Assignment 2
GEOG 321 / Knox
Winter 2024

Soil thermal properties and dynamics

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Preamble: On the website you will be provided with one day of soil measurements from a climate station (the actual day is selected based on your student number, please read instructions on webpage):

https://geog321.github.io/assignment2/

The data-set consists of 15-min averages of the following variables: four soil temperatures (T_1, T_2, T_3, and T_4) measured at depths of 5 cm, 10 cm, 20 cm and 50 cm, respectively, soil heat flux density Q_G from a soil heat flux plate installed at a depth of 7.5 cm, soil volumetric water content θ_w measured using TDR at -7.5 cm, net all-wave radiation Q^* measured 2 m above the surface, and sensible heat flux density in the atmosphere Q_H measured 2m above the surface. Use this data-set to answer all the questions.

The soil at the climate station has been analyzed in the lab and the following values were determined: porosity is $P = 0.57$, bulk density of the dry soil is $\rho_s = 1.13$ Mg m^{-3}. The soil organic mass fraction was determined 3.77 % (of total dry soil mass). Assume that those values apply to the entire vertical profile.

Instructions: Please return your answers including all calculations, graphs and discussions in a well-structured report (either word or PDF). Note that if you knit an html file, please go to 'print', then 'Save as PDF'. Label the report document with your name, your student number, the course and year. Upload your answers to myCourses by Wednesday, February 22, 2024, 11:59 pm. Marks are indicated in square brackets. In total there are 50 marks.

1. Calculate the net warming/cooling of the soil over the 24 hours separately for the 5 cm, 10 cm, 20 cm and the 50 cm depth (i.e. the temperature change from midnight to midnight). Speculate what causes the warming or cooling. [3]

2. Calculate the daily average soil temperature for each of the four depths where temperatures are provided (T_1 to T_4). Using those, determine the direction of the daily total Q_G in the soil layers from 5 - 10 cm, 10 - 20 cm and 20 - 50 cm ? † [3]

3. Calculate the daily total of Q_G at 7.5 cm depth in $\mathrm{MJ\,m^{-2}\,day^{-1}}$ using the measured values from the soil heat flux plate. Compare the direction of Q_G to the direction of the heat flux obtained for the 5 -10 cm layer in question 2. † [4]

4. Find a method to estimate the thermal conductivity of the soil k at noon that day. Is k constant throughout the day? [4]

5. Find a method to estimate the phase-shift between the temperature wave at 5 cm and 10 cm depth. Using the phase-shift and your estimated k in Question 4, calculate the soil's heat capacity C assuming sinusoidal soil temperature waves. [4]

6. Calculate the heat capacity C of the soil using the lab analysis results (see introduction text) and measured soil water content θ_w. Does your value obtained agree with C calculated based on the phase-shift in Question 5? Why or why not? [6]

   For subsequent calculations, use C from your answer to question (6), and not C from your answer to question (5).

7. With C from question 6, calculate the depths where you expect the amplitude of the diurnal and yearly waves to drop below 5% of the amplitude of the sinusoidal surface temperature wave. [5]

8. The soil heat flux density Q_G is not measured at the surface, but rather at 7.5 cm depth. Using $\Delta T_1/\Delta t$ as a surrogate for the average warming / cooling rates in the whole layer from 0 to 7.5 cm, correct the soil heat flux density and find the value at the surface $Q_{G(0)}$ at 10:00 and at 19:00. [5]

9. Predict the time of the maximum temperature at 20 and 50 cm based on the timing of the maximum at 5 cm. Do the times predicted agree with the observed maxima? What could explain any differences? [4]

10. Calculate the thermal admittance of the atmosphere μ_a at noon. [3]

11. The Bowen ratio β describes the ratio between the sensible and latent heat flux densities directed into the atmosphere, i.e. $\beta = Q_H/Q_E$. Calculate β from the available data for noon that day. Neglect the energy use for photosynthesis. [4]

To answer questions marked by a † it is highly recommended to use a computer / graph software or R (or other programming language including Excel). See the course web-page for help documents on how to use the most common graph software (e.g. Excel) or R. However, if you decide to not use a computer, it is appropriate to consider only the values at each full hour (i.e. 00:00, 01:00, 02:00 etc.) and manually calculate results / draw the graphs using this reduced data-set of 24 values.