Assignment 4
GEOG 321 / Knox

Convective Energy and Mass Fluxes

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Preamble: On Canvas you will be provided with one day of eddy covariance and profile data over a peat bog. Data has been measured on UBC's flux tower in Burns Bog, Delta, BC[1]. The actual day is selected based on your student number (please follow instructions on webpage):

https://geog321.github.io/assignment4/

The data-set includes half-hourly values of the following variables: absolute temperature $\overline{T}$ at 0.4 m and 2 m above ground, mean horizontal wind $\overline{u}$ at 0.4 and 2 m above ground, net allwave radiation Q^* at 5 m above ground, and measured covariances $\overline{u'w'}$, $\overline{w'T'}$, $\overline{w'\rho_v'}$, $\overline{u'\rho_{\mathrm{CO_2}}'}$ and $\overline{u'\rho_{\mathrm{CH_4}}'}$, all measured at 2 m above ground using an eddy covariance system. Here u and w are horizontal and vertical wind, respectively, T is temperature, ρ_v is absolute humidity (in $\mathrm{g\,m^{-3}}$), $\rho_{\mathrm{CO_2}}$ is the molar density of the greenhouse gas carbon dioxide (in $\mu\mathrm{mol\,m^{-3}}$) and $\rho_{\mathrm{CH_4}}$ is the molar density of the greenhouse gas methane (in $\mu\mathrm{mol\,m^{-3}}$).
For your calculations, you might need to look-up appropriate values in the Appendix Tables of T. R. Oke, 'Boundary Layer Climates' (for temperature-dependent parameters select nearest value)[2].

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, April 9, 2024, 11:59 pm. Marks are indicated in square brackets. In total there are 50 marks.

[1] You can read more about UBC's research at Burns Bog under https://www.biogeosciences.net/14/2799/2017/bg-14-2799-2017.pdf, and you can see pictures of the set-up under https://www.flickr.com/photos/188943790@N03/sets/72157714757894551/

[2] An electronic version of this Appendix is available on Canvas

1. The eddy covariance system in Burns Bog measured u, v, w, T, ρ_v, $\rho_{\mathrm{CO_2}}$, and $\rho_{\mathrm{CH_4}}$. How many different covariances can you theoretically form from this set of 7 variables? List those. [4]

2. From the data-set provided on the web-page, calculate Q_H at 01:00 and 16:00 from the covariance $\overline{w'T'}$. Hint: You can program this and the next formula in the spread-sheet and repeat it for the entire day - the diurnal course of Q_H and Q_E will be needed in question 7. Alternatively you can calculate these values using R. [4]

3. Calculate Q_E at 16:00 from $\overline{w'\rho_v'}$. [2]

4. Calculate the Bowen ratio at 16:00. [2]

5. Calculate the daily total evapotranspiration E in mm day^{-1}. [2]

6. If all energy from Q^* during daytime (for simplicity assume 6:30-18:00) would be put into Q_E, i.e. vapourizing water, what would the total evapotranspiration be in mm over this day (assume zero E during rest of day, i.e. night)? You can use a fixed $L_v = 2.453\mathrm{MJ\,kg^{-1}}$ for this estimation. How does this estimation compare to you answer in Question 5? [4]

7. Create a graph with time of day on the x-axis and the three measured flux densities of the surface energy balance (Q^*, Q_H, Q_E) on the y-axis. Briefly discuss their diurnal course (point-form is adequate). [4]

8. For 16:00, Calculate Q_H based on the aerodynamic method using the simultaneously measured profiles of $\overline{u}$ and $\overline{T}$. How does the value of Q_H compare to Q_H in your answer to question 2? Why could it differ? [4]

9. Using the covariances and the profile measurements, calculate the eddy diffusivities for sensible heat K_H and momentum K_M at 16:00. Is Reynold's analogy fulfilled or not at 16:00? [4]

10. For 16:00, calculate Rf. What is the stability regime you find under those conditions? [4]

11. For 16:00, calculate the Obukhov-length L and the stability parameter $\zeta = z/L$. Does ζ qualitatively agree with Rf? Is $\zeta = z/L$ really indicating 'neutral' as assumed in Question 8? [4]

12. In the process of photosynthesis, energy is extracted from photons in the PAR range. To assimilate one mole of CO_2, it requires an energy of 469 kJ. The same amount is released back during respiration (metabolism, decomposition of organic matter). We call this energy flux density the *net biochemical energy storage* ΔQ_P. Calculate ΔQ_P at 13:00 in $\mathrm{W\,m^{-2}}$. At 13:00, what fraction of Q^* is used up in the process of photosynthesis? Is ΔQ_P a relevant term in the surface energy balance of this bog or not? [4]

13. Determine the average carbon dioxide (CO_2) flux density between the bog and the atmosphere for this day and convert it to $\mathrm{g\,CO_2\,m^{-2}\,day^{-1}}$. Is the surface a net sink or net source for atmospheric CO_2? [2]

14. Determine the average methane (CH_4) flux density between the bog and the atmosphere for this day and convert it to $\mathrm{g\,CH_4\,m^{-2}\,day^{-1}}$. Is the bog a net sink or net source for atmospheric CH_4? [2]

15. To compare the warming potential of different greenhouse gases, we use the metric of *global warming potential* (GWP). The GWP of methane over 100 year is 28 kg CO_2 per kg of CH_4. This means that emitting 1 kg methane into the atmosphere has the same warming potential over 100 year as emitting 28 kg carbon dioxide. Considering the GWP of methane, determine the combined effect of both, carbon dioxide and methane fluxes during your selected day. Do the combined greenhouse gas fluxes from the bog during your day contribute to climate warming, or do they sequester greenhouse gases? (Hint: Multiply the mass flux of methane from question 14 times the GWP of 28 kg $\mathrm{kg^{-1}}$ to retrieve the carbon dioxide equivalent. Then compare the carbon dioxide equivalent flux to that of carbon dioxide in question 13). [4]