Simulation and Validation of Seasonal Soil Temperature Variations Using COMSOL Multiphysics^{È} Software

Matel, Larry J, P.E., Green Streets Infrastructure LLC, 34626 SE Swenson Drive #H108, Snoqualmie, Washington 98065, ljm@greenstreetsinfrastructure.com

Abstract: The influence of the energy (heat) stored in the earth as a major factor in environmental soil processes is recognized by the soil science community. The heat (energy) supplied by the earth is known to fluctuate with depth below ground surface and time of year, obviously as a function of solar radiation variations through the seasons. The variation of energy available to drive evaporation can be represented by soil temperature. This paper presents a case example of the use of COMSOL Multiphysics in simulating and validating this earth science application.

Keywords: soil, temperature, variations, solar, radiation

1. Introduction

The influence of the energy (heat) stored in the earth as a major factor in environmental soil processes is recognized by the soil science community. The heat (energy) supplied by the earth is known to fluctuate with depth below ground surface and time of year, obviously as a function of solar radiation variations through the seasons. The variation of energy available to drive evaporation can be represented by soil temperature. Seasonal soil temperature variation as reported by Hillel (2004) has been shown to follow a wave or sinusoidal function of the form:

$T = T_0 + A \sin(wt)$ where:

T = Temperature at a given time and location

T_0 = Index temperature for a given location

A = Constant determined for a given location

w = Periodic frequency factor

t = Time variable from beginning of period.

A more robust version of the above concept can be represented through the heat transfer equation available in COMSOL Multiphysics. This equation is of the form:

$$\rho C_P dT/dt + \rho C_P U \cdot \nabla T - \nabla \cdot (k \nabla T) = Q$$

Where

- ρ = density of material
- C_P = specific heat capacity at constant pressure
- T = absolute temperature in degrees Kelvin
- t = time
- ∇ = the differential(gradient) operator
- k = thermal conductivity
- Q = heat transfer

With this concept in mind, one can conceptualize a “wave” of heat (energy) passing though the near depths of the ground surface throughout the year. This “wave” of energy ultimately drives environmental soil processes.

2. Methodology and Data

Below ground soil temperature data was acquired from temperature probes placed in a standard piezometer tube at a location in the City of Bremerton, Washington in the Puget Sound region. A 10 foot long piezometer, 2 inches in diameter, was placed near latitude 47.5805N and longitude 122.6203W, and elevation 200 feet above sea level. Hoboware temperature and barometric pressure recording devices were suspended in the tube at depths of .5 feet and 10 feet below the ground surface.

The instruments collected and stored temperature and barometric pressure information every 2 to 5 hours. Information collected by the probes was downloaded monthly during the period of December 2010 to July 2011. Data collection was discontinued short of the planned twelve month collection period due to resource limitations.

At the end of the data collection period the temperature data was post processed to develop a data set reflective of a constant period between observations of one hour. Figure 1 displays the time series temperature information collected for the 217 day period.

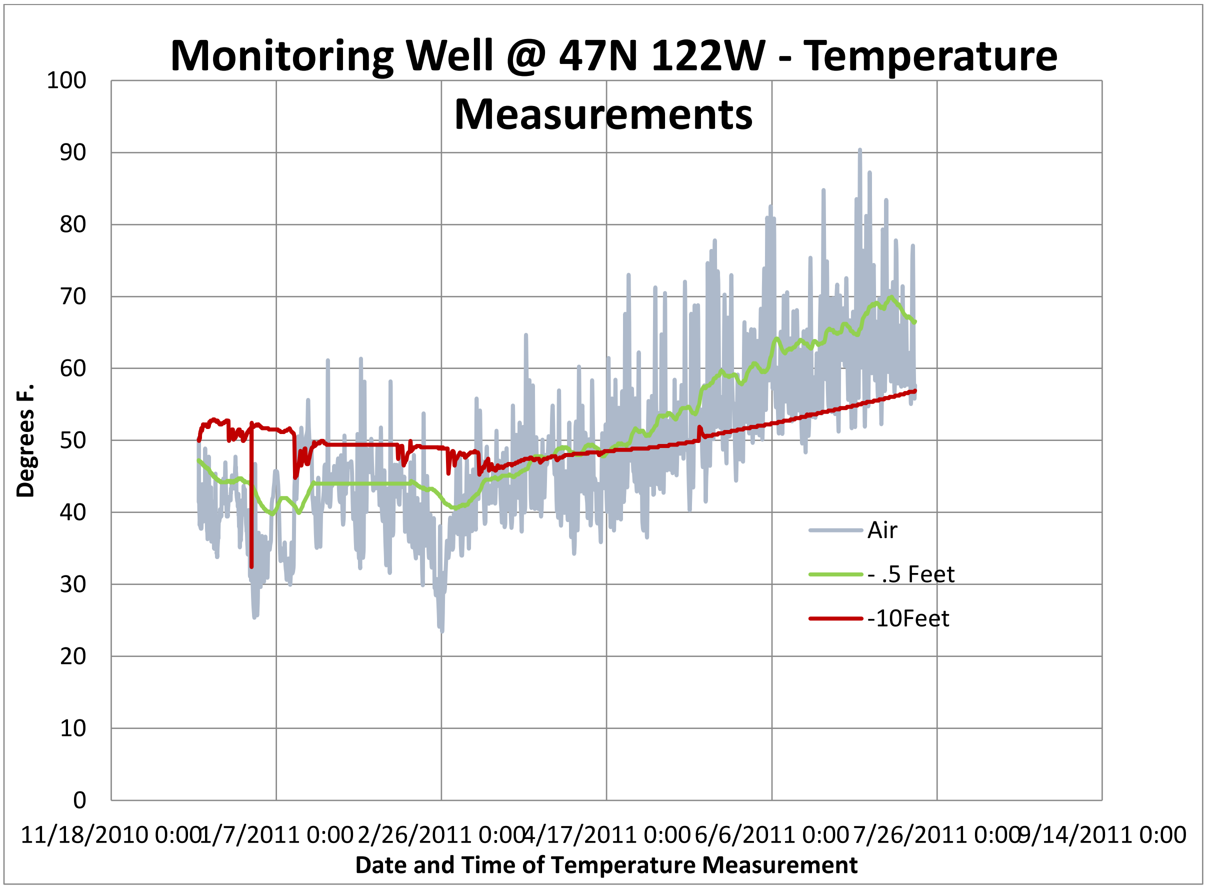

Figure 1. Actual Soil Temperature Variations

3. Analysis and Results

Figure 1 displays the measurements of above ground air temperature and underlying ground temperatures at .5 feet and 10 feet below the ground surface at the referenced monitoring well. From Figure 1 one can see the difference in temperature variability between just below the ground surface and at the ten feet deep level through the year. Note the soil temperature stability of the probe placed at the ten foot depth. The minor peaking at the -10 feet level is estimated to be a result of either intrusion into the piezometer of water or due to removal and replacement of the probes for data downloading.

Temperature measurements at the .5 foot depth appear to correlate to the variability of the ambient above ground air temperature. The figure does illustrate the stabilizing factor of the ground at depths as shallow as .5 feet below the earth surface.

The collection of this temperature data provided the opportunity to validate simulation modeling of earth temperature fluctuations. Temperature fluctuations in the ground and the piezometer at this location were simulated using the Heat Transfer in Solids Interface available in COMSOL.

Two temperature regimes are illustrated by Figure 1 that govern the physics of the simulations. The probe at .5 feet below the ground surface in the well tube is probably dominated by heat transfer in a fluid with temperature, density of air, heat conductance and heat capacity of air affecting the temperature recorded by the probe as this point.

Conversely, the probe at the 10 feet deep level is dominated by heat transfer in a solid with the density of soil, moisture content, thermal conductance and heat capacity of the soil affecting the temperature recorded by the probe at this point. While the probe is suspended in the void of the well tube, the overwhelming thermal mass of the earth surrounding the tube at this point undoubtedly influences the temperature in the tube at this point.

Based on these considerations it was concluded that the Heat Transfer in Solids Interface could provide a reasonable basis for simulation. Ambient air temperatures would be used for the top boundary temperature condition.

Parameters used in the simulation include the following:

Solar Radiation. Input into the simulation included solar radiation data for the Seattle, Washington area obtained from a National Oceanographic and Atmospheric Administration report by Geotz and Nicholas (1979). Figure 2 presents a graph of the solar radiation data used in the simulations presented here.

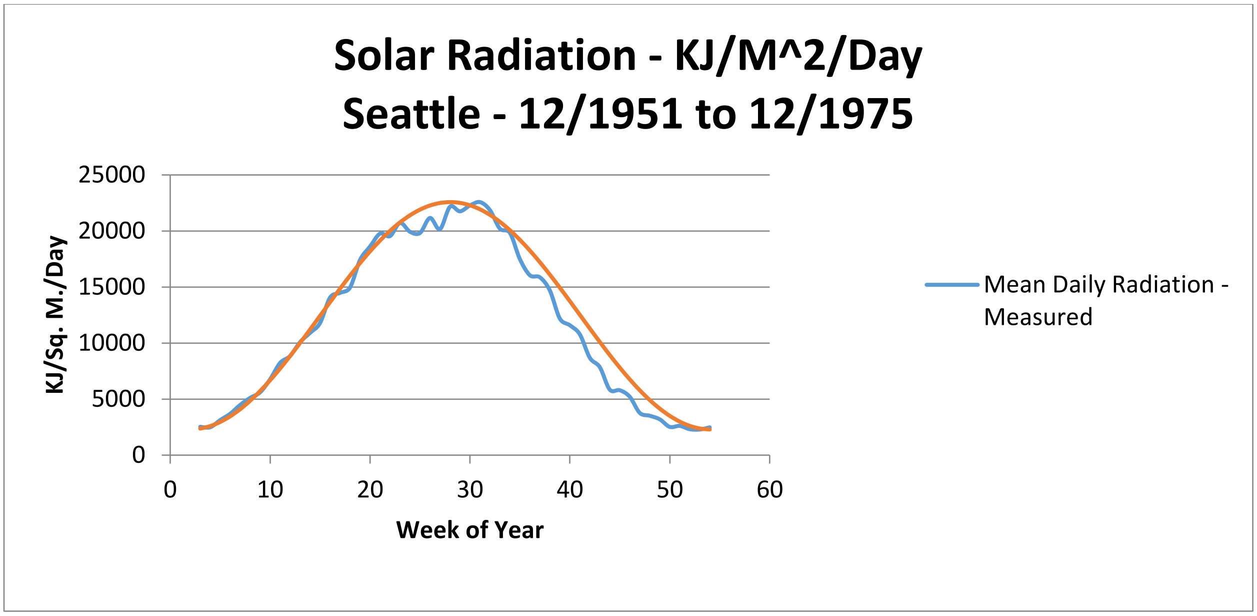

Figure 2. Solar Radiation Data

Ambient Air Temperature. Hourly ambient air temperature was obtained by Hoboware temperature and barometric pressure recording devices situated within one-quarter mile of the monitoring well site.

Determination of the thermal properties of soil can be a rigorous process because of the nature of dependence of soil parameters on such things as mineral and organic content, grain size and shape distribution, moisture content, void ratio, and temperature. Farouki (1981) presents a comprehensive work on this topic that served as the primary basis for values used in this paper.

Because of the wide variability of these soil parameters and the difficulty in determining their in-situ values they lend themselves to being used as the "calibration" parameters for the simulation process presented here. The methodology used in the simulation started with average or typical values which were then adjusted in an attempt to more closely match the simulated soil temperatures with the actual measured values.

Heat capacity and conductivity values for various soil types can be readily obtained from a number of published sources. A value of 600 Joules/ (Cubic Meter-Degree Kelvin) combined with a value of 1.5 Joules/ (Kilogram-Degree Kelvin) produced the simulation results presented here. Both values are in reasonable agreement with values reported in the literature. A density value of 1,660 Kilograms/Cubic Meter was used for the soil.

Figure 3 presents the results of the simulation. Figure 3 indicates a temperature stability that closely agrees with that of the recorded temperatures at the ten feet deep level in the well that are displayed in Figure 1.

Figure 3 also presents the results of simulating the temperature at the top of the monitoring well. This figure indicates a temperature variation that closely follows that of the recorded ambient air temperature above the ground near the well site.

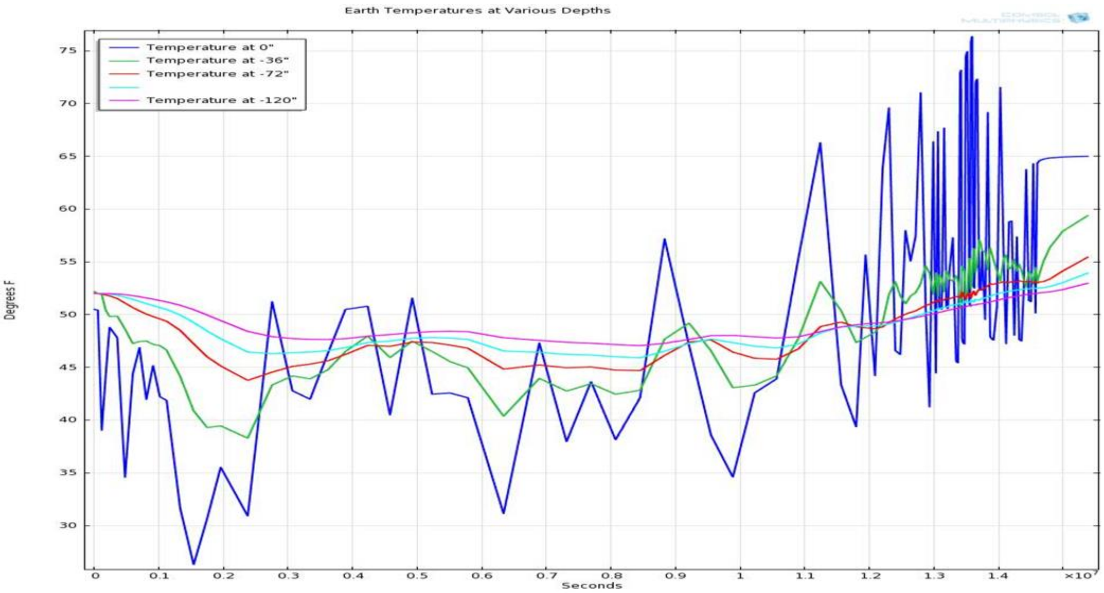

Figure 3. Simulated Temperatures at Various Depths vs. Time

Finally, Figure 3 displays the variations of ground temperature at various times and depths that were simulated.

4. Conclusions

The data that was collected over the limited time period is consistent with principles reported by others and follows the "sine wave" pattern. It is reasonable to conclude that the procedure and simulation information presented here can be used, as a minimum, for further investigation and analysis of soil physics and soil temperature simulations.

5. References

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