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A Web-Based Resource for Investigating Environmental Change: The Emigrant Pass Observatory

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ABSTRACT

We present a user-friendly, data-driven Web site (http://thermal.gg.utah.edu/facilities/epo/) for a geothermal, climate change observatory that is educational for the general public, students, and researchers alike. The Emigrant Pass Observatory (EPO), located in the Grouse Creek Mountains in northwestern Utah, gathers both meteorological data (solar radiation, air temperature, rainfall, wind speed and direction, and snow depth) and subsurface temperatures in shallow drillholes. Our website has three main functions: (1) it provides a tutorial for understanding both local climate and climate change, and their relation to diffusion of temperatures into the Earth's subsurface; (2) it facilitates user-defined accessibility to download available climate data; and (3) it contains lesson ideas for using real data to understand local climate. EPO data and resources are ideal for active learning projects. Additionally, our collaboration with ongoing outreach projects (e.g., NSF-sponsored GK–12) in Utah promote the use and understanding of climate change data among students and educators, thus filling a valuable niche in local education. © *2012 National Association of Geoscience Teachers*. [DOI: 10.5408/11-252.1]

Key Words: climate change observatory, subsurface temperatures, data-driven Web site, active learning projects

INTRODUCTION

The surface temperature of our planet has increased on average by nearly one degree Celsius over the last century, with much of the warming occurring since 1975 (Smith and Reynolds, 2005, Brohan et al., 2006, Hansen et al., 2010). The fourth, and most recent, assessment of the Intergovernmental Panel on Climate Change (IPCC; 2007) showed that the only way to explain the temperature increase is via anthropogenic causes. Although there is still lingering debate among the public and policymakers over the cause of climate change (e.g., Newell and Pitman, 2010), when past and future temperature change is put into perspective (Chapman and Davis, 2010), there can remain little doubt about its anthropogenic origin.

As Newell and Pitman (2010) point out, part of the uncertainty among non-scientists over the reality of global warming has psychological underpinnings related to how people make decisions. An additional contribution to this uncertainty can be traced to deficiencies in science education as has been reported on by several studies authored by scientific (American Association for the Advancement of Science, 1990; National Research Council, 2011) and government (National Science Foundation, 1996) bodies. A key issue in all of these studies is that "hands-on" or active learning is an important aspect of science literacy. Using and analyzing real data is one way of providing students with an active learning environment (e.g., Hays et al., 2000).

This commentary follows an assertion by Martin and Howell (2001) that science should be "minds-on." Minds-on science involves a student's exploration of a scientific question, as opposed to focusing on the answer. This investigation of the question requires students "to analyze large sets of real data, to evaluate the data critically, to observe patterns and anomalies, to make inferences and predictions based on the data, to interpret the data, and to form testable hypotheses to explain their observations" (Martin and Howell, 2001, p. 158).

To be able to accomplish minds-on project learning, it is necessary to have access to both the relevant tools and datasets required to satisfy the project objectives (Roberts et al., 2010). The use of such tools in science education is becoming more commonplace throughout the educational system (Underwood et al., 2008), and online data use in the classroom has been shown to enhance student satisfaction and learning (Brey, 2000). One of the key issues is knowing where to find such data.

The Emigrant Pass Observatory (http://thermal.gg.utah.edu/facilities/epo/) provides a way of understanding how climate change is studied and offers real research data that can be obtained easily through an online interface. This commentary describes the operations of the EPO, the data products that are available, and potential lesson ideas that can be used by interested educators for students in learning about climate processes and change.

EMIGRANT PASS OBSERVATORY

The Emigrant Pass Observatory (EPO) is located at the southern end of the Grouse Creek Mountains of northwestern Utah (Fig. 1). It was established in 1993 next to a 150-m deep borehole GC-1 as part of a climate change observatory that would allow concurrent monitoring of both meteorological conditions (such as air temperature, solar radiation, snow, and rainfall) and subsurface temperatures (Putnam and Chapman, 1996). The station ran continually through 2004, with minor operational setbacks due to battery, data storage, and instrument failures (Bartlett et al., 2006). A major upgrade of the station near the end of 2004 allowed telemetry of daily observations at EPO (Bartlett et al., 2006), and near 100% data recovery.

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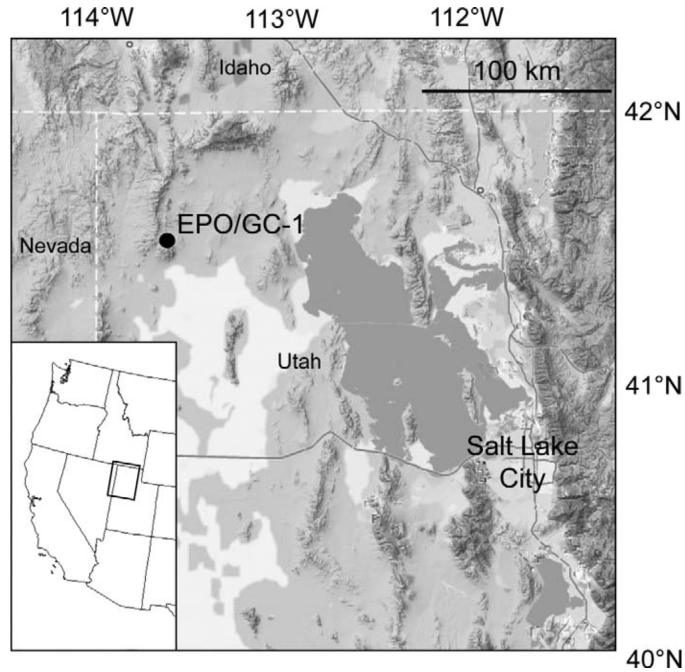

FIGURE 1: Map of northwestern Utah, USA, showing the Emigrant Pass Observatory (modified from Davis et al., 2010).

The borehole and weather station are located on a granitic outcrop in the midst of a sparsely vegetated area of piñon pine and juniper (Fig. 2). The topography is generally flat with a gentle slope to the northeast. These factors aid in making this desert environment an ideal location for such an observatory.

The instruments at EPO include a solar powered Campbell Scientific CR-10 data logger that controls a collection of meteorological instruments (air temperature, solar radiation, precipitation, snow depth, wind speed, and wind direction) and several shallow thermistor strings designed to measure temperature in the granite outcrop and nearby soil (Fig. 2). The data logger interrogates the sensors every 60 seconds and stores 30-minute averages.

USE OF EPO AND BOREHOLES TO STUDY CLIMATE

Boreholes, long used to investigate heat flowing out of the Earth through measurements of temperature with depth, are also an important source of information of changing temperatures at the surface of the Earth. Changing surface temperatures diffuse into the subsurface, as described by the one-dimensional heat diffusion equation,

$$\frac{\partial T(z,t)}{\partial t} = \alpha \frac{\partial^2 T(z,t)}{\partial z^2}, \quad (1)$$

where T is temperature, z is depth, t is time, and α is thermal diffusivity. Because it is a diffusive process, there is both an attenuation of the temperature amplitude and a phase lag (Fig. 3) in the ground temperatures. Figure 3 shows a simplified annual sinusoidal surface temperature wave (Fig. 3, solid line $z = 0$ m) with a mean temperature of $\sim$10°C and an amplitude of 20°C. At a depth of 1 m (Fig. 3, dashed line), the amplitude of the temperature wave is 73% of the surface amplitude, and the peaks and troughs occur 18 d later than at the surface. At a depth of 5 m (Fig. 3, dotted line) the amplitude is further attenuated to 41% of the surface amplitude, and the peak occurs 91 d after the surface peak. Also noteworthy in this simplified model, the surface temperature is below freezing for 121 d, whereas at 1 m the temperature is below freezing for only 94 d. The ground at 5 m depth never freezes, with a minimum temperature of 5.9°C. This attenuation property allows one to avoid freezing water pipes by burying the pipes to a particular depth.

The process of diffusing surface temperature into the subsurface can be used to examine changing surface air temperature (SAT) over periods of years, decades and centuries. Changes in SAT (and hence, surface ground temperatures) produce transient departures from the background, steady-state thermal regime measured in boreholes. Figure 4 illustrates a hypothetical, fluctuating SAT plotted with the mean as zero (Fig. 4a). Beginning in 1900, this imaginary SAT has a warming trend of nearly 20 y before slowly cooling for the next 40 y. Following this overall cooling trend is approximately 40 y of warming until the record ends in 2000. If one were to measure the ground temperatures in a borehole at three distinct times (1956, 1976, and 1998; indicated by triangles, Fig. 4a), the resulting borehole temperature-depth profiles would be affected by the fluctuating SAT. In the absence of a changing surface temperature, the constant, background thermal gradient (Fig. 4b, heavy solid line) facilitates heat flowing steadily out of the Earth and would be drawn to show the surface temperature intercept equal to the mean surface temperature. However, as the SAT changes (remembering that in this case it warms, cools, and warms again), a transient temperature anomaly is recorded in the subsurface temperature measurements that are different from the background thermal profile (Fig. 4b). In our example, the initial borehole temperature measurements are made in 1956. The resultant temperature-depth profile (Fig. 4b, dotted line) is cooler than the background thermal gradient to a depth of approximately 50 m, due to the borehole temperatures being measured after nearly 40 y of SAT cooling. Returning to the borehole after 20 y, measured ground temperatures show that the anomaly from the cool temperatures has continued to diffuse into the subsurface, with temperatures cooler than the background geotherm extending to around 75 m (Fig. 4b, thin solid line). However, the SAT has begun warming during this 20 y period, so the upper portion of the borehole is now warming, with the uppermost temperatures being greater than the background thermal profile (Fig. 4b, thin solid line). With continued warming over the next two decades, a final borehole temperature-depth profile would show the transient anomaly to be warmer than the background temperature-depth profile (Fig. 4b, dash-dot line) down to a depth of about 45 m. Below this depth, the earlier cooling trend measured previously still affects the borehole temperatures, as temperatures below 50 m are slightly cooler than background. These cooler temperatures extend to below 100 m depth, although they are strongly reduced due to the diffusive nature of this process as described by Eq. 1.

Because the transient temperature component is often small (the cool temperatures extending to below 100 m in the third temperature-depth profile, for example), it is

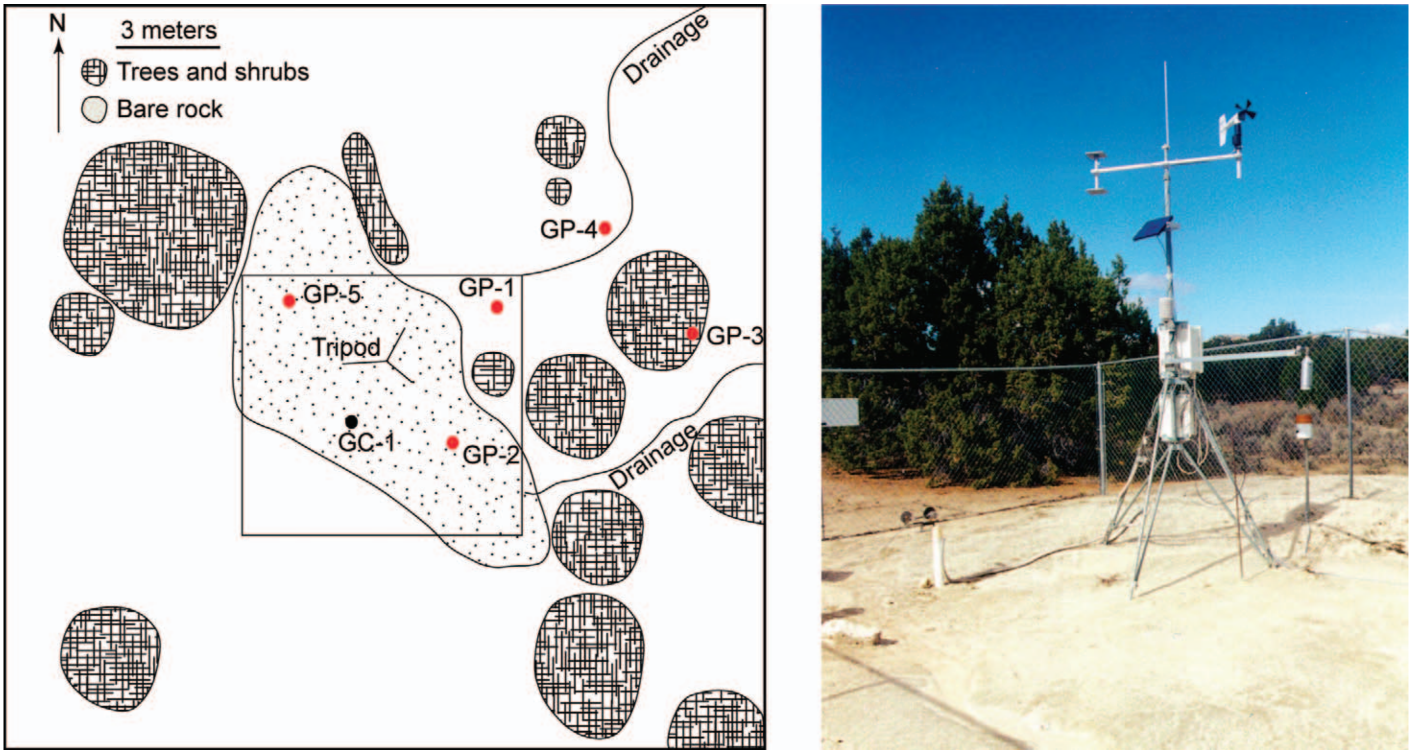

FIGURE 2: The Emigrant Pass geothermal climate change observatory EPO. (Left) Cartoon map view of EPO with locations of the ground temperature probes (GP1-5), the borehole GC-1, and surrounding vegetation. (Right) Image of EPO looking towards the large piñon pine on the northwest of the enclosure.

convenient to remove the background thermal gradient and present the transient anomaly as reduced temperature (Fig. 4c) with an expanded temperature scale. This transform allows one to isolate the transient anomaly and make comparisons with the steady state case. In our example, the effects of cooling extend the entire depth of the borehole by the final borehole temperature log (Fig. 4c, dash-dot line). In practice, instrument precision and geologic noise limit detection of small signals and it would be difficult to see the entire anomaly. However, the larger the anomaly, the deeper it can be identified, such that surface temperature reconstructions for the past 100 y can be found in the upper 150 m of the Earth, and surface temperature change in the past millennium can be made from temperatures measured in 500 m deep boreholes. For further information see Davis et al. (2011) and references therein.

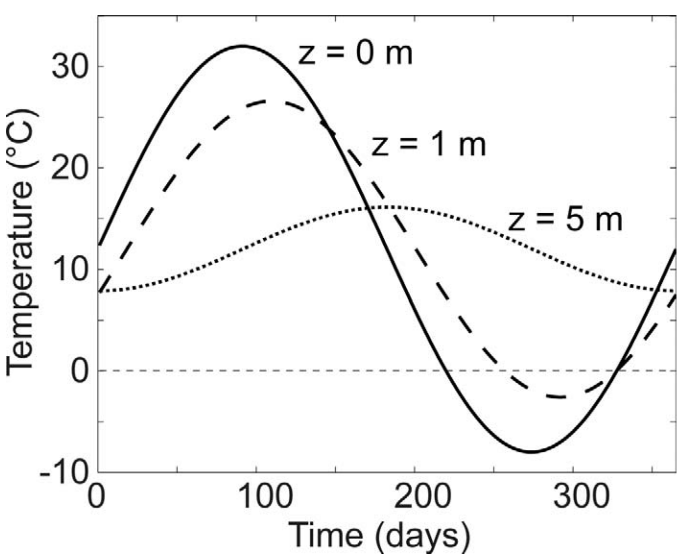

FIGURE 3: Diffusion of a sinusoidal annual surface temperature wave into the subsurface. Note the phase lag and attenuation of the surface temperature. See text for details.

When multiple borehole temperature-depth profiles are available, it is most informative to examine the temperature changes between logs by differencing them relative to the initial log (Fig. 4d). Differencing allows one to identify transient temperatures and eliminate perturbations in a temperature profile not related to climate. A convincing case for climate reconstruction can be made when air temperature changes are modeled and produce good fits to the changes seen in the differenced temperature. For further information see Davis et al. (2010).

Monitoring of meteorological variables, in addition to temperature, are important to understanding coupling between ground and air temperatures. Snow, for example, insulates the ground from the very cold conditions in the air, resulting in the ground being warmer than would be expected. On the other hand, site conditions like excessive vegetation or shade, in association with incoming solar irradiance, can result in cooler ground temperatures. A site such as EPO where changing conditions are continually monitored allows us to connect ground and air temperatures, particularly in an effort to investigate past climate changes.

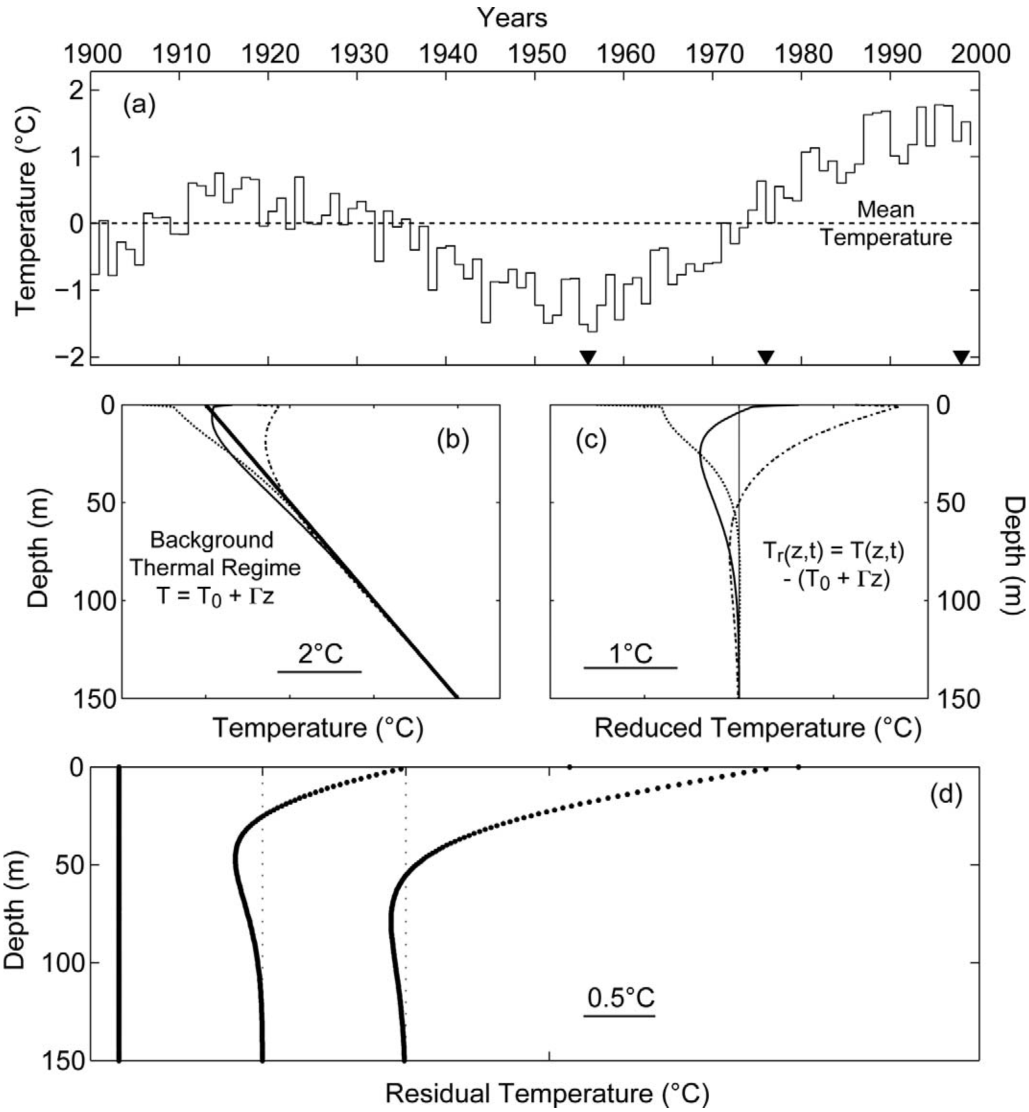

FIGURE 4: Basic aspects of using borehole temperatures to understand surface temperature change. (a) A 100-year record of SAT plotted with the mean temperature as zero. Borehole temperatures are measured at three distinct times as indicated by triangles. (b) Temperature-depth profiles at these three times shown with respect to the background thermal gradient (solid line). (c) Reduced temperature profiles with the background thermal gradient removed. (d) Temperature differences with respect to the initial temperature log (modified from Davis et al., 2011).

DATA PRODUCTS

The Emigrant Pass Observatory Web site allows specific downloading of climate parameters measured at the site. Individual sensors and time periods can be selected for downloading (Table I). With simple text files as output, the Web site allows for easy use in data analysis packages such as Matlab or Microsoft Excel (Fig. 5). Figure 5, for example, shows meteorological variables and ground temperature measured at EPO during one annual cycle starting in January 2007. The surface air temperature (SAT; Fig. 5a) clearly shows the seasonal variation but also fluctuates with shorter periods indicating cold and hot spells. Air temperature at the EPO site in Utah varies by 50°C during the year, from a low of −15 to a maximum of 35°C. Ground temperatures can be seen to follow the SAT, with similar patterns of temperature change throughout the year, especially for the shallow measurements, but are warmer than air temperatures in the summer months. The attenuation and the phase lag of the ground temperatures that are described by Eq. 1 are more apparent in the deeper measurements. The amplitude of the temperature fluctuation at 1 m is greatly subdued not only annually, but high frequency variation is not seen at shorter time scales. There is also a notable lag in the time of peak SAT and peak ground temperature at 1 m.

Other available data include precipitation in the form of both rain (Fig. 5b) and snow (Fig. 5c), as well as solar insolation (Fig. 5d). Precipitation at EPO is very low, with small rain events throughout the year (Fig. 5b). The majority of the precipitation comes in the form of snow, with some years having little snow (e.g., 2006–2007) and others having considerably more (e.g., 2007–2008; Fig. 5c). Solar radiation at the site varies throughout the year (Fig. 5d) and is the primary driver of temperatures recorded at EPO (Putnam and Chapman, 1996; Bartlett et al., 2006).

TABLE I: Available sensors at EPO (modified from Bartlett et al., 2006).

Measured[1] parameter	Precision[2]	Installation[3]
Air temperature	0.05 K	2 m above granite
Solar radiation	0.1 Wm^{-2}	Incident
Rainfall	0.1 mm	1-m mast height
Snow depth	1.0 mm	Sonar "pinger"
Wind speed	0.04 m s^{-1}	3-m mast height
Wind direction	5.0°	3-m mast height
Wind variability	5.0°	3-m mast height
Ground temperature	0.01 K	0.025, 0.1, 0.2, 0.5, 1.0 m

[1]Meteorological variable measured at EPO.
[2]Precision of individual instruments and data at EPO.
[3]Location (height or depth) of instruments at EPO.

A closer examination of the SAT and the ground temperatures is shown in Fig. 6. Over the course of one week, the SAT has a daily variation of greater than 10°C and is highly variable throughout the day. The shallowest ground temperature at 2.5 cm depth follows the general trend seen in the SAT, but with an obvious time lag. The ground temperature at 2.5 cm also is much warmer at its peak than the SAT. This observation can be directly related to the heating the granite surface at EPO receives from the incoming solar radiation (Putnam and Chapman, 1996). Also notable is the attenuation of the ground temperatures with depth when compared with the SAT (Fig. 6).

LESSON IDEAS

Depending on the grade level of the students (K–12, undergraduate, graduate), as well as the objective of the lesson or class, it may be necessary to introduce some basic principles (e.g., how the sun affects climate) prior to using the EPO data. However, it may also be useful to just "jump in" and begin examining the data. For many students, seeing and using real scientific data can lead to greater interest (Brey, 2000), so the jump in approach can be effective. Alternatively, we suggest performing a pretest that examines a student's prior knowledge and understanding. This can be an excellent springboard to determine the direction to proceed (e.g., Martin and Howell, 2001). In such a pretest, students can first be asked to sketch a plot of how air temperature changes over a given period of time. A good starting point is looking at the daily variation of temperature, as most students should be able to identify roughly the rise and fall of temperature that occurs over the course of a day. After discussing the student responses, a consideration and discussion of measured EPO air temperature is warranted. For example, the air temperature plotted in Fig. 6 illustrates the warming of the air through the day, followed by cooling into the evening and night. However, the warming and cooling of the air temperature does not smoothly increase and decrease, but instead shows higher frequency fluctuations throughout the day. Inspection of other parameters such as solar radiation, wind, and precipitation could then elucidate what may be happening to cause the uneven rise and fall of air temperature. Is there a storm passing? Is it cloud cover? Examining this phenomenon gives students the minds-on experience of working with and analyzing real-world data.

A second lesson could involve investigating how the ground temperatures change over time (Fig. 6). A pretest procedure that asks students to sketch how ground temperatures would change with respect to air temperature might lead to a discussion on how hot the ground gets (e.g., a comparison of asphalt versus grass) and why this occurs (albedo effects). After this discussion, an examination of the ground temperatures would yield minds-on questions such as, why does the ground temperature change lag the air temperature change, and why do the ground temperatures have smooth variations with time. Further inquiry of the ground temperature data during and after the winter snow and an observation that ground cleared of snow freezes "hard," while ground covered by snow rarely freezes can also lead to excellent discussion and opportunities for inquiry-based learning.

In both cases discussed, data from EPO serves as a basis for understanding how changes at the surface affect the ground beneath our feet. This consideration provides an additional element for understanding climate and environmental change, as much climate related data is limited to surface meteorological data only.

OUTREACH

The rich resource of climate information from the northwestern Utah EPO creates a potential for science outreach. One way we are promoting the use of our Web site is with ongoing National Science Foundation-sponsored GK–12 outreach projects in Utah. These projects promote the use of scientific data in the classroom through inquiry-based learning by placing University of Utah science graduate students in contact with elementary, middle, and high school students and educators in the Salt Lake City School District. Through weekly meetings, graduate students are introduced to the EPO website and the various learning activities that are available. After presenting lessons in K–12 classrooms, these graduate students provide feedback and assessment that will help to improve the offerings of the website.

SUMMARY

The Emigrant Pass Observatory in northwest Utah offers near–real-time climate data that can easily be accessed for

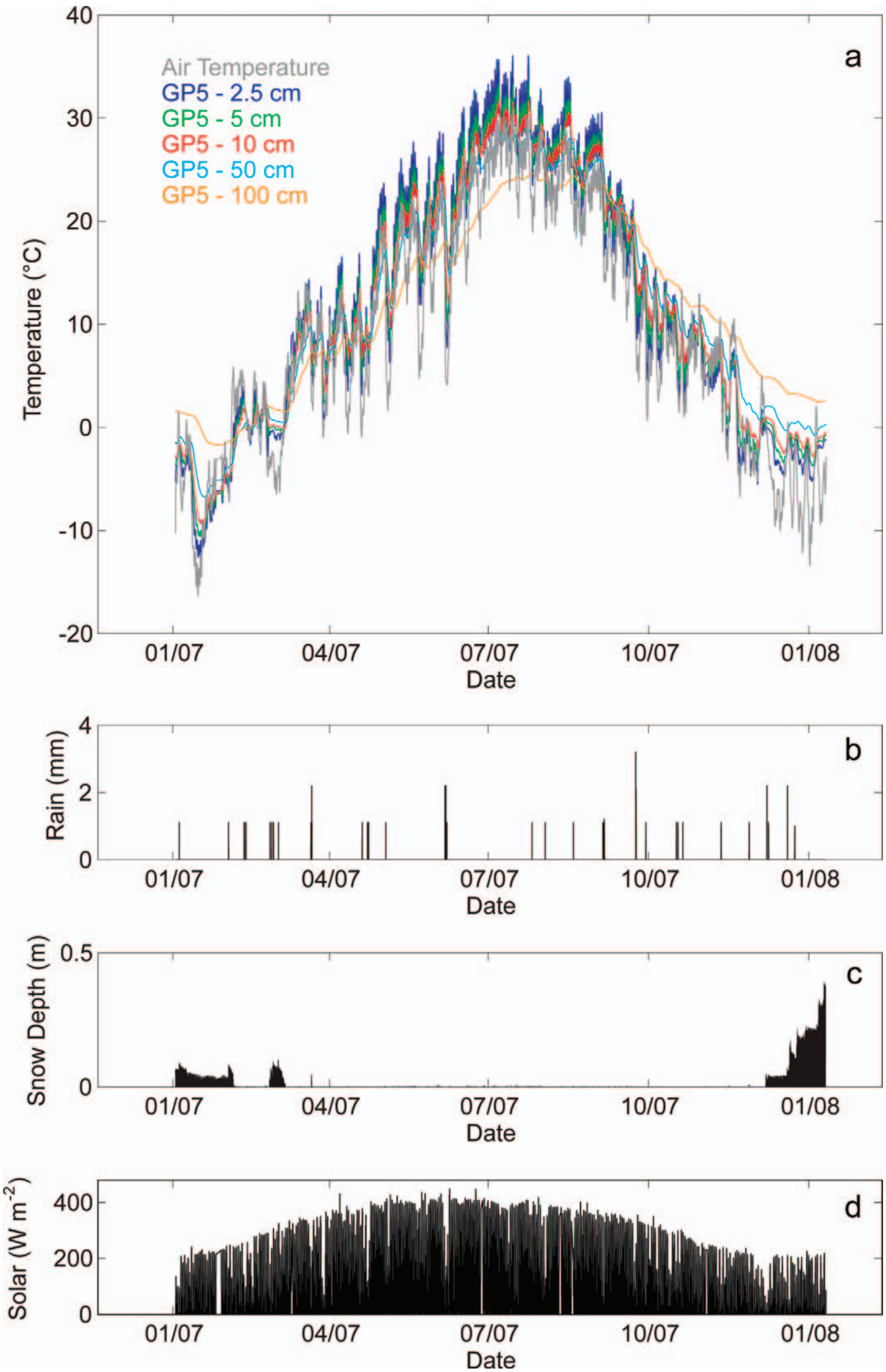

FIGURE 5: Meteorological variables and ground temperatures at EPO for the year 2007. (a) Daily air and ground temperatures. Note the tracking of air temperature by the ground temperature. (b) Annual rainfall (75 mm). (c) Snow depth. The 2007–2008 winter was an exceptional snow year. (d) Solar insolation.

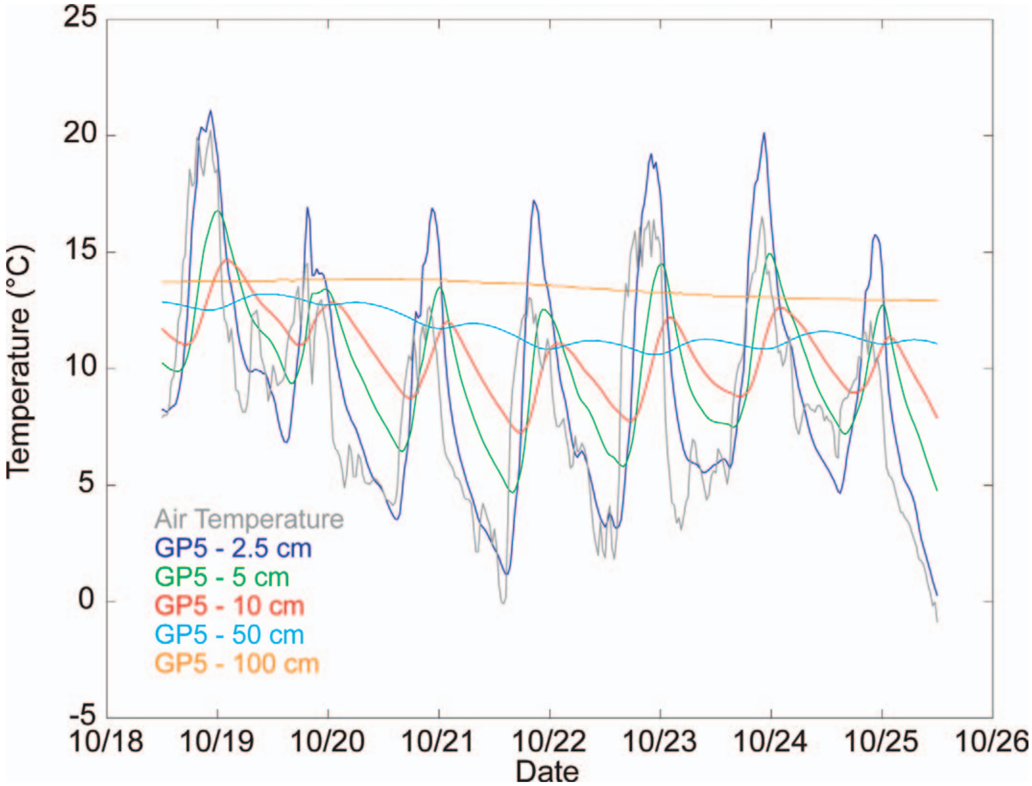

FIGURE 6: Air and ground temperatures at EPO over the course of one week in October of 2009. The phase lag and attenuation of the air temperature is clearly seen in the subsurface temperatures.

minds-on, inquiry-based learning. Available data include air and ground temperatures, precipitation, wind speed and direction, and solar radiation. These data can be easily accessed at the Emigrant Pass Observatory Web site (http://thermal.gg.utah.edu/facilities/epo/). We suggest using a pretest of a student's knowledge and understanding of physical processes as a springboard to jump in and examine the EPO data, thus investigating the process as opposed to finding an answer.

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