University of Massachusetts Boston – Department of Environmental, Earth, and Ocean Sciences

EEOS 383 - GISCIENCE FOR WATER RESOURCES RESEARCH – Spring 2010

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Exercise 08: Using the Bowen Ratio to Estimate Evaporation

Introduction

In the first half of this course, the exercises were designed to familiarize you with approaches to characterizing the movement of water near the surface based upon topographic information. In the second half of this course, we will focus on remote sensing approaches that use the response of vegetation to infer surface moisture condition in space and time.

In upcoming exercises, we will use a combination of ArcGIS with Microsoft Excel to work with remotely sensed data in the raster GRID format to obtain surface moisture information. However, before we get there, we will first do an introductory exercise that serves two functions: First, this exercise will introduce you to the use Microsoft Excel to perform simple spreadsheet-based calculations. And second, this will be a chance to work with the energy balance/Bowen ratio based approach to estimating evaporation: Our future exercises will all rest on the theoretical notion that detecting surface moisture condition by remote sensing can be accomplished by gaining a sense of the energy partitioning between the latent and sensible heat fluxes in vegetated locations. This exercise will reinforce just what that means, and how we can work with these concepts.

Data

This exercise will use the following dataset:

- hourlyevap.xls – Hourly micrometeorological data in an Excel spreadsheet

Micrometeorological data were measured on July 17, 1995 using instruments mounted on a floating deck at the center of a small pond within the Peace-Athabasca Delta, northern Alberta (58°46'N, 111°W) (see Figures below). Air temperature, relative humidity, and wind speed were measured at 0.5 m and 1.5 m above the water surface. Net radiation (all wave) was measured at 0.9 m above the water surface and water temperature was measured near the mid-depth. The pond has a radius of about 150 m and a maximum depth of 1.2 m. The surrounding levees are forested.

Special thanks go to Dr. Daniel L. Peters, Water-Climate Impact Research Centre, Environment Canada, for collecting, formatting, and providing this dataset.

Procedure and Questions

Calculating the Bowen Ratio

- Begin by copying the required Excel spreadsheet from the course data directory to your H:\ space. You will be modifying and saving the spreadsheet, so it will be necessary to work on your own copy. Open your own copy of the hourlyevap.xls.
- Recall the formula that defines the Bowen ratio:

$$\beta = \frac{H_S}{LE} = \gamma \cdot \frac{\Delta T}{\Delta e}$$

  The Bowen ratio (symbolized by lowercase beta, β) is the ratio of sensible heat (H_S) to latent heat (LE), or the ratio of the difference in temperature (ΔT) to the difference in vapor pressure (Δe), multiplied by the psychrometric constant (symbolized by lowercase gamma, γ). The dataset spreadsheet provides hourly observations of temperature and vapor pressure and two levels, along with hourly values of the psychrometric constant; everything you need to calculate an hourly Bowen ratio.
- First, calculate the hourly ΔT values. Fill in cell E11 with the required formula, in this case =D11-C11 (that is, $\Delta T = T_1 - T_2$). Then, you may copy the result from cell E11 to cells E12 through E34; Excel will automatically copy the formula properly in this case to all the other cells.
- Now, calculate the hourly Δe values. You should be able to use the same method as described above for ΔT (by typing an appropriate expression in for cell H11, and then copying it to cells H12 through H34), moved over to the appropriate cells in the H column (where $\Delta e = e_1 - e_2$).
- You now have everything you need to calculate the Bowen ratio on an hourly basis using the values in columns E, H, and I. You should be able to come up with the appropriate expression to fill in for cell J11 by looking at the equation for the Bowen ratio (remember $\beta = \gamma * \Delta T / \Delta e$, so simply substitute the cells where each of these quantities are stored to figure out the expression). As usual, copy the result from J11 to J12 through J34 to do the calculations for the remaining 23 hours of the day.
- We can also calculate the mean values for ΔT, Δe, and β by using Excel's AVERAGE function. In cell E36, enter the expression =AVERAGE(E11:E34) to obtain the mean of all the hourly temperature differences. Do the same for the vapor pressure differences and Bowen ratio values in cells H36 and J36 (if you use copy to do this, be sure to format cell H36 to contain 5 decimal places).

Question 1 – What are the mean values of hourly ΔT, Δe, and β from July 17, 1995 on the pond? To show your work here, also hand in a printout of the left half of the spreadsheet (columns A through J, rows 1 through 36).

Question 2 – How does the Bowen ratio vary throughout the day? To supplement your descriptive answer, create and hand in a plot of the hourly Bowen ratio values versus time (use a line plot with markers displayed at each data value, make sure the hour is on the x-axis, the Bowen ratio values on the y-axis, with both axes properly labelled, and that the plot includes a title that is descriptive and appropriate).

Calculating Latent and Sensible Heat Fluxes

- Now that we have calculated the Bowen ratio, we can use those values in conjunction with observations of net radiation (R_N) and calculated values of the change in energy storage inside the pond (H_G, calculated for you using the change in mean water temperature over the hour, the mean water depth, and the heat capacity of water, C_w = 4,190,000 J m^{-3} °C^{-1}) to come up with estimates of the latent and sensible heat fluxes.
- Recall how we can rewrite the net radiation balance equation in terms of latent heat:

$$R_N = H_S + LE + H_G$$
$$R_N = (\beta * LE) + LE + H_G$$
$$LE = (R_N - H_G) / (1 + \beta)$$

  We make use of the Bowen ratio to help us deal with the fact that the sensible heat flux is difficult to measure, thus we can use β to express H_S in terms of LE. In this fashion, if we have R_N, H_G, and β, we can calculate LE. Use this final equation to figure out an Excel expression that will allow you to calculate LE, using it in cell P11 and copying it to cells P12 through P34.

- Once you have calculated values for LE in column P, it is straightforward to rearrange and use the first equation shown above to calculate HS. As usual, enter the proper expression for cell Q11, and copy it to cells Q12 through Q34.
- Calculate the mean latent and sensible heat fluxes using the methods you employed to find the mean values for other columns previously.

Question 3 – *Over the 24 hr period, is the net radiation predominantly used to heat the air, warm the water body or to evaporate water (**Hint: To answer this question, you will need to compare the mean values of hourly R_N, H_G, LE, and H_S from July 17, 1995 on the pond**)? To show your work here, also hand in a printout of the right half of the spreadsheet (columns K through S, rows 1 through 36).*

Question 4 – *Why is the net radiation positive during the day and negative during the night (**Hint: Think about the difference between conditions during the day and night**)?*

Question 5 – *Why is the latent heat flux positive all day long / what does this mean? To supplement your descriptive answer, create and hand in a plot of the hourly fluxes (R_N, H_G, LE, and H_S) versus time (use a line plot with markers displayed at each data value, make sure the hour is on the x-axis, the flux values on the y-axis, with both axes properly labelled, and that the plot includes a legend to distinguish the various flux series and a title that is descriptive and appropriate).*

Calculating Evaporation

- Once we have calculated LE, it is easy to calculate the quantity of water evaporated (assuming no water limitation and sufficient mixing of air, which we shall). Recall that LE and the amount of water evaporated are related by the latent heat of vaporization (λ_V), which is generally about 2.45 million joules per kilogram (or millimetre of depth, assuming water has a density of 1000 kilograms per cubic meter), although this varies by temperature, and specific values for each hour of our data are given in column K. Specifically, LE divided by λ_V gives evaporated water, but remember that the LE flux is expressed in Wm^{-2}, and a watt is a joule per second, thus to calculate the quantity of millimetres of evaporation per hour you would need to use LE / λ_V * 3600 seconds per hour.
- Use the aforementioned equation to create an appropriate expression to calculate hourly evaporation, entering it in cell S11 and copying it to cells S12 through S34.
- Calculate the total evaporation throughout the day by summing the values in the S column. This can be accomplished by using Excel's SUM function, entering the expression =SUM(S11:S34) in cell S36.

Question 6 – What is the total amount of evaporation in millimetres from the pond on July 17, 1995?