**GEOG:4470 Ecological Climatology**
**Lab 4: Evapotranspiration**
**Due: 5:00 p.m. on Friday March 13, 2020**

**Goals:**
- Continue practicing programming in R.
- Calculate aerodynamic resistance of the canopy using wind speed.
- Calculate the net radiation of the plant canopy.
- Think about assumptions and uncertainties in modeling leaf/canopy evapotranspiration.

**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 Lab 3 (canopy net radiation)
- Wind speed (Wind), 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 3. Download Lab4_Dannenberg.R from ICON, and save it to your Labs folder, replacing my last name with your last name. Also save GppLeHMay2001-Daytime.txt from ICON to your data folder.

Open Lab4_<your lastname>.R in RStudio. Run all of the lines from the previous labs (through line 66). Once this is done, we can pick up where we left off.

In this lab, we will use three new functions from eco_model.R:
- `canopy_aerodynamic_resistance()`: computes boundary layer resistance based on wind speed and empirical parameters
- `compute_soil_surface_resistance()`: computes resistance to latent heat flux from the soil surface based on soil moisture
- `penman_monteith()`: computes evapotranspiration of the ecosystem based on air temperature, net radiation, stomatal and aerodynamic (i.e., boundary layer) conductance, and vapor pressure deficit

## 1. Aerodynamic resistance.

Calculate aerodynamic resistance of the canopy and convert resistance to conductance (lines 70-73). This uses methods similar to those from Bonan Chpt 15 to estimate aerodynamic (i.e., canopy boundary layer) resistance based on wind speed.

Make three plots: a time series of wind speed, a time series of aerodynamic resistance, and a scatterplot of aerodynamic resistance (y-axis) vs. wind speed (x-axis). Describe the temporal (diurnal to seasonal) variation of wind speed and aerodynamic resistance. Describe how wind speed and aerodynamic resistance are related. Based on your understanding from Chpt 15, does the scatterplot make sense? Is it what you expected to see?

**2. Soil resistance.**
Now calculate resistance of the soil surface to latent heat flux based on soil moisture (run lines 75-77).

Make a time series of soil moisture (dat$Tdr) and a time series of soil resistance. Describe the temporal (diurnal to seasonal) variation of soil moisture and soil resistance. There were two large rain events during May 2001. Based on the soil moisture time series, when do you think these occurred?

Now make a scatterplot of soil resistance (y-axis) vs. soil moisture (x-axis). Describe how soil moisture and soil resistance are related. What is the approximate soil moisture threshold where resistance is minimized?

**3. Calculate latent heat flux of the ecosystem.**
Now use the Penman-Monteith model to calculate latent heat fluxes from sunlit and shaded leaves and from the understory (run lines 79-98).

Make a time series graph that includes separate lines for latent heat flux (LE) from sunlit leaves, shaded leaves, the understory, and the total ecosystem (i.e., the sum of all three components). How do the three components of LE compare to each other? How do they vary daily and seasonally? How do you think the latent heat flux is related to temperature, net radiation, and VPD?

**4. Compare to measured LE.**
Load the flux tower-measured latent heat flux (run lines 100-101). Make a scatterplot of measured LE (x-axis) vs. our modeled LE (y-axis). How well did our model do? What assumptions or uncertainties do you think led to mismatch between the model and the observations?

**5. Do something fun.**
There are a lot of variables that go into these functions: wind speed, temperature, soil moisture, vapor pressure deficit, stomatal/aerodynamic resistance, 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 (Lab4_<your lastname>.pdf) on the Assignments page of ICON. Also submit your final R script (Lab4_<your lastname>.R) with your assignment.**