GEOG:4470 Ecological Climatology
Lab 6: Photosynthesis
Due: 5:00 p.m. on Friday April 17, 2020

Goals:
- Continue practicing programming in R.
- Calculate photosynthesis of Duke Forest using the Farquhar model.
- Think about assumptions and uncertainties in modeling photosynthesis.

Hints:
- Follow best practices for creating graphs (units, labels, etc.), *even if you are not explicitly told to do some in the question*.
- Don't forget units!
- Include an informative legend on all graphs.
- When in doubt, check (and copy-paste-modify) your code from previous labs!

Inputs:
- Outputs from previous labs
- Photosynthetically active radiation (Par), air temperature (Ta), soil moisture (Tdr), and vapor pressure deficit (Vpd)

0. Load the data and ecological model

Double-click your Labs.Rproj file to open RStudio and begin where we left off after Lab 5. Download Lab6_Dannenberg.R from ICON, and save it to your Labs folder, replacing my last name with your last name.

Open Lab6_<your lastname>.R in RStudio. Run all lines through line 77. Once this is done, we can pick up where we left off.

In this lab, we will use two of the same functions from eco_model.R that we used in Lab 5:

- `compute_psn_parameters()`: computes parameters necessary for the Farquhar photosynthesis model (V_{cmax}, CO_2 compensation point, dark respiration, etc.)
- `compute_bwb_farq_psn()`: solve the Farquhar and Ball-Berry system of equations for photosynthesis (A) and stomatal conductance (g_s)

1. Photosynthesis.

Calculate photosynthesis for sunlit and shaded leaves by running lines 82-100. This solves a system of equations with two unknowns: photosynthetic rate (A) and stomatal conductance for CO_2 (g_c). We solve this system of equations for both the electron-transport and Rubisco-limited rates of photosynthesis (A_j and A_v, respectively), and then calculate net photosynthesis (A_n) as the minimum of these rates minus "dark" (i.e., mitochondrial) respiration, scaled by LAI of sunlit and shaded leaves (line 100).

Make a time series of photosynthetic rate (μmol CO_2 m^{-2} s^{-1}) for sunlit and shaded leaves (`psn_sunlit` and `psn_shaded`, respectively) on the same graph. Describe the temporal (diurnal to seasonal) variation of photosynthesis. Based on your understanding from class and the

Bonan textbook, do these patterns make sense? What do you think are the major meteorological factors that drive the temporal patterns that you observe in the photosynthesis time series?

2. Light and photosynthesis.
Now make three scatterplots showing the relationships between photosynthetically active radiation (PAR) on the x-axis and photosynthesis on the y-axis:

- Canopy net photosynthesis (`Anet`) vs. incoming PAR (`dat$Par`)
- Photosynthesis of sunlit leaves (`psn_sunlit`) vs. absorbed PAR by sunlit leaves (`canopy_shortwave$sunlit_apar`)
- Photosynthesis of shaded leaves (`psn_shaded`) vs. absorbed PAR by shaded leaves (`canopy_shortwave$shaded_apar`)

Describe how photosynthesis relates to incoming light. Based on these relationships, if you wanted to develop a simplified photosynthesis model, what could you do? What would you need to know and what assumptions would you need to make?

3. Compare modeled and "observed" photosynthesis.
Load in the observed[1] fluxes (`GppLeHMay2001-Daytime.txt`) using Line 103.

Similar to question 3 of Lab 5, make a scatterplot of "observed" GPP (x-axis) vs. our modeled total Anet (y-axis), both in μmol CO_2 m^{-2} s^{-1}. How well did our model do? What assumptions or uncertainties do you think led to mismatch between the model and the observations?

4. CO_2 fertilization.
In this lab so far, and in all previous labs, we have been using a CO_2 concentration of 410 ppm (roughly corresponding to current levels). But what happens to photosynthesis with different CO_2 levels? Using our model, we will run a simple experiment with five different CO_2 concentrations:

- 280 ppm (roughly corresponding to pre-industrial levels)
- 400 ppm (roughly corresponding to current levels)
- 560 ppm (double pre-industrial levels, roughly similar to RCP4.5 at 2100 CE)
- 800 ppm (double current levels, roughly similar to RCP6.0 at 2100 CE)
- 1120 ppm (quadruple current levels, roughly similar to RCP8.5 at 2100 CE)

While we will vary the CO_2 concentrations, we will keep all other variables constant: temperature will be set at 25°C, absorbed PAR will be set at its maximum observed value (i.e., light saturating conditions), and VPD will be set at 1,000 Pa.

To run this experiment for sunlit leaves, run lines 112-123. Copy-and-paste lines 117-122 below line 126 and ***modify*** this copied code to run the same experiment for shaded leaves.

a) Make plots of CO_2 concentration (`CA`) on the x-axis and our new sunlit and shaded photosynthesis estimates on the y-axis. Describe how CO_2 concentration affects photosynthesis in our model. If you double the CO_2 concentration from the pre-industrial

[1] Note however that GPP is not actually measured by flux towers (hence the scare-quotes around "observed"). Flux towers measure total carbon flux (NEE), and GPP is estimated from this total flux.

level (from 280 to 560 ppm), how much does photosynthesis increase (in other words, what is the ratio of photosynthesis under pre-industrial vs. enhanced CO_2)? If you double it again (from 560 to 1120 ppm), does this ratio stay the same? What does this tell us about how photosynthesis might change with further increases in CO_2 concentration?

b) Do you think the modeled response of photosynthesis to CO_2 concentration is realistic? In other words, what assumptions are we making in the model that may or may not apply to real-world ecosystems?

5. Do something fun.

There are a lot of variables that go into these functions: CO_2 concentration (`CA`), photosynthetically active radiation, temperature, vapor pressure deficit, etc. Think of a simple experiment you could run using these models but changing one or more of these input variables. Modify the functions or inputs to run this experiment. What did you test (i.e., what is your research question)? What did you expect to happen? What actually happened?

Submit your answers as a PDF document (Lab6_<your lastname>.pdf) on the Assignments page of ICON. Also submit your final R script (Lab6_<your lastname>.R) with your assignment.