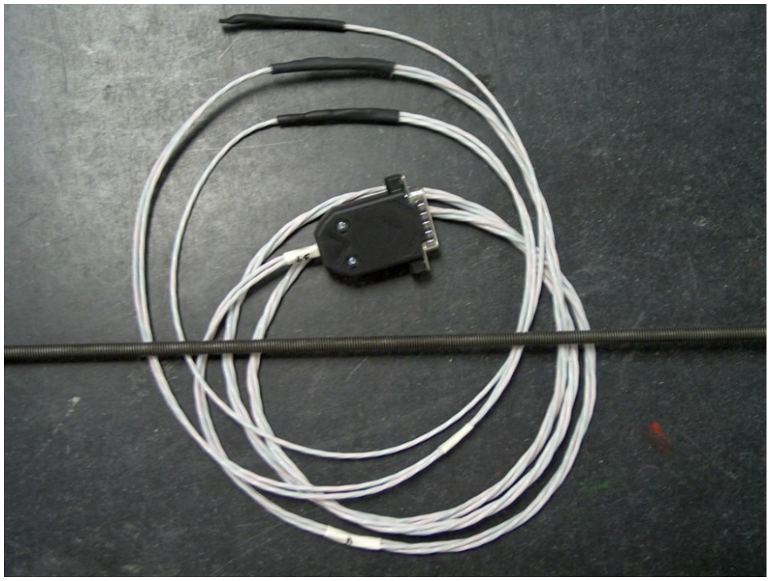

Figure 2: Great Basin Center for Geothermal Energy 3 zone RTD, with RTD's at 0.5m spacing.

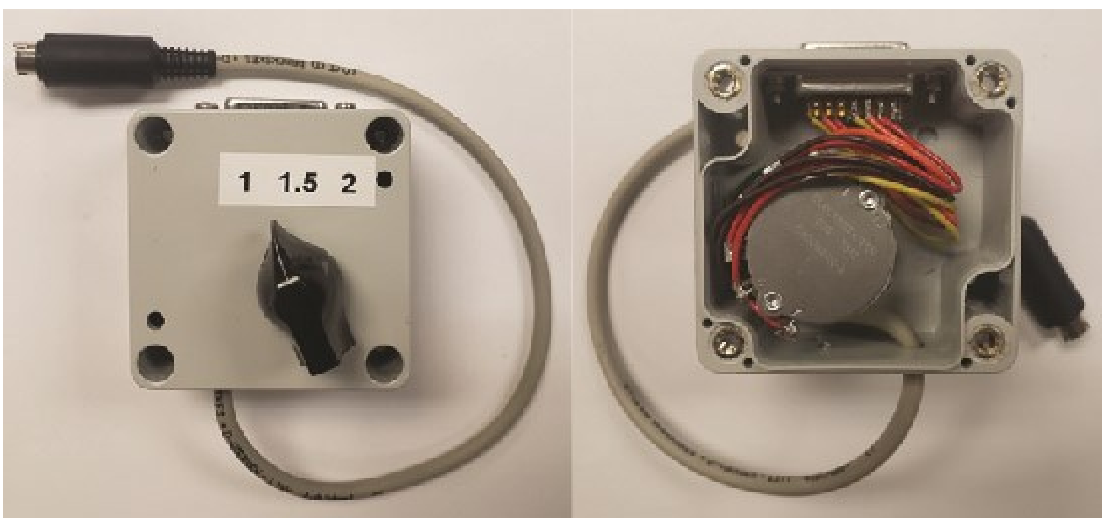

Figure 3: Switch box detail. Switch (Electro Switch C4D0604N-A) and 15 pin D connector are mounted in Hammond 1554B2GY enclosure. See supplemental material for schematic of switch box and RTD string.

A correction factor is calculated for each RTD To calculate the RTD correction factor, number each RTD. Place the RTDs in room temperature stirred water bath, bathtub, sink, or bucket. A fish bubbler can be used for stirring the water bath. Bundle the temperature sensors together to keep them in close proximity to reduce potential temperature gradient effects. Go through each sensor and measure the temperature. Decide which RTD sensor to correct to, and then create a table of the difference between the chosen RTD and the measured temperature for each RTD sensor. Ideally a reference RTD, not used for field applications, is best. This can be a single RTD rather than a three zone string. An example table is shown here (Table 1). Notice how the correction factor is on the order of .1 to .2 °C. To perform the RTD correction, add the RTD correction factor to each measurement (the RTD # is recorded for each field measurement).

Table 1: RTD correction example for RTD's utilized by the GBCGE.

RTD #	1 m Corr Value	1.5 m Corr Value	2 m Corr Value
15	0	0.1	0
16	-0.1	0.1	0.1
17	0	0	0
18	0	0	0
19	0	-0.1	0
20	0.1	0	0.1
22	0.1	0	0
24	0.1	-0.1	0.1
26	0	-0.1	0.2
27	-0.1	0.1	0.2
28	0.1	0	0
29	0	-0.1	0
30	0	0.1	0.1
31	0.1	0	0.1

2.4 Probe Retrieval

Two different probe retrieval tools were designed/utilized by the GBCGE. The recommended tool is a cable puller that consists of a ratchet winch attached to the base of steel column (Figure 4a). The puller cable runs over a pulley at the top of the column and is attached to the top of the probe to be pulled by an eye-nut. Overall length is approximately 6' (185cm). The puller is designed so that winch parts can be easily replaced in the field. The puller is relatively low cost, with a material cost of approximately $200, and is simple to assemble (See supplemental text 1). The second tool is a high-lift jack similar to a modified removal jack sold by AMS for soil sampling (Figure 4b). Minor modifications to this off the shelf jack improved its function (See supplemental text 2).

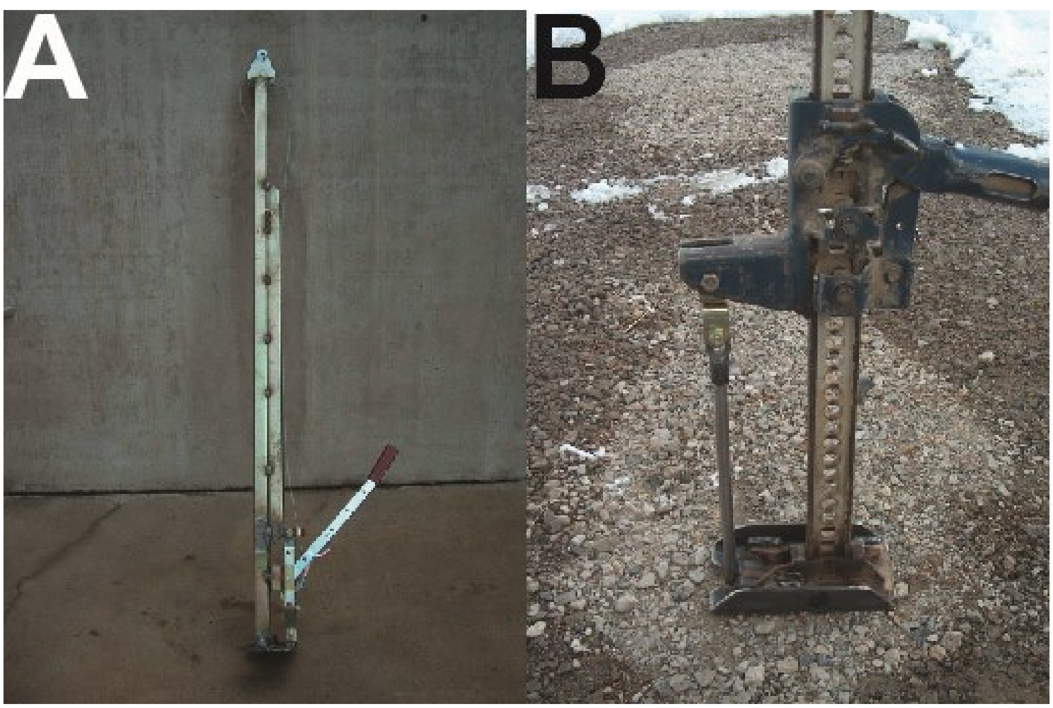

Figure 4: Probe retrieval tools. A: Cable Puller. B: Modified high lift puller jack similar to AMS tool.

2.5 Additional Miscellaneous Equipment

Several additional items are also utilized. Small orange survey flags are left following the placement of the 2-m temperature probe to aid in relocation following equilibration of the probe prior to temperature measurement, as well as to mark the possible hazard (driving over the probe top). A GPS and/or tablet computer is utilized to mark the location of the temperature measurement, and can assist in relocation the probe locations. Special modified locking pliers (Figure 5) are useful for probe retrieval. Finally, a file can be used for opening a broken "mushroomed" top of the probe (a failure that occurs sometimes during hammering) to allow space to put the RTD down to obtain a measurement. Personal protection equipment including safety glasses, hearing protection, and work gloves are a requirement. Straps and bungee cords are utilized to secure equipment while traveling between measurement locations.

Figure 5. Locking pliers with ½" pipe extension welded to the fixed jaw. Some probes can easily be pulled out of the ground using these pliers.

2.6 Field Vehicle

Personnel from the GBCGE and the Navy GPO have utilized both trucks and field ATVs (also called a buggy). There are several advantages and disadvantages to both. The primary advantage of utilizing a field ATV is for more maneuverability for offroad surveys. This can allow for surveys to be performed in otherwise inaccessible areas. Examples of field conditions that benefit from higher maneuverability include areas with road washouts, drainages, hills, rocky areas, dunes, and vegetation. The relatively small size and maneuverability of the buggy allows for maneuvering around vegetation (e.g. individual sage brush), thus limiting impact on the environment. However, there are several cons to utilizing a buggy: because it is an additional piece of equipment, it requires additional cost, including maintenance. In addition, it can introduce safety risk (for example when loading/unloading from the trailer, or when operating in the field). Possible safety risks include rolling the ATV over when operating improperly. Utilizing a truck or field vehicle has several advantages: first, it is usually something you may already have, second, if surveys are performed along roads (which is sometimes easier regarding access and permitting), the benefits of the ATV are unnecessary.

3.0 SURVEY DESIGN, FIELD ACTIVITIES, AND DATA COLLECTION

3.1 Survey Design

Survey design geometry depends on the level of reconnaissance of the survey. Initial reconnaissance surveys can begin with widely spaced data points collected parallel to the range front and/or targeting known zones of structural complexity and/or paleo-geothermal deposits. Detailed surveys best resemble a grid with at least equal number of points within and without a thermal anomaly that map the extents in 2-D space of the anomaly. Recommended point spacing is 100-1000 m between points. Initial reconnaissance points can be widely spaced (~1 km), with infilling once an anomaly has been identified. It is extremely important to collect measurements both within and outside of thermal anomalies to accurately evaluate background temperature conditions to estimate the magnitude of the anomaly and to merge surveys collected at different dates at the same location (see discussion of base stations).

During survey design, and again at the data collection stage, here are some suggestions: Target similar locations in terms of albedo, vegetation, slope, elevation, and sediment composition/type. Minimizing differences between data collection sites can minimize the effects of the listed factors. Remember, it is easiest to compare like with like. Avoid anomalous areas such as the bottom of stream beds, areas with visible standing water or mud, within mineral exploration pits or trenches, directly on steep scarps, etc., because these sites may not be directly comparable with the rest of your survey. However, areas adjacent to things like paleo-geothermal deposits, or other geothermal indicators may be good places to collect measurements. Use your best judgement, these aren't strict rules, but you want to compare like with like whenever possible.

3.2 Base Station Locations

If you are returning to a site to collect more data points, or will be collecting data for longer than ~5 days, it is important to select several sites to make base-station measurements. Ideally, you have at least 2, but recommend 3-4 base station measurements. One base station should be within the thermal anomaly, and one should be outside the thermal anomaly. Base station locations should be representative of the field area. For example, if the majority of your survey is on an alluvial fan, make sure the majority of your base stations are on the alluvial fan and not in a playa or a stream channel etc. Base station measurements are only needed to be taken once per survey (assuming the survey is over less than 1 week). However, taking base station at a minimum of every other day can reduce the potential of any analytical or other measurement error when generating a base station correction. At Granite Springs Valley, base station measurements revealed that the ground at 2-m depth was heating up an average of 0.1 °C per day between June and August. Therefore 10 days may result in at least 1 °C difference in temperature. It is okay if you cannot locate the exact site of a previous measurement. A base station measurement within ~10s of meters of the original point should be acceptable for this kind of correction.

3.3 Data Collection Procedures

Here are the data collection procedures for utilizing the GBCGE buggy and equipment for 2-m temperature surveys.

Stop the survey vehicle in a safe location, watch for vegetation under the buggy for potential fire risk, and make sure the survey vehicle is secure with the parking brake on, and is not in danger of rolling downhill. We typically leave it in gear when parking for a measurement.

The two-person team is then responsible for two different jobs:

- Probe Preparer - > Selects rod for placement. Puts plumber's tape on threads, uses wrench and vice grips to securely screw on probe cap. This cap should be put on very tightly to minimize risk of breaking the top of the probe off during hammering. Once the probe cap is secure, the probe preparer holds and stabilizes probe during hammering, and assures that the probe is vertical and not slanted. If the probe does start to tilt due to deflection by deeper rocks as it is driven it is best to follow this deflection.

- Hammerer -> The hammerer waits for the probe preparer to put on the probe cap. Then the hammerer starts the generator. The hammerer then climbs on to the back of the buggy/truck, and picks up the impact hammer. They then place the top of the hammer on top of the probe. The probe preparer from the ground makes sure the probe is straight/vertical, and then signals the hammerer to begin to hammer. Ideally, the probe goes into the ground with minimal effort, and the hammerer or probe preparer finishes hammering the probe from the ground.

Fairly often, a boulder or other difficult to penetrate material in the subsurface is intersected. In some cases, additional time is required to hammer the probe through the obstruction, but in other cases that additional time hammering the probe into a boulder can lead to failure of the probe cap, which can break off or mushroom, or cause excessive bending of the probe in the subsurface. Therefore, it is important for the probe preparer to watch the progress of the probe from the ground and let the hammerer know if no progress is being made for ~5 seconds, after which it is usually best to extract the probe and try a different location, perhaps several feet away (the other side of the back of the buggy). Repeated failure may necessitate minor movements of the buggy or the decision to not collect a point at this location (but perhaps come back and try again later)

Care is made to make sure consistent probe depth into the ground. Typically, a few inches is left exposed to allow for vice grips to grab in cases of broken probe tops or difficult to remove probes.

Mark the station number and location on the GPS and/or tablet. Record the time in which it was placed. Do not return to collect for at least 1 hr. (time it takes for the probe to equilibrate with the ground, see Coolbaugh et al., 2007). Equilibration is dependent on specific hardware utilized, and should be retested for new setups. Snake the RTD device down the hollow probe. Make sure that the RTD connector is not in mud/sand. Place flag into probe top to assist in finding the probe again. If using a tablet, it can be beneficial to take a picture of the probe that includes the wider site, to allow for finding the site again, and for recording the ground conditions at the site, which may be useful later on if the site is found to be anomalous. Probes may be left in for up to 48 hours, however it is best not to leave RTD device in overnight especially in an area with cattle who may damage the equipment. Rodents and other wild animals are also known to gnaw or remove RTD's. RTD device takes about 10-15 minutes to equilibrate with probe.

After 1 hour or longer, return to the location using the tablet or GPS. To record the data: attach the RTD to the data logger. Record temperature at 1, 1.5, and 2 m in °C. Make sure the data logger is on the correct setting (for the GBCGE equipment, this information is provided on a sticker on the data logger). Write down the RTD number used for each station to correct for later, or to identify faulty RTDs which can go bad and cause errors. When data collection is complete wind up the RTD and store, as well as storing notebook/tablet/data logger, and prepare for probe retrieval.

Probe Extraction Step 1: Person one can bring the probe puller to probe from the buggy. Meanwhile, the other person can prepare the site. It may be necessary to begin working on/rotating the probe with the modified vice grips prior to attaching the probe puller to assist in extraction.

Probe Extraction Step 2: Place probe puller near probe. Disengage lock to gain slack, and attach the puller wire to the top of the probe.

Probe Extraction Step 3: Person 1: move probe puller closer to probe tip, and remove tension from wire. Then proceed to use the lever to pull the probe. Person 2: Stabilize probe puller. Alternatively: Person 1 stabilizes while using the lever. Person 2 uses the modified vice grips to rotate the probe back and forth to ease extraction.

Probe Extraction Step 4: Person 2 lets Person 1 know when the probe has reached the top of the probe puller. The probe is extracted. The probe puller is returned to its place. The probe is potentially straightened if it is bent. Probe is returned, and the probes are secured.

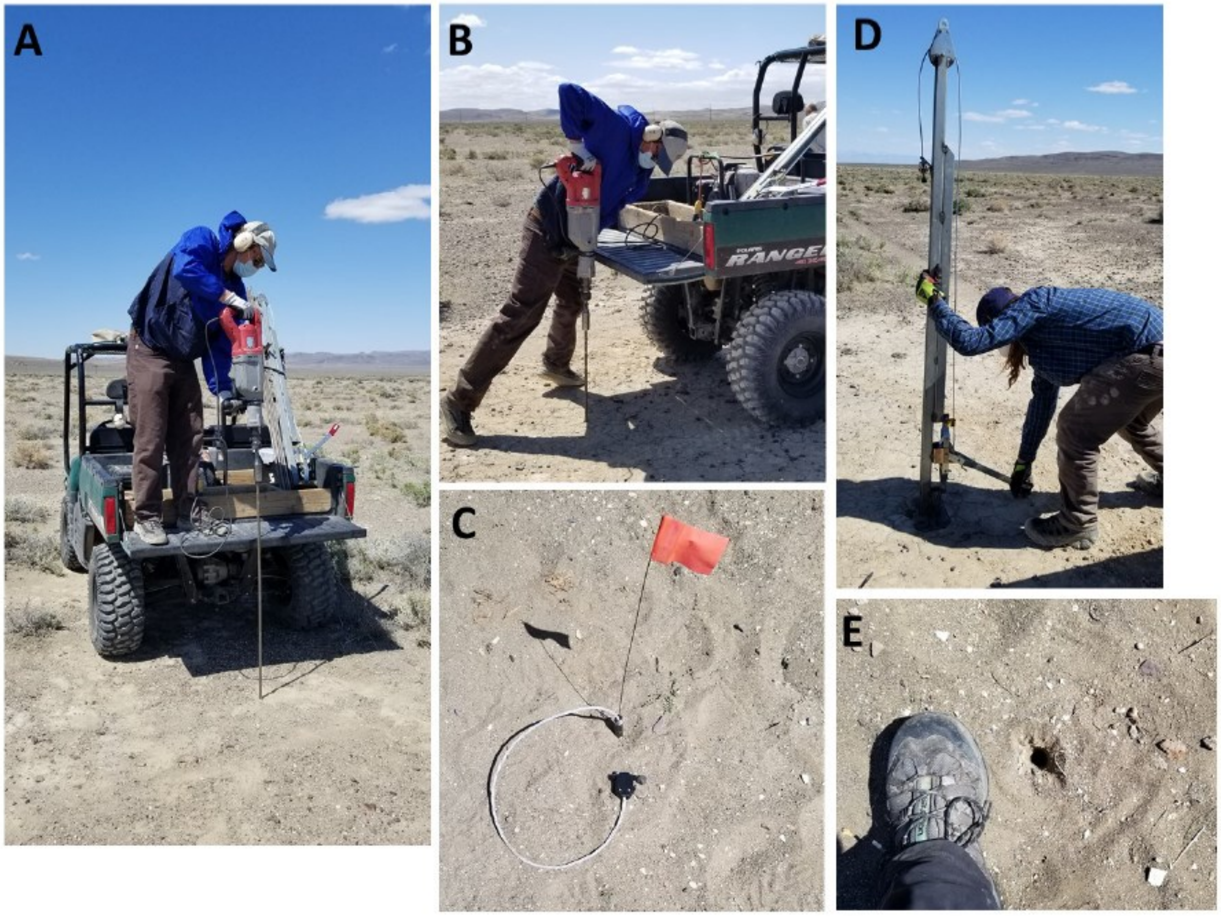

Figure 6: Steps for collecting a 2-m measurement. A: Driving a 2-m rod into the ground from using the demolition rod from the back of the vehicle. B: Finishing driving the probe into the ground. C: RTD snaked down the hollow prove, left for 1 hour with flag before measurement of temperature at 2 m. D: Extraction of probe using the cable puller. E: Small hole left behind that caves in on its own soon after extraction.

General Comments:

- ~10 – 25 measurements possible per day depending on ground conditions and space between points
- Usually, we put out 10-15 probes before coming back to collect data/retrieve probes.
- It is recommended to park somewhere in the middle of your planned line to minimize distance from the truck in case of buggy breakdown.
  - People have had to walk a surprise 10 miles back to the truck.
- Bring extra water, snacks, and sun protection.
- Always wear your PPE (Safety glasses, Ear/hearing protection, heavy duty gloves).

3.4 Safety Considerations

Along with any field survey technique, there are several potential safety concerns. To mitigate this, the GBCGE has instituted required safety training, as well as written a safety focused SOP for 2-m temperature surveys (see supplemental document 3). The primary safety concerns fall into 3 categories: 1) Potential hazards resulting from the operation of field vehicles and trailers, 2) Hazards present using hand and power tools during the collection of 2-m T data, and 3) hazards related to performing field work in remote areas in poor climate conditions.

3.5 Cultural and Environmental Impact

Archeological and cultural sites should be avoided, as well as sensitive ecosystems. Care is taken to avoid damaging vegetation by remaining on existing roads and two tracks when possible. When performing surveys offroad, the high maneuverability of the ATV can avoid driving over vegetation by going around and in between shrubs. In general, ground disturbance is minimal, with a small hole left behind that caves in on itself.

4.0 DATA PROCESSING STEPS

We will now describe the basic data processing steps, which will be gone over in section 5 in more detail with a case study.

1. RTD Sensor Correction:
   a. The raw 2-m temperature data should be corrected based on the RTD sensor correction. This correction is based on the RTD calibration described in section 2.3.
2. Multi-Survey Correction:
   a. This step is necessary when either two or more surveys were performed at the same site, or if a single survey was performed over longer than ~5 days. There are two techniques for multi-survey corrections: base station correction, and a background normalization technique.
   b. The base station correction is the simpler option: this involves repeat measurements performed at 1, or preferable 3-4 base stations between surveys (see section 3.2 for discussion of choosing base station locations). A simple linear correction can be performed based on the average temperature change between survey dates. If one of the measured delta-Ts is significantly different at one base station than the others, the outlier can be left out. In general, surveys are corrected to the date of the largest or most significant survey at the site, therefore requiring minimum correction.
   c. A second multi-survey correction technique is discussed in Sladek et al., (2013), and involves collecting enough measurements in background conditions to establish average background conditions, and to normalize the surveys to have consistent backgrounds.
   d. We have found that both techniques can be performed and compared for the same multi-survey correction.
3. Convert data to Degrees Above Background (as presented in Sladek et al., 2013):
   a. First, establish background conditions, and convert 2-m data to “Degrees Above Background” in order to remove the effects of annual temperature cycles and background conditions in order to facilitate comparison with other 2-m temperature survey sites with different background conditions.
   b. Alternatively, the survey can be adjusted to a background temperature of 20 °C (roughly the average temperature at 2-m for many locations in the Great Basin region).
4. Account for non-geothermal thermal anomalies:
   a. Solar Radiation variables (Albedo, Elevation, Slope Aspect) – can be empirically corrected if values can be estimated (through remote sensing data or digital elevation models). Albedo, elevation, or slope aspect values for each point are plotted against 2-m temperature, and if a statistical correlation can be identified, the slope can be used to calculate a correction factor (see LeShack and Lewis, 1983; Sladek et al., 2009).
      i. Albedo - Anomalies of at least up to 5 °C have been observed due to surface albedo alone (e.g. at Columbus Marsh, Sladek et al., 2009), therefore albedo should be investigated if an anomaly is identified, especially in areas where there are obvious color contrasts (as seen in imagery). Following the methods of Sladek et al., (2009), we demonstrate the correction for surface albedo by utilizing ASTER satellite imagery in section 5.4. This correction may not be useful if surface albedo variability is low in the survey area.
      ii. Elevation – Useful when elevation difference is > ~100 m. LeSchack and Lewis (1983) estimate an adiabatic lapse rate of –1.0 °C / 100 m elevation change (see section 5.5 for an example).
      iii. Slope Aspect – North facing slopes tend to be cooler than south facing slopes (as seen at Desert Queen, Sladek et al., 2009).
   b. Thermal Conductivity/Diffusivity – Variability can produce false 2-m thermal anomalies. Sladek et al. (2012) found relatively minor (typically < 1 °C) for typical soils found at Desert Queen. The impact becomes more important when comparing measurements taken in bedrock to measurements taken in soils (see Sladek et al., 2012).

   c. Soil moisture - low-lying areas with high moisture are typically ~4 °C lower than surrounding areas likely due to convective linkage to underlying groundwater or evapotranspiration effects due to vegetation (see Sladek et al., 2012).

5. Interpolation and Geostatistics – not required for interpretation, but may be useful in some situations, especially for calculating conductive heat loss or using as a surface constraint in 3-D models.

6. Incorporation into conceptual models

5.0 CASE STUDY: PETRIFIED SPRINGS

Here we will present a case study from Nevada: the blind and hidden Petrified Springs geothermal system, discovered during the Nevada Play Fairway project using an example and data from Craig et al. (2021). We will walk through the various data correction and processing techniques performed by Craig et al., as well as some additional corrections, interpretation and analysis.

5.1 Survey Design and Data Collection

Gabbs Valley in western Nevada is the location of several known shallow temperature anomalies (Figure 7), including one associated with the Don A. Campbell geothermal powerplant (operated by Ormat), an anomaly associated with Rawhide hot springs, a subtle anomaly in northern Gabbs valley, and an anomaly located at Cobble Cuesta. Structurally, this basin is located at the boundary between the Walker Lane (a zone of right-lateral shear) and the Basin and Range Province characterized by northwest directed extension. Southeast Gabbs Valley (the location of the Petrified Springs geothermal system) is the location of a broad displacement transfer zone between the northwest striking right-lateral strike-slip Petrified Springs fault and several northeast-striking dip-slip faults. This structural setting was revealed as a target during the NVPFA project, and an initial 2-m temperature survey was performed in August, 2016 (Figure 8).

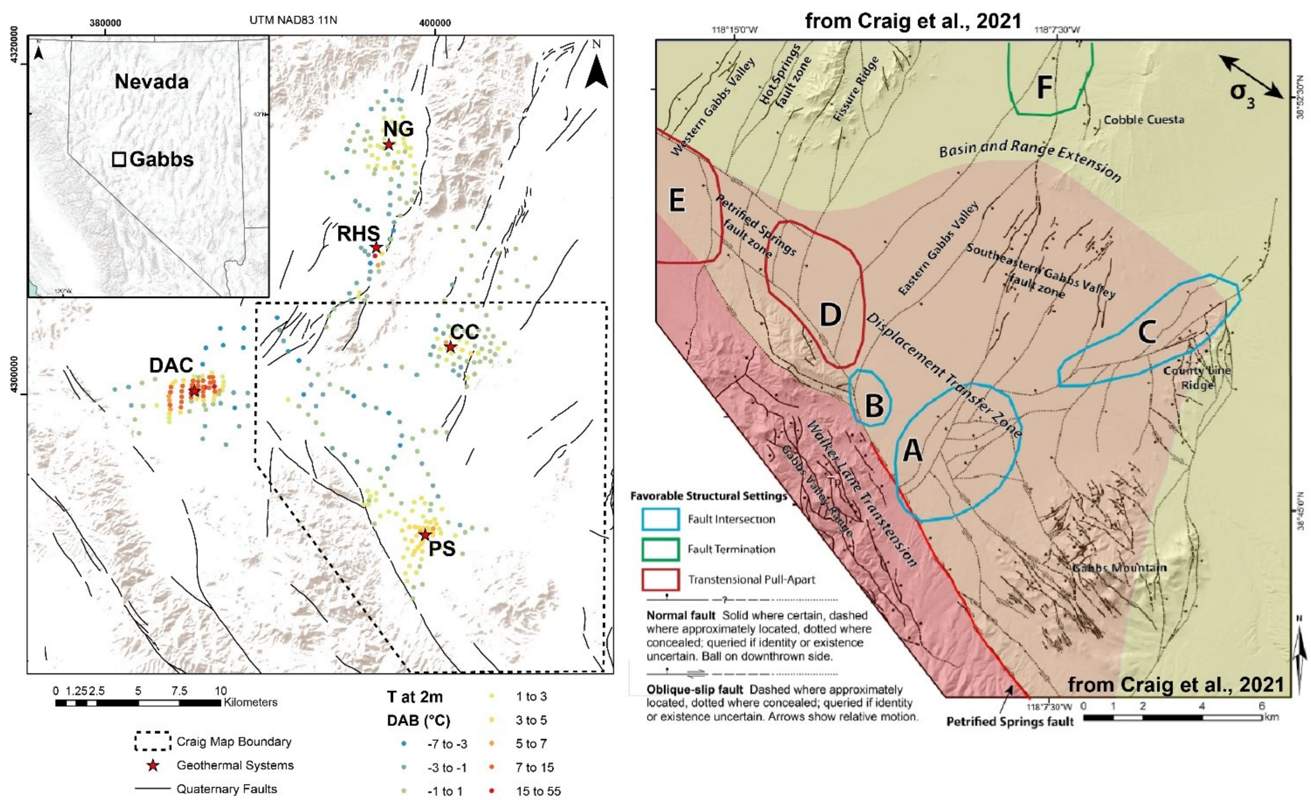

Figure 7: (Left) Location of Gabbs Valley, quaternary faults and 2-m temperature data from Ayling et al. (2022), known geothermal systems, and location of map from Craig et al. PS refers to Petrified Springs geothermal system in southwest Gabbs, NG refers to North Gabbs, RHS refers to Rawhide Hot Spring, CC refers to Cobble Cuesta, and DAC refers to the Don A. Campbell geothermal power plant. (Right) Fault map reproduced from Craig et al., 2021, showing favorable structural settings for geothermal activity at and around Petrified Springs.

The initial survey focused on the inferred displacement-transfer zone between the Petrified Springs Fault and the northeast-trending Fissure Ridge (Figure 8). At this location, a positive temperature anomaly was not identified, so the survey continued to the southeast targeting an area higher on the alluvial fan surface. Here they identified significantly warmer temperatures (~5 °C above inferred background temperatures). Several months later, a second survey was performed to map the extent of this southeast anomaly. A "scatter shot" approach was performed to attempt to outline the extent of the shallow temperature anomaly and to locate the maximum shallow temperatures. A third survey was performed a month later to investigate a second possible thermal anomaly to the northwest where there was a hot point from the first survey. The third survey found that this area was not anomalous. This demonstrates that a single hot point is not enough to confirm a shallow temperature anomaly: several factors can lead to a "bad" measurement or false temperature anomaly, and therefore it is important to collect additional measurements near a hot point to validate the existence of the anomaly.

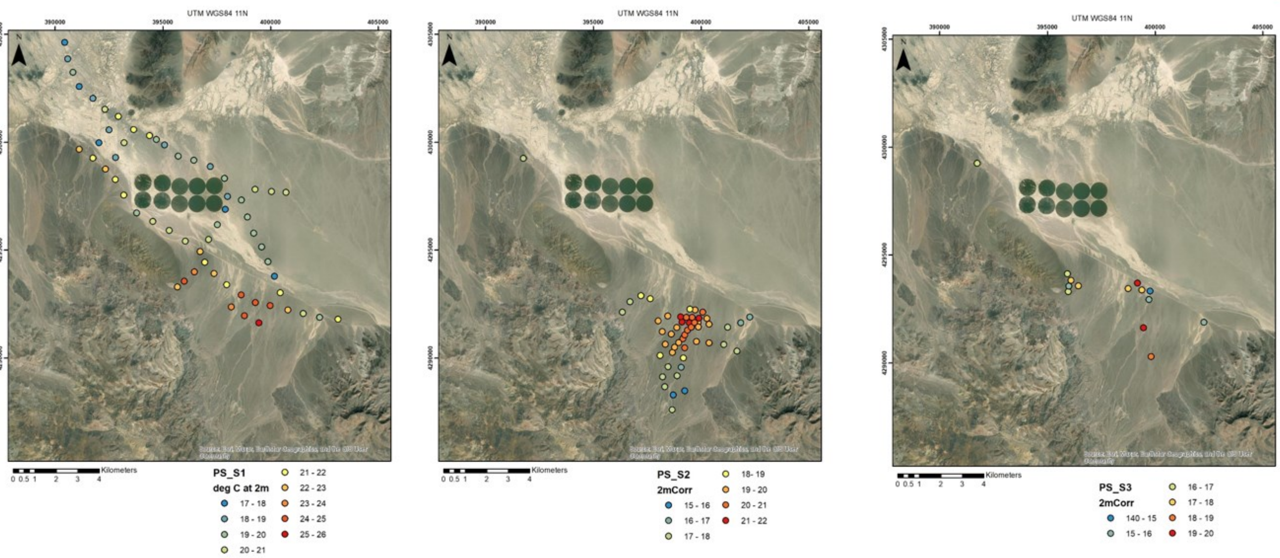

Figure 8: Three survey phases in southeast Gabbs Valley in August, early December, and late December 2016.

5.2 Multi-Survey Correction

Temperature resister corrected 2-m data is then ready for multi survey correction. Three base stations were chosen for repeat measurements between the three surveys. One base station was the hottest point from the first survey, the second base station point was chosen as a background point, and a third point was chosen that was slightly cold (Figure 9).

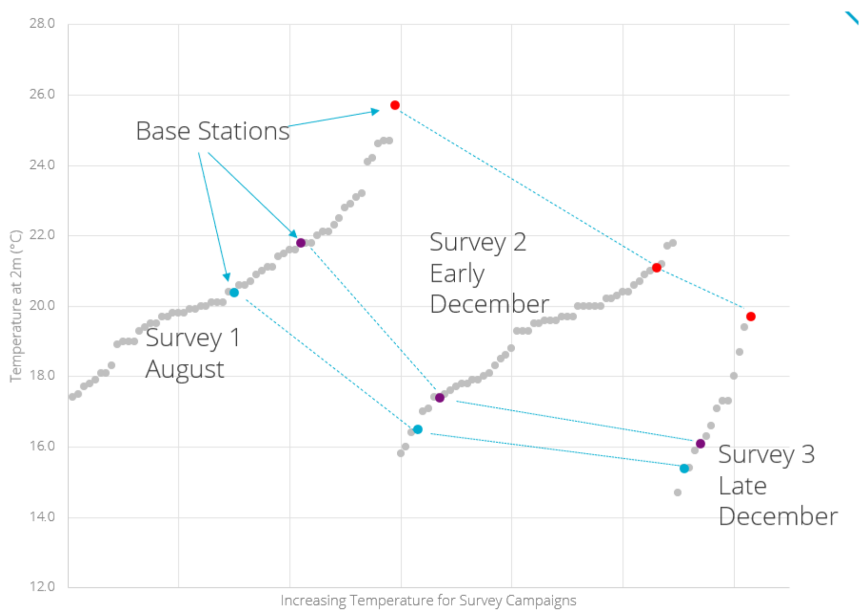

Figure 9: Survey point temperatures between each phase of data collection, with the temperatures of repeat base-station measurements labeled.

Craig et al., (2021) decided to correct the data to the second survey data since the majority of the data points within the area of interest were collected at this survey date. Figure 9 shows the temperature data from each survey plotted in increasing order, including the base station points: between Survey 1 and Survey 2, the temperature at 2-m decreased by an average of -4.1 °C. Between survey 2 and survey 3, temperatures at 2-m decreased by an average of 1.3 °C. Using these values, a simple linear correction is performed by subtracting 4.1 °C from the first survey, and adding 1.3 °C to the third survey. Note that if one of the base station measurements shows a change in temperature significantly different than the other two base stations (which has been observed for some surveys), it is acceptable to leave that base station measurement out when calculating the correction. This is another reason that it is important to collect more than 1 base station location.

5.3 Establishment of Background Temperatures

In order to remove the effects of seasonal temperature variation at 2-m, and to facilitate comparison with between survey areas, background temperatures must be inferred or calculated. Once these are calculated, temperatures should be plotted either relative to background (displayed as Degrees Above Background, DAB), or to a standard background temperature (often 20 °C is utilized for the Great Basin region).

One method for estimating background temperatures is to remove any points that are obviously anomalous (either positive or negative). This can be performed using statistical methods or by plotting temperatures in increasing order (Figure 10). As shown, the red and blue points are significantly warmer or colder and therefore should be left out when averaging background temperatures. The next thing to do is to calculate the average temperature of the remaining points. If there are any points remaining that are 3 °C above or below background, these should be removed and a new average temperature should be calculated. Continue to perform this step until all of the background points are within 3 °C of the background.

Once this is performed, DAB can be calculated by subtracting the average background temperature from the measured 2-m temperature data. To adjust to a 20 °C background, simply add 20 to the DAB. At this point, your survey has been adjusted to regional background temperatures. Multi-survey corrected temperatures are plotted as DAB in Figure 11.

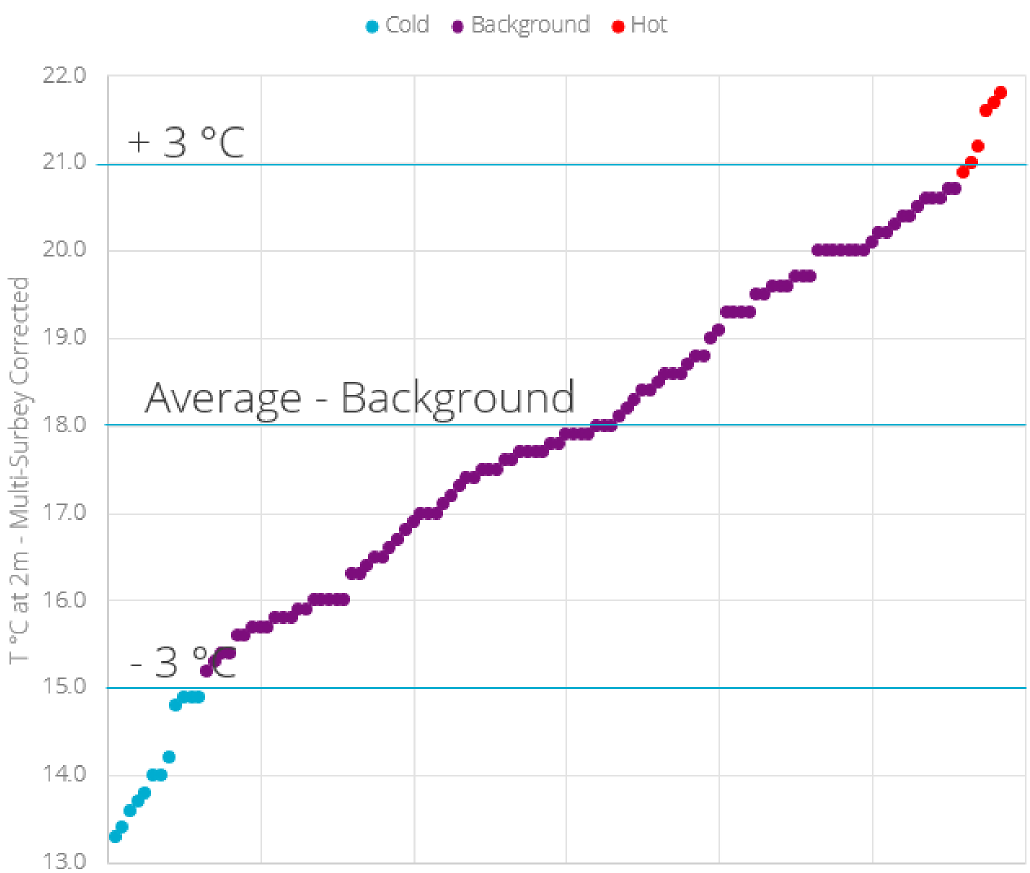

Figure 10: Multi-Survey corrected 2-m temperature data arranged from coldest to warmest. The infered average background is calculated to be 18 °C. A significant anomaly is considered to be >3 °C, with anomaly detection limit of ~2 °C.

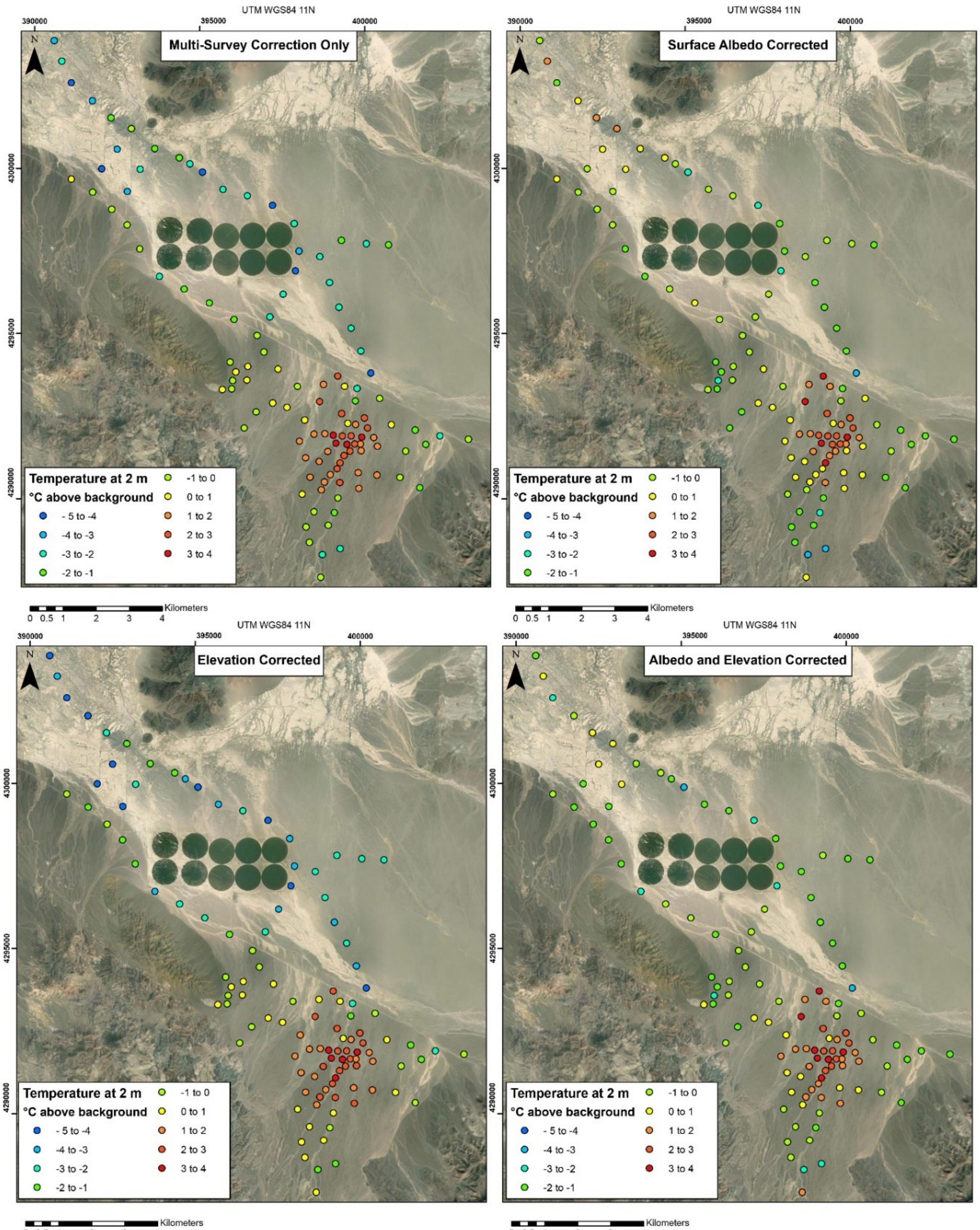

Figure 11: Multi-survey corrected (Top Left), multi-survey and albedo corrected (Top Right), multi-survey and elevation corrected (Bottom Left), and multi-Survey, albedo, and elevation corrected (Bottom Right) 2-m temperature (plotted relative to background (DAB)).

5.4 Surface Albedo Correction

Thermal anomalies should be investigated for potential albedo effects, especially when there is an obvious albedo contrast across the field area (e.g. between high-albedo playa and low-albedo alluvial fan surface, or with low-albedo alluvial fan surfaces due to erosion of low-albedo bedrock in the adjacent range). Here, we utilize data from the Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (available for free from NASA's Earthdata search). The ASTER data product utilized is the 09XT (or 07XT) satellite imagery. Shown here is Band 2 (0.63-0.69 µm) Surface Radiance VNIR with a 15 m pixel size. Surface Radiance is roughly proportional to spectral albedo, and measuring absolute albedo is not important for this type of application. The data has been atmospherically corrected already. Typically, there are multiple ASTER images of your field area – choose one with low cloud cover, from the day, and near in time to when you performed the survey (in case surface albedo has changed, for example, caused by a fire or a land-use change). To correct for the effects of surface albedo, use the equation from the best-fit line. For each data point, input the albedo and calculated the modeled temperature due to albedo. Subtract this value from the measured 2-m temperature value to remove the effects of albedo. You may need to correct your survey results to background/20 °C background temperatures.

At Petrified springs there was a strong negative correlation between estimated surface albedo and temperatures at 2-m (Figure 12). The R^2 value for this line is 0.4681. Once this influence was subtracted, the magnitude of the 2-m temperature anomaly remained, however the geometry of the anomaly is modified slightly: the zone of anomalously high temperatures narrowed, and several points in the southern portion of the anomaly were corrected closer to background temperatures, shifting the footprint of the anomaly to the north (Figure 11). In addition, two points closer to fissure ridge now appear anomalously hot with the removal of the effects of surface albedo.

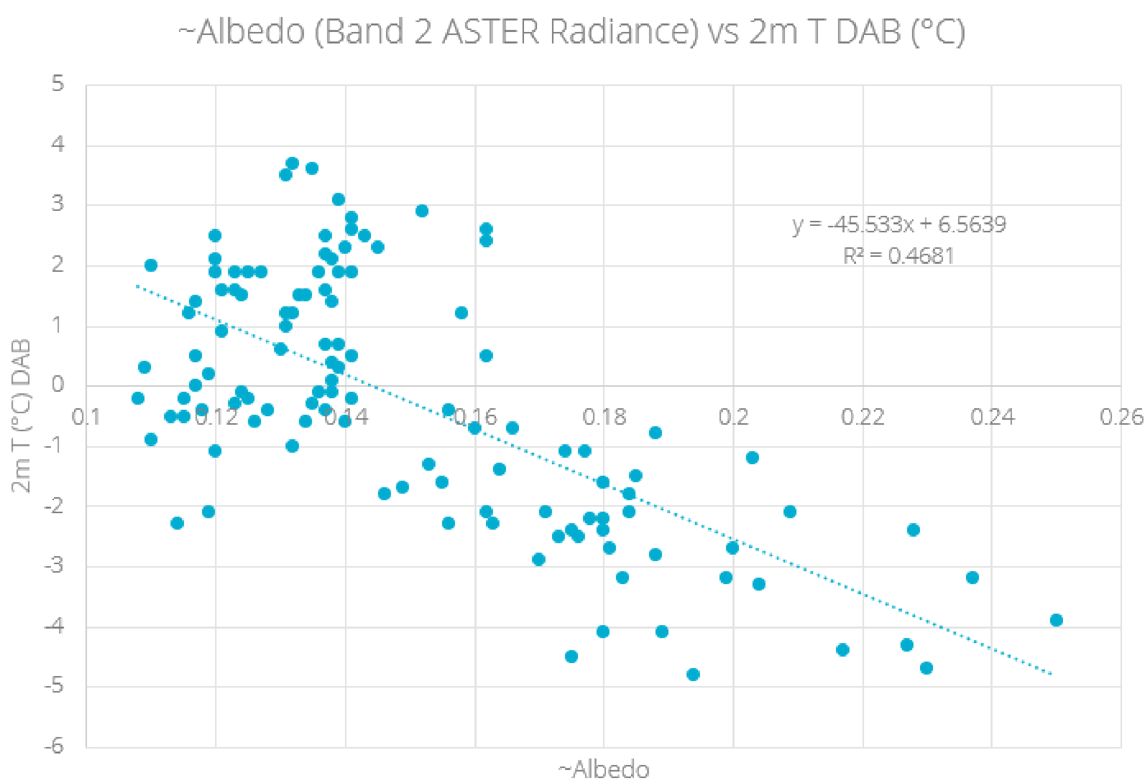

Figure 12: Estimated albedo from ASTER Band 2 surface radiance versus temperatures at 2-m (plotted as °C DAB). Also shown is a best fit line through the data that was utilized to correct the data for the effects of surface albedo.

5.5 Elevation Correction

Next, these data were corrected for elevation as the survey covered an area with > 100 m of elevation change. The methods presented by LeSchack and Lewis (1983). A datum of 1375 m was chosen for calculating the elevation correction to minimize the amount of correction applied since this elevation is roughly the elevation where the temperature anomaly is. The elevation correction factor (Yt) was calculated using the adiabatic lapse rate of 1°C/100m where Xz is the elevation of the probe's location at the ground surface (Equation 1).

$$Yt = (1375\text{m} - Xz)(-1°\text{C}/100\text{m}) \quad (1)$$

Equation 1 is applied to each probe location. Calculated Yt values were then added to the measured 2-meter temperature values. Figure 13 shows the temperature at 2-m plotted against the elevation, as well as the elevation correction factor. Minor changes to the geometry of the anomaly are apparent following the elevation correction (Figure 11).

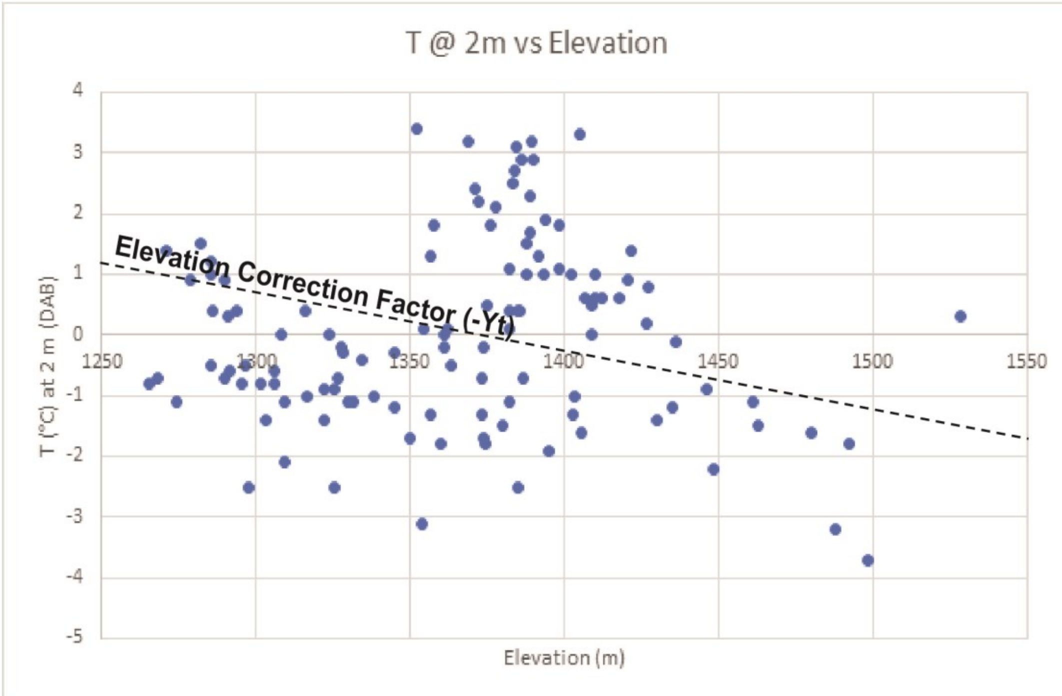

Figure 13: Elevation versus surface-albedo-corrected temperature at 2-m (plotted °C against background). Dashed line shows the trend for elevation vs temperature used for the correction. The correction factor is -1*trend line for each elevation.

5.6 Interpolation and Calculation of Heat Loss

The values representing the 'degrees of background' were subjected to interpolation, resulting in the creation of a contoured surface (Figure 14). In general, 2-meter surveys do not require interpolation for result interpretation, although sometimes it has been found useful for understanding the geometry of the thermal anomaly. Here we utilize interpolation in order to perform heat loss analysis. The chosen interpolation method was Empirical Bayesian Kriging (EBK), a geostatistical technique. EBK offers the advantage of effectively modeling data with potential non-stationarity, proving to be more accurate than alternative kriging methods when dealing with small datasets (Krivoruchko, 2012). Similar to other geostatistical interpolations, EBK relies on variogram calculations to estimate spatial correlation.

Calculation of excess conductive heat loss due to the shallow thermal anomaly is a way to quantify its size and assist in comparison with other known shallow thermal anomalies. Here, we apply the methods proposed by Coolbaugh & Sladek (2013) and Coolbaugh et al., (2014). Coolbaugh et al., (2014) presents the following equation for calculation of excess heat loss from a shallow thermal anomaly based on a temperature anomaly from a single point in time:

$$\text{Heat loss} = (g_a - g_b) * K * A \quad (2)$$

Where ga-gb is the anomalous temperature gradient, K is the thermal conductivity (0.627 W/m°C used here following Coolbaugh et al., 2014), and A is the surface area of the anomaly. Coolbaugh et al. (2014) demonstrates that the magnitude of the anomaly above background divided by two can be substituted for ga-gb

We utilize the interpolated temperature map from Figure 14 to estimate the area of the thermal anomaly at 1, 2, and 3 °C (total anomalous area ~13 km^2). Using equation 2, we calculate an excess heat loss of 6.2 MWt. Compared to other estimated values from Coolbaugh et al., (2014), the maximum temperature is below average (13.2 °C above background), the area is above average (9.3 km^2), and heat loss is below average, but within 2.5 MWt of Tungsten Mountain (8.6 MWt), but significantly less than Don A. Campbell (24.5 MWt), both existing electricity producers proximal to Petrified Springs.

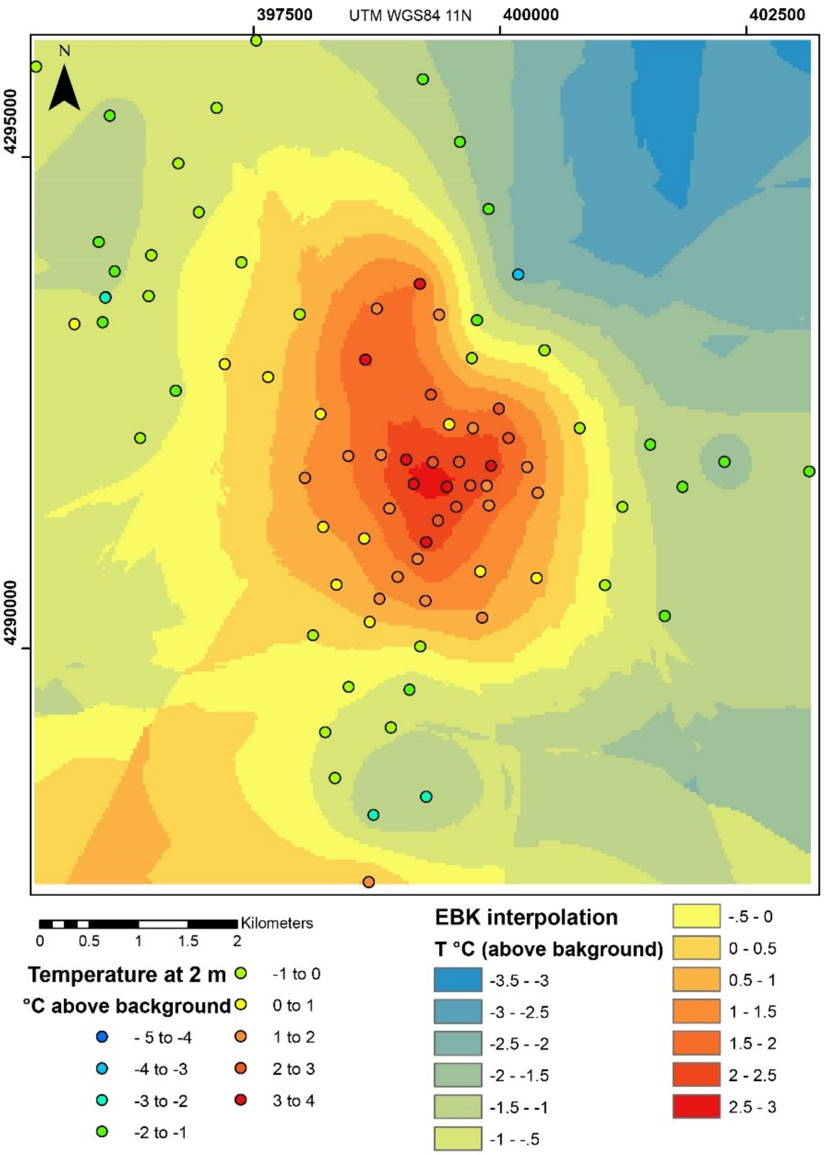

Figure 14: Interpolation of a subset of the albedo and elevation corrected 2-m temperature data. Several points distal to the anomaly were left out of the interpolation to provide a better geometry for interpolation in the area of interest.

5.7 Contribution of Shallow Temperature to the Resource Conceptual Models

Due to depth of detection limits of the 2-m temperature method, it is most effective at mapping the extent of relatively shallow thermal outflow plumes (~50-200 m depth), rather than locating the high temperature "upflow" zone (typically found in the damage zone of faults in complex structural settings at ~1-2 km depth), where the geothermal reservoir with economic resource potential may be located. However, 2-m temperature data (providing knowledge of outflow geometry) can be integrated with existing data (such as structural mapping, geophysical data, existing well data, geochemistry, etc.) to determine possible locations of the geothermal resource by producing resource conceptual models (e.g. Cumming, 2009; Ayling and Hinz, 2020; Craig et al., 2021) that are essential for determining drilling targets and resource estimates.

During the NVPFA project, Craig et al., (2021) integrated the 2-m temperature data, detailed structural mapping, geophysics (gravity, magnetotelluric, magnetics) and geochemistry of nearby wells into a resource conceptual model. Targeting inferred geologic structures (from geophysics) co-located with the shallow temperature anomaly, a series of TGH (~150 m depth) were drilled across the anomalous zone (Figure 15). The maximum TGH temperature at 150 m depth was 125 °C, proximal to the highest shallow temperature anomaly. Using the evidence from the new TGH data, Craig et al. proposed a possible upflow location (Figure 15). Based on the shallow temperature data, a possible outflow location is drawn with a black arrow (Figure 15).

In this particular example, the inferred upflow location is the same as the zone of highest 2-m temperatures, however this is not always the case: often the highest 2-m temperatures are offset from the inferred upflow location (such as at Tungsten Mountain and Desert Queen geothermal fields).

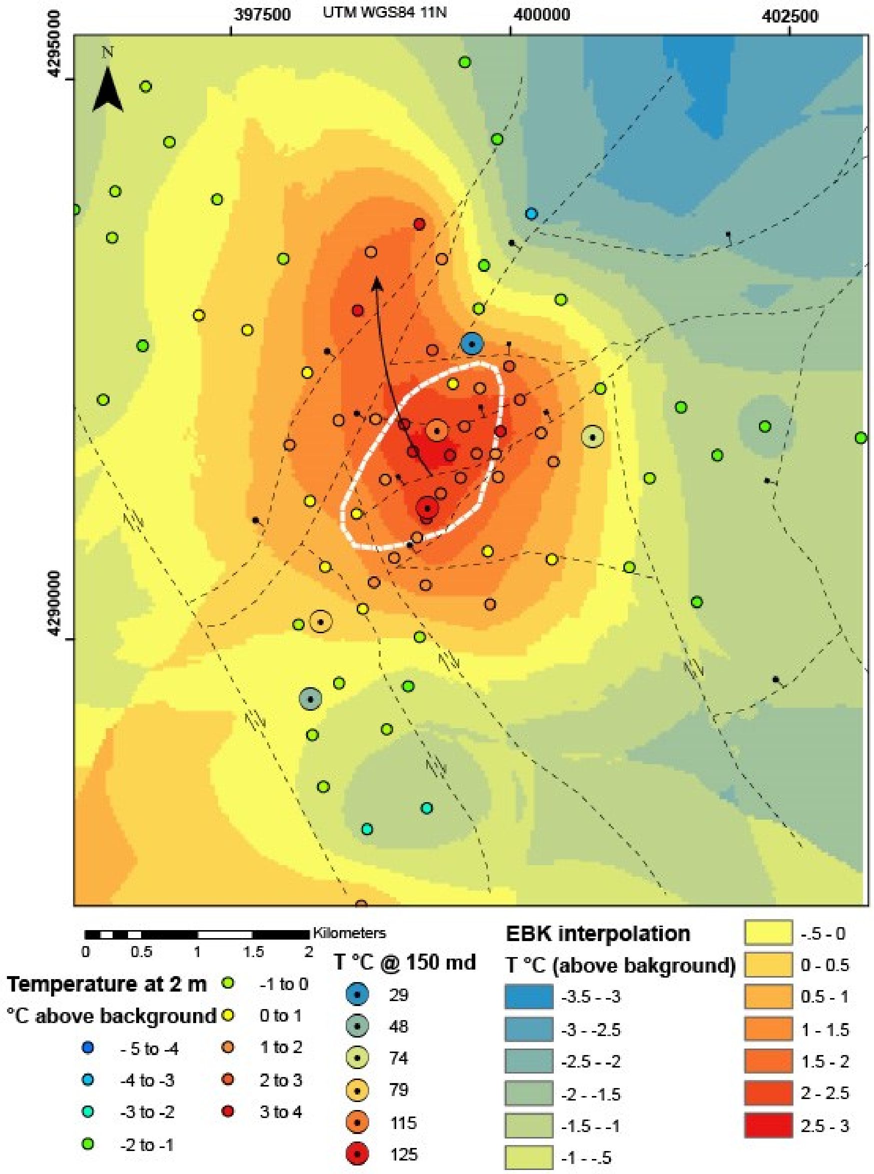

Figure 15: Simplified resource conceptual model adapted from Craig et al., 2021, including 2-m temperatures, interpolated temperature surface, TGH temperatures at 150 m depth, faults from mapping and inferred from geophysics (from Craig et al., 2021), location of inferred upflow (P90 resource extent from Craig et al., white dashed line), and possible outflow direction as indicated by the black arrow.

6.0 FUTURE WORK

The goal of this paper is to provide comprehensive information necessary to begin collection and interpretation of 2-m temperature data. Subsequent efforts will involve the development of a Python-based Jupyter Notebook, intended to serve as a chapter in a developers' playbook for exploration of hidden geothermal systems. This initiative is a collaboration of the BRIDGE and INGENIOUS projects with an anticipated release in 2025/26. The chapter will encompass complete code for processing 2-meter temperature data, incorporating relevant corrections, and will delve into discussion regarding collection methodology and model interpretation. Additionally, a manuscript is in preparation focusing on the integration of shallow temperature data into resource conceptual models through the examination of several case studies. Future plans extend to modeling the shallow thermal environment aiming to comprehend the geometry of outflow, magnitude of shallow thermal anomalies, and depth of detection limits.

7.0 ACKNOWLEDGEMENTS

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Supplemental Text 1: Cable 2-Meter Probe Puller

This document written by Chris Sladek and is dated 2/2/11

Introduction

This document gives a brief description and construction details of the cable 2-meter probe puller designed by the Great Basin Center for Geothermal Energy. The cable probe puller (Fig. 1) consists of a ratchet winch attached to the base of steel column. The puller cable runs over a pulley at the top of the column and is attached to the top of the probe to be pulled by an eye-nut. Over all length is approximately 6' (185cm). The puller is designed so that winch parts can be easily replaced in the field. The puller is relatively low cost, with a material cost of approximately $200, and is fairly simple to assemble.

Basic Material List

1 ea. 1000 lb. ratchet puller.

1 ea. 10' (3m) length of 1 ½" (40mm) unistrut

1 ea. 3 ½" (90mm) steel pulley block. McMaster Carr 3099T62

2 ea. Bolts and nuts to replace rivets in pulley.

1 ea. 5" x 8" to 10" (130mm x 200 to 250mm) 3/16" or 1/4" (5 to 6mm) plate steel (foot).

1 ea. 2" x 8" to 10" (200 to 250mm) 3/16 or 1/4" (5 or 6mm) strap steel for reinforcement rib on foot.

2* ea. pipe couplings.

2* ea. chain links to weld onto pipe coupling for pulling eye.

* It is recommended to make two pulling eyes, because the threaded end of the 2-meter probe may break off when pulling, and can be difficult to remove in the field.

Notes

The winch cable and spool assembly should be removed before welding, because weld splatter can burn the cable causing fraying.

The top end of the short section of the unistrut should be cut at an angle or rounded to eliminate the sharp 90^{o} corners.

Avoid over-heating the pulley and damaging the pulley bearing when welding.

I also make a wip-check by putting a unistrut roller in the channel with a nylon cord loop to go around the cable a small steel carabiner is convenient for snapping onto the cable.

Figure 1. The cable probe puller is constructed from a 1000 lb ratchet winch and 1 1/2” (40mm) unistrut, with a 3/16” (5mm) thick steel plate foot and a 3 1/2” (90mm) diameter steel pulley block on the top. A single 10’ (3m) length of unistrut is cut into a 6’ (185cm) length for the main column and a 4’ (115cm) length for a reinforcement member. Unistrut is used for the column because it is commonly available. The rolled edge of the unistrut also eliminates sharp edges. The puller is attached to the 2-meter probe with an eye nut made from a chain link and pipe coupling, and is attached to the free end of the cable.

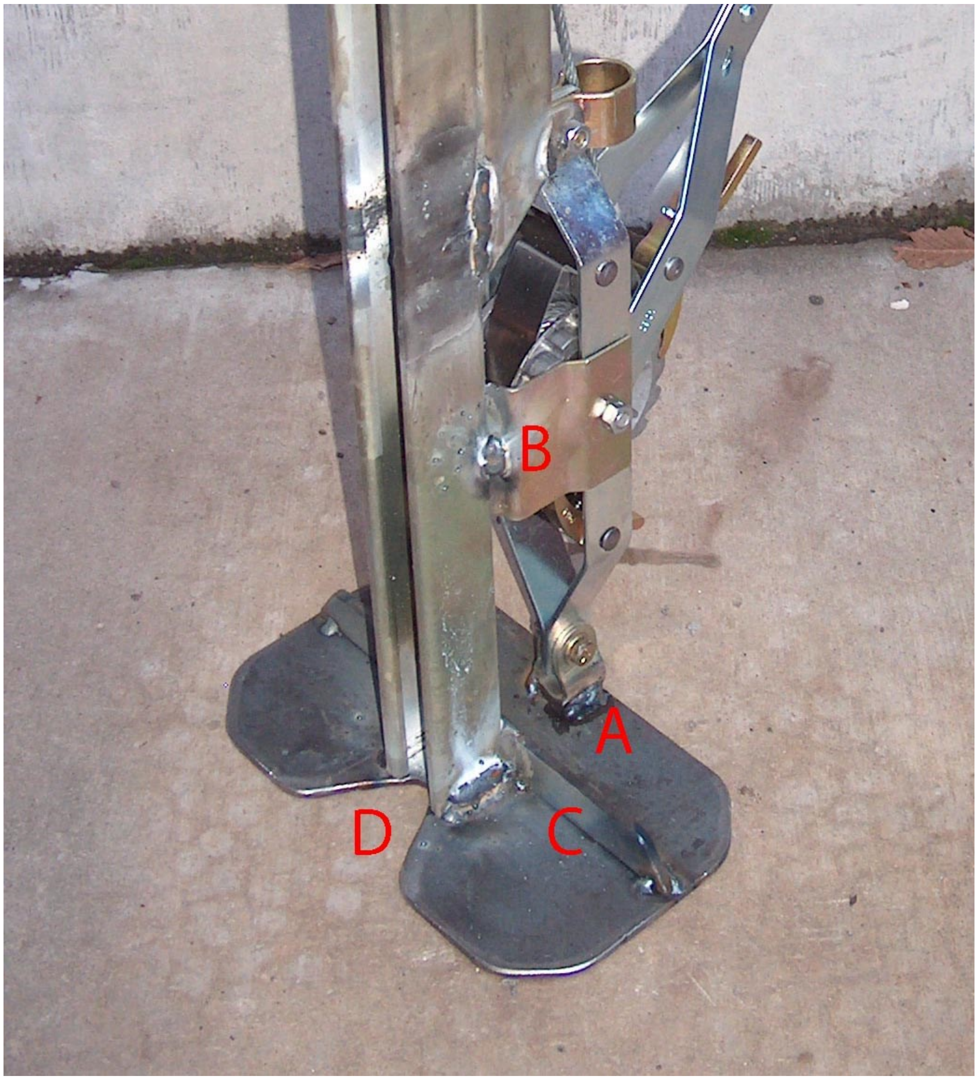

Figure 2. Foot detail. The brackets for mounting the winch (A) are made from cutting the winch hook swivels apart. The "C" shaped shell is welded to the puller frame (B) for additional stability. The foot is reinforced with a strap steel web (C). A "V" Is cut in the foot (D) to center the puller around the 2-meter probe to be pulled. Note the winch cable assembly was installed after welding.

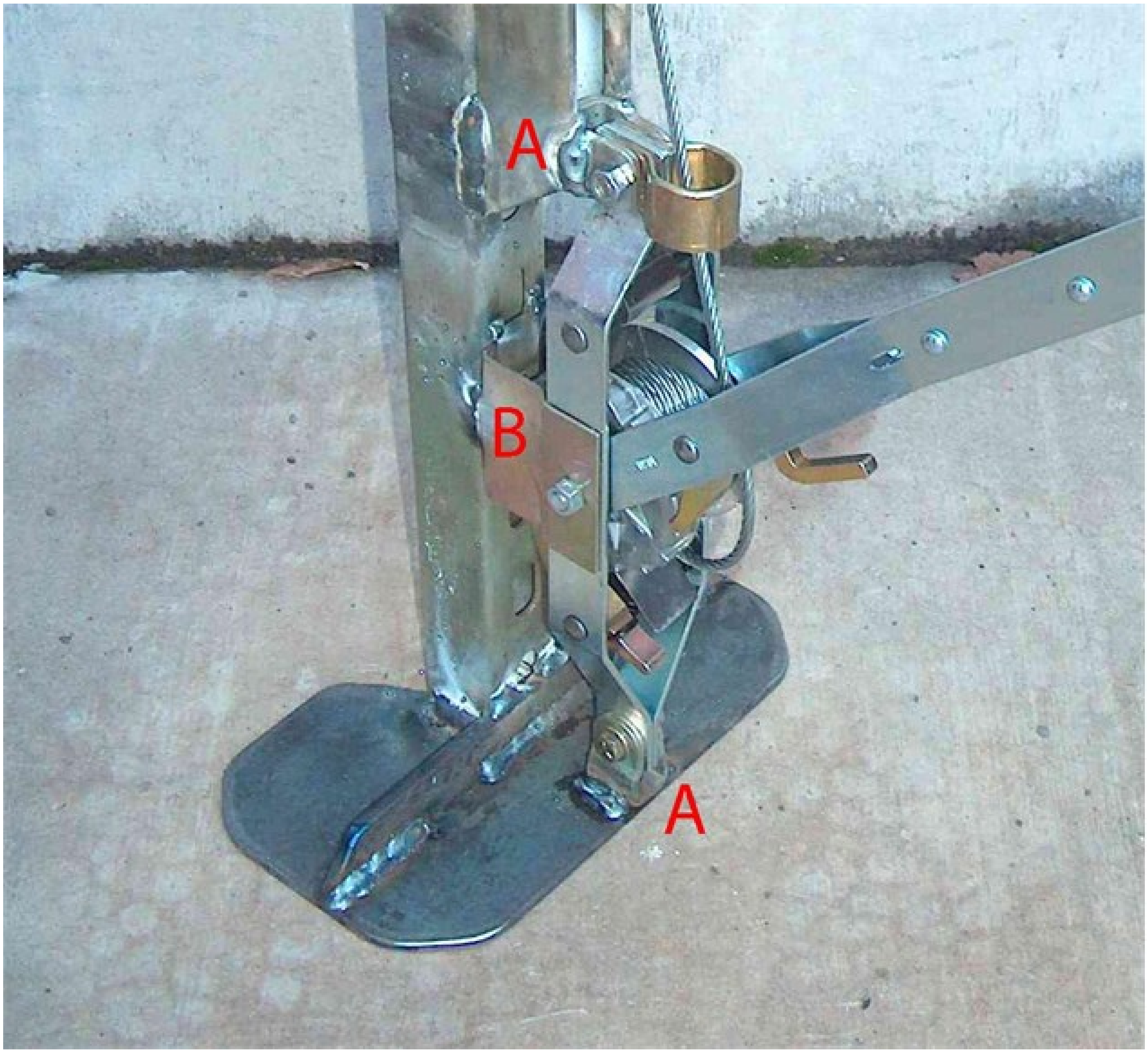

Figure 3. Foot detail showing ratchet winch attachment detail. The brackets for mounting the winch (A) are made from cutting the winch hook swivels apart. The "C" shaped shell is welded to the puller frame (B) for additional stability. <u>Note the winch cable assembly was installed after welding.</u>

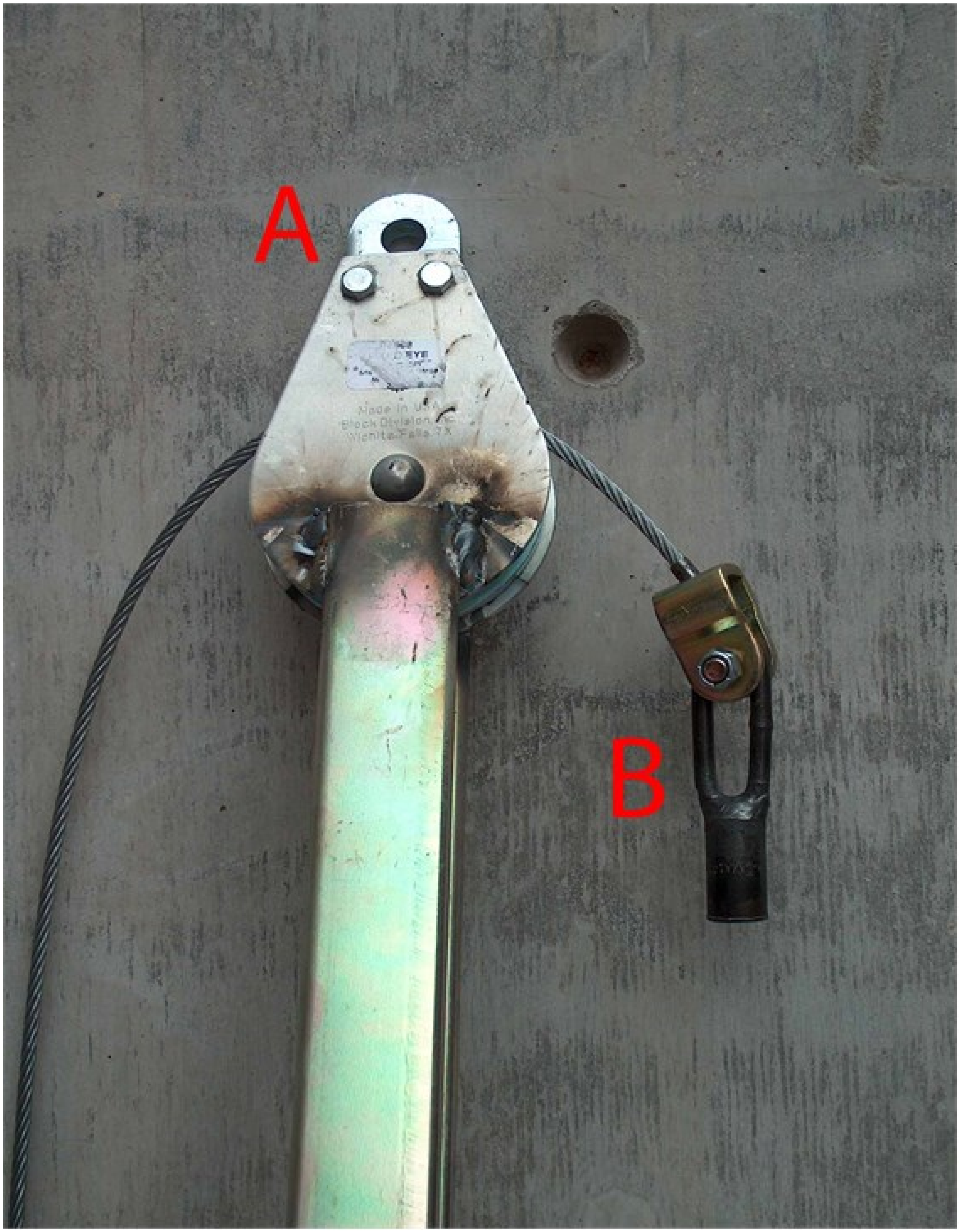

Figure 4. Pulley and pulling eye detail. The rivets for the pulley eye (A) have been replaced with bolts so that the steel plates of the eye can be removed to install the cable. B) pulling eye made from a chain link and a pipe coupling. Note a slot is cut in the unistrut to fit the pulley for attachment.

SUPPLEMENTAL TEXT 2: HIGH-LIFT JACK 2-METER PROBE PULLER

This document written by Chris Sladek and is dated 4/12/11

This document illustrates a modified high-lift jack and associated accessories used for pulling 2-meter probes. The jack featured in this document is similar to a Removal Jack sold by AMS for soil sampling. Although the AMS jack works well off the shelf some minor modifications will improve its function. These modifications are described at the end of this document.

Figure 1. Pulling a probe with a threaded eye screwed to the top of a 2-meter probe using a modified jack.

Accessory Tools and Pulling Methods

A number of off the shelf and easily built tools make pulling probes with a modified High-Lift jack more efficient. These include: a hex cap welded to a washer and a pipe coupling welded to a chain link to form an eye-nut (Fig. 2), a standard pair of 10" locking pliers and a pair of locking pliers with an extension welded to the fixed jaw (Fig. 3), and an unthreaded 2' length of ½" or ¾" pipe. Additional heavy washers are useful for distributing load on the jack toe when the 2' pipe is used or as spares to place under a hex pipe cap.

Figure 2. Left side, a hex nut welded to heavy 3/16" thick washer for load distribution on the jack fork, and right side, a pipe coupling welded to a chain link to form an eye-nut

Figure 3. Locking pliers with ½" pipe extension welded to the fixed jaw. Some probes can easily be pulled out of the ground using these pliers.

Either the hex cap and eye-nut are screwed to the top of the 2-meter probe to for basic probe pulling, as in figure 4. The locking pliers are used for pulling probes by hand or clamped onto probes with broken threads as seen in figure 5. When pulling probes by hand or with the jack twisting the probe can loosen it up and aid in pulling. The ½" or ¾" pipe is used to extend the pulling range of the jack when probes cannot be pulled by hand after the limit of the jack lift height has been reached. (Fig. 6) Figures 4 through 6 show the use of an out of production high-lift jack made from stamped steel. The AMS jack has a similar notched jack toe for removing soil sampling tools.

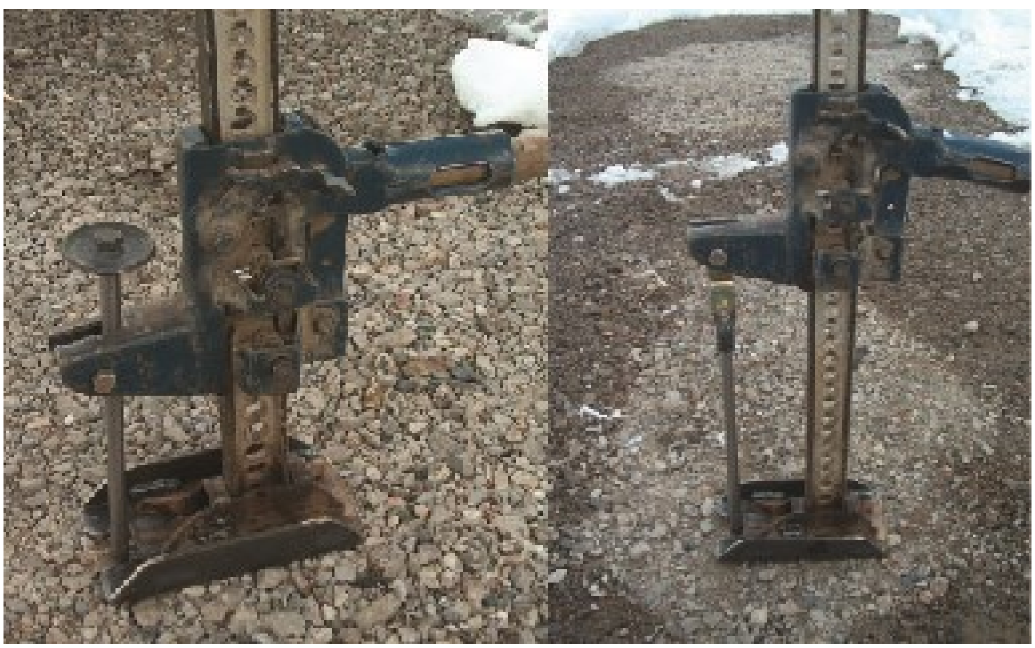

Figure 4. Standard methods of pulling a 2-meter probe showing the use of the hex nut welded to a washer (left) and (right) eye-nut linked to the jack toe. The heavy washer welded to the hex cap distributes the load on the jack toe to prevent marring of the slot in the toe and hex cap. Using the method on the left works well when the probe is far enough out of the ground to slip the slotted toe around the probe, or when the ground is soft enough to kick some dirt away to get the jack low enough to get the toe around the probe. Using the eye-nut, as seen on the right allows pulling probes with tops close to the ground without the need to dig a hole to get the jack toe around the probe. When screwing the hex cap or eye-nut onto the top of a 2-meter probe for pulling, screw the cap or eye on hand tight and then loosen it one eight to a quarter turn. This allows easy removal of the thread stub if the threaded end of the probe should break when pulling.

Figure 5. Using locking pliers to remove a probe with broken threads. A second set of pliers may sometimes be necessary when the pliers slip and gouge the probe. In some cases, it may be necessary to bend the probe over to prevent the locking pliers from slipping.

Figure 6. A 2’ length of ½” pipe slipped over a 2-meter probe to extend the range of pull after the height limit of the jack has been reached. Locking pliers can also be clamped at the base of the probe for additional pulling range or when the threaded end of the probe has been broken off, however the locking pliers can cut deep groves and leave sharp burs on a probe. Also note the “T” handle at the top of the jack column made from sections of ½” pipe and a thru-bolt. This provides a grip for a second person to stabilize the jack when removing difficult probes. The person stabilizing the jack should be alert for pinch points when the jack running gear approaches the top.

Modification of AMS Removal Jack

The following modifications will improve the function of the AMS jack for removing 2-meter probes. The foot of the jack should be welded to the jack column, and the foot should be extended slightly by welding angle iron to its base. This improves the stability when pulling probes. Holes should be drilled into the lower part of the fork to allow a pin or bolt to be inserted to prevent the probe from slipping off the fork when pulling. These two modifications are best seen on the left side of figure 4. A “T” handle made form ½” pipe bolted to the top of the jack column as seen in figure 6 provides a grip for supporting the jack when pulling. This is often needed when pulling difficult probes. A shorter, approximately 2’ jack handle should be made. This improves efficiency, because the leverage of the full-length handle is typically not required for removing most probes. Alternatively, a two-piece extendable handle can be made.

Safety

Warning the jack may have pinch points, probes may have sharp burs from locking pliers and parts may break during pulling operations. Be sure to ware safety glasses and work gloves during probe pulling operations. Make sure to have solid footing when pulling or driving probes, and be alert of obstacles in the immediate area. Breakage or bending of probes or tools can cause you to lose balance. Inspect probes especially threaded ends for cracks or bending of the threaded ends before driving probes with the impact hammer or pulling.

University of Nevada, Reno

Great Basin Center for Geothermal Energy

Shallow (2-meter) Safety Procedures and

Equipment checklist

3rd June 2022

All persons participating in 2-meter temperature surveys must receive training and be signed off as having received that training before conducting surveys. Additionally, all persons conducting 2-meter surveys must have completed the University of Nevada, Reno Defensive Driving Course.

2-meter survey training can only be provided by person(s) recognized as “instructors”. Currently, the only recognized instructors are Chris Sladek, Chris Kratt, Bridget Ayling, and Kurt Kraal.

Background

In 2006 the GBCGE began developing methods to improve the efficiency of conducting shallow temperature surveys (Coolbaugh et al. 2007, Sladek et al. 2007) with the use of an impact hammer to drive a 2-meter long, 14mm diameter probe, made from 1/4'” schedule 80 pipe, into the ground and subsequently inserting a Pt RTD to measure the temperature using a digital thermometer. This has significantly increased the efficiency of conducting shallow temperature measurements. The following standard operating procedures describe safety procedures and basic field methods.

Safety

All persons participating in 2-meter temperature surveys must receive training and be signed off as having received that training before conducting surveys. This training at a minimum will consist of the following components:

1. use of ATVs, including proper maintenance, field handling, loading/unloading from trailers, and proper storage, and limitations to their use on roads/highways,
2. proper use of trailers, including proper hook-up to vehicles, load restrictions, load distributions, proper driving procedures on and off highways, and techniques for backing up and parking,

3. use and storage of 2-meter temperature equipment in the field, including electrical safety, generator maintenance and safe use, fire hazards, and proper/safe stowage of equipment, especially while traveling.
4. proper inspection procedures immediately prior to driving with loaded equipment on the highway or use of equipment in the field.

In addition of normal safety considerations of conducting field work, conducting 2-meter temperature surveys involves the use of power tools, driving an ATV off road, and trailer towing on highway and unimproved roads. These tasks require attention to safety guidelines and safe operating procedures.

Always be aware of what is going on and be aware of where other crew members are located, especially when loading and unloading equipment. Be aware of trip hazards especially when handling equipment or entering or exiting vehicles. Do not jump out of an ATV, you may land on unstable ground.

ATV driving

The Polaris Ranger is a side-by-side 4wd ATV that seats three people. Because this vehicle is operated off road in uneven terrain, special attention must be given to safety. Sharp turns and accelerating or braking in a turn or on a hill can cause the vehicle to roll over. Avoid driving over brush with tires. Do not park on tall grass or weeds as hot exhaust and exhaust pipes can cause fires. Check that grass and debris do not build up around exhaust system.

- Wear seat belts and keep arms and legs inside the ATV.
- Bring the ATV to a complete stop before shifting between gears, or when shifting in and out of 4wd.
- Stop and put ATV in 4wd as soon as wheels spin in soft surfaces to avoid digging in.
- Avoid rapid starts, this causes excessive wear on the drive belt and clutch, leading to premature failure.
- Use low gear when traveling off dirt roads. Soft surfaces and climbing hills or over road berms in high range causes excessive wear on the drive belt. It is best to shift from high range to low range when leaving established dirt roads.
- Do not side hill on steep slopes or cross deep ditches diagonally, as this increases the potential of a roll over. Similarly, do not turn on steep slopes. Sudden acceleration when turning on a steep slope or crossing a ditch diagonally may also lead to a rollover.
- If you do not feel comfortable climbing or descending a steep slope, find an alternate route.
- If you are descending a steep slope the clutch may start to free wheel, and you will lose engine braking. A slight addition of throttle will often allow it to lock up again and regain engine braking.
- Do not drive on paved roads. If you need to drive along a paved road drive on gravel part of the shoulder.

Loading ATV on Trailer

Load or unload the ATV on the trailer only when the trailer is hitched to the tow vehicle and all safety pins and chains are in place, and the trailer jack is up and latched. Make sure the tow vehicle is in neutral and has the park brake set. Make sure all persons are clear of the trailer before driving ATV on trailer. Place ATV in low range and center it on the loading ramp and drive all the way forward to the front of the trailer. The ATV should be no more than about 3 inches off center in the trailer to ensure the trailer is loaded. If the ATV is too far off center it can cause instability when towing. Set parking brake and place transmission in neutral once ATV is properly positioned. Secure ATV with two heavy ratchet straps. One across the front of the ATV floor and attaching towards the front on the trailer side rails, and one through the roll bar loops above the seat and attached towards the rear on the trailer aide rails. Make sure that all items in the ATV and trailer are secure. Ensure there are two nylon straps around the probes and puller. **Bungee cords are to be used only for securing items in the ATV when driving it off road.** Make sure there are no items such as empty trash, empty bottles, empty coolers or pin flags that may blow out of the ATV or trailer when driving. When returning from the field and driving on unsealed roads, be sure to stop before returning to paved roads and re-check the ATV and straps: adjust and tighten if needed.

Trailer Towing

Trailer towing affects stability and performance of the tow vehicle. Braking distance is significantly increased. And acceleration is decreased. Rapid movements such as swerving to avoid an obstacle can cause loss of control more easily than driving without a trailer. Attention must be given to turning because the trailer cuts a tighter circle than the tow vehicle. You may need to swing wide to avoid curbs, posts or also, the trailer's track width is wider than the tow vehicle. Following distance should be double that of normal driving to allow for reduced braking and to allow more time to avoid hazards. It may be difficult to maintain a greater following distance in heavy traffic, so it is best to reduce speed in heavy traffic.

The following tips are from the National Highway Transportation Safety Administration, http://www.nhtsa.gov/Cars/Problems/Equipment/towing/safety_tips.htm

General Handling

- Use the driving gear that the manufacturer recommends for towing.
- Drive at moderate speeds. This will place less strain on your tow vehicle and trailer. Trailer instability (sway) is more likely to occur as speed increases.
- Avoid sudden stops and starts that can cause skidding, sliding, or jackknifing.
- Avoid sudden steering maneuvers that might create sway or undue side force on the trailer.
- Slow down when traveling over bumpy roads, railroad crossings, and ditches.
- Make wider turns at curves and corners. Because your trailer's wheels are closer to the inside of a turn than the wheels of your tow vehicle, they are more likely to hit or ride up over curbs.
- To control swaying caused by air pressure changes and wind buffeting when larger vehicles pass from either direction, release the accelerator pedal to slow down and keep a firm grip on the steering wheel.
- Keep an eye on engine temperatures, especially if climbing long hills.

Braking

- Allow considerably more distance for stopping.
- If you have an electric trailer brake controller and excessive sway occurs, activate the trailer brake controller by hand. Do not attempt to control trailer sway by applying the tow vehicle brakes; this will generally make the sway worse. (not applicable to the ATV trailer)
- Always anticipate the need to slow down. To reduce speed, shift to a lower gear and press the brakes lightly.

Acceleration and Passing

- When passing a slower vehicle or changing lanes, signal well in advance and make sure you allow extra distance to clear the vehicle before you pull back into the lane.
- Pass on level terrain with plenty of clearance. Avoid passing on steep upgrades or downgrades.
- If necessary, downshift for improved acceleration or speed maintenance.
- When passing on narrow roads, be careful not to go onto a soft shoulder. This could cause your trailer to jackknife or go out of control.

Downgrades and Upgrades

- Downshift to assist with braking on downgrades and to add power for climbing hills.
- On long downgrades, apply brakes at intervals to keep speed in check. Never leave brakes on for extended periods of time or they may overheat.
- Some tow vehicles have specifically calibrated transmission tow-modes. Be sure to use the tow-mode recommended by the manufacturer.

Backing Up

- Put your hand at the bottom of the steering wheel. To turn left, move your hand left. To turn right, move your hand right. Back up slowly. Because mirrors cannot provide all of the visibility you may need when backing up, have someone outside at the rear of the trailer to guide you, whenever possible.
- Use slight movements of the steering wheel to adjust direction. Exaggerated movements will cause greater movement of the trailer. If you have difficulty, pull forward and realign the tow vehicle and trailer and start again.

Parking

- Try to avoid parking on grades. If possible, have someone outside to guide you as you park. Once stopped, but before shifting into Park, have someone place blocks on the downhill side of the trailer wheels. Apply the parking brake, shift into Park, and then remove your foot from the brake pedal. Following this parking sequence is important to make sure your vehicle does not become locked in Park because of extra load on the transmission. For manual transmissions, apply the parking brake and then turn the vehicle off in either first or reverse gear.
- When uncoupling a trailer, place blocks at the front and rear of the trailer tires to ensure that the trailer does not roll away when the coupling is released.
- An unbalanced load may cause the tongue to suddenly rotate upward; therefore, before un-coupling, place jack stands under the rear of the trailer to prevent injury.

ATV Pre-trip and Post-trip Check List

1. Tires at recommended pressure (~10-11 psi) . Check spares as well.
2. Engine oil level ok. Spare oil onboard
3. Coolant level ok
4. First aid kit
5. PPE: safety glasses, hearing protection, gloves.
6. Fire extinguisher
7. Shovel
7. Lug wrench.
8. Jack.
9. Tire repair kit.
10. Air compressor.
11. 10 mm socket and handle.
12. Spare drive belt.
13. Fuel (gas can) – fill up on way to the field; ensure leftovers are emptied into either buggy, generator, or tow vehicle when storing ATV.
14. 2M probes secured with 2 nylon ratchet straps while towing ATV (no bungees) Several bungee cords onboard for field operations
15. ATV clear of any items that may blow out for towing. (pin flags, empty containers and coolers).
16. ATV hood is secured with the two rubber latches (to avoid hood blowing up and off the buggy during freeway driving)
17. Check below the ATV and clean up any remaining plants/branches (fire hazard)

Turn on ATV to make sure it starts, reverses, and ride it a bit to make sure it works

Tow Vehicle and Trailer Check List

1. Tow vehicle first aid kit.
2. Trailer license plate.
3. Tire pressure checked: tow vehicle and trailer and spares. Trailer psi should be around 45 psi
4. 4-way lug nut wrench for trailer wheels is onboard
5. Wheel lug nuts are tight, tow vehicle and trailer.
6. Trailer axle and springs look ok.
7. Trailer height, loaded: Trailer is level front and rear. If not, select proper height trailer ball mount. If trailer has potential to drag in the front or rear and tow vehicle hitch cannot be adjusted, use a different tow vehicle.
8. Hitch pins and latches. Latched and safety pins in.
9. Safety chains hooked, crisscrossed, and loose and clear of dragging.
10. Trailer lights operating, and cable loose and clear of dragging.
11. ATV secure in trailer with two ratchet straps, brake set, transmission in neutral.
12. Items in trailer and ATV secure.
13. Trailer gate latch pins are closed.

2-meter Equipment Pre-trip and Post-trip Check List

1. 2M probes and caps.
2. Make inventory of bad and good 2M probes, and communicate it back to the team
3. Generator. Make sure it turns on and runs.
4. Spare fuel for generator
5. WD-40
6. Oil for generator
7. Impact hammer, and ground rod driver.
8. Vice grips.
9. 11/16 open end wrench or adjustable wrench.
10. Probe puller.
11. Bungee cords for securing probes and puller (only to be used when driving the buggy off-road)
12. Temperature sensors and Meter.
13. Spare AAA and AA batteries for meter and GPS.
14. GPS.
15. Flags