GEOG:4470 Ecological Climatology
Lab 2: Solar Radiation
Due: 3:30 p.m. on February 19, 2020

Goals:
- Continue practicing programming in R.
- Develop a model that calculates incoming solar radiation at any place on Earth's surface and at any time.

New R tools:
- The `source` function: run code directly from another file.

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:
- Latitude and longitude.
- Measured total photosynthetically active radiation (Par)
- Month, day, and hour of measurements
- Air pressure

Theory

Solar radiation is the ultimate source of energy that drives all ecosystem process. It is essential to know how much solar radiation arrives at the Earth surface in order to model other ecological processes. At the very top of the atmosphere, the solar radiation flux density is usually considered a constant, known as the "solar constant" (S_0=1367.0 W/m^2). However, for scientific computation, it cannot be considered as constant, since it actually varies as a result of Sun-Earth distance changes through the year.

$$S_0 = 1367 * (1.0 + 0.033\cos(2\pi(J - 10)/365)),$$

where J is Julian date (i.e., day of year from 1-365). The amount of solar radiation arriving at the Earth surface changes because of the change in atmospheric conditions and position of the Sun in the sky. The total radiation at the top of the atmosphere is composed of ultraviolet (S_U), visible (S_V) and near-infrared (S_N) as in the following:

$$S_U = 0.034 S_0$$
$$S_V = 0.439 S_0$$
$$S_N = 0.527 S_0$$

Since there is little information about S_U in the literature, let's assume ultraviolet has the same properties as the Visible and combine them into a single component of S_{VU}. Then we will separate Visible light out from S_{VU} when modeling photosynthesis. For convenience we will call S_{VU} as S_V.

$$S_V = 0.473 S_0$$

According to (Weiss and Norman, 1985), the potential U and V direct radiation is

$$R_{DV} = S_V \exp(-0.1556\,(P/P_0)m)\cos(\theta)$$

Where P is air pressure, and P_0 is standard air pressure (P_0=101,325P_a). m is the atmospheric optical depth as

$$m = 1/\cos(\theta)$$

The potential diffuse Visible reaching the horizontal surface is considered 40% of the scattered radiation:

$$R_{dV} = 0.4(S_{VU}\cos(\theta) - R_{DV})$$

Note: this equation is $R_{dV} = 0.4(S_{VU} - R_{DV})\cos(\theta)$ because R_{DV} has already been converted to the horizontal surface.

The potential direct NIR reaching the horizontal surface is

$$R_{DN} = S_N \exp(-0.0086\,(P/P_0)m - w)\cos(\theta)$$

And the potential diffuse NIR radiation on the horizontal surface is

$$R_{dV} = 0.6((S_N - w)\cos(\theta) - R_{DN})$$

Note: this equation is $R_{dV} = 0.6((S_N - R_{DN}) - w)\cos(\theta)$ because R_{DN} has already been converted to the horizontal surface.

ω is the water absorption in the near infrared for 10 mm of precipitation water

$$\omega = S_N \times anti\log_{10}(-1.195 + 0.4459\log_{10} m - 0.0345(\log_{10} m)^2)$$

Then, the fraction of direct beam in PAR and NIR are

$$f_V = \frac{R_{DV}}{R_V}\left(1 - \left(\frac{A - Ratio}{B}\right)^{\frac{2}{3}}\right)$$

$$f_N = \frac{R_{DN}}{R_N}\left(1 - \left(\frac{C - Ratio}{C}\right)^{\frac{2}{3}}\right)$$

Where A=0.9, B=0.7, C=0.88, and D=0.68. RATIO is the measured to potential solar radiation ratio, defined as RATIO=$R_T/(R_V+R_N)$. R_T is the measured total radiation on the ground, $R_V=R_{DV}+R_{dV}$ and $R_N=R_{DN}+R_{dN}$. Often we do not have R_T measured, but R_V only, we can convert R_V to R_T as $R_T=R_V/0.439$ in our area based on the data measured in Duke Forest.

Calculating solar zenith angle by time of day:

$$\cos(\theta) = \sin(h) = \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\cos(\tau)$$

Where τ is local time hour angle. τ=15×(t-12) degrees, t is in hours; φ is latitude; δ is sun declination angle.

$$\delta = 23.5\sin\left(\frac{2\pi(J+284)}{365}\right)$$

0. Load the data and ecological model

Double-click your Labs.Rproj file to open RStudio and begin where we left off after Lab 1. In RStudio, open a new script for Lab 2 and save it as Lab2_<your lastname>.R. Copy the code from Lab 1 to load the file TdrTsoilWindLaiPrecParTaVpdMay2001-Daytime.txt as a data frame, to add a header to the data frame, and to add a new variable for year (2001) and R-formatted date (using the `ISOdate` function).

Save eco_model.R from ICON to your Lab folder. Open this file in RStudio so that it is visible in the code editor. Add the line `source('eco_model.R')` to your Lab 2 script and run this line to load the ecological model functions. There are a lot of functions in this model, but in this lab, we will only use three:

- `define_global_variables()`
- `compute_sun_angles(lat, long, year, month, day, hour, minute)`
- `compute_toc_down_rad(Par, zenith angle, julian day)`

Examine the eco_model.R script and familiarize yourself with these three functions.

Add (and run) the line `define_global_variables()` in your Lab 2 script. When run, this function (which has no inputs) will load in all of our site constants, including the latitude (LATI), longitude (LONGI), and mean air pressure (PA) of the Duke Forest site, which we will need to calculate sun angles.

1. Sun angles and solar radiation

Use the `compute_sun_angles()` function to calculate julian day, zenith angle, declination angle, and hour angle for each observation time at Duke Forest (see Step 0 for the list of necessary inputs). Then use `compute_toc_down_rad()` to calculate diffuse and direct components of PAR and NIR radiation (in W m^{-2}); note that you will need outputs from `compute_sun_angles()` as inputs into `compute_toc_down_rad()`.

Make a time series plot with X-axis being time and Y-axis being solar radiation (in W m^{-2}) for four components: visible direct, visible diffuse, NIR direct, NIR diffuse. Explain the diurnal (daily) and seasonal patterns.

2. Modify the program to calculate fraction of diffuse radiation.
Save a new version of eco_model.R (called eco_model_lab2_<your lastname>.R). Modify the `compute_toc_down_rad()` function so that it will also export the fraction of total radiation (for both the visible and NIR radiation) that is *diffuse* as additional columns in the output data frame. Make a similar plot as in (1), but for the *fractions* of diffuse radiation for visible and NIR radiation only. Explain the diurnal and seasonal patterns.

3. Calculate radiation for different locations.
Run both functions for a place 10 degrees further north in latitude on the same longitude, and then 10 degrees further south in latitude on the same longitude. Make a plot for the ***visible (PAR) direct radiation*** for the three places and make a graph similar to (1). Explain the pattern you observed.

4. Do something fun.
Think of a simple experiment you could run using these models. 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 (Lab2_<your lastname>.pdf) on the Assignments page of ICON. Also submit your final R script (Lab2_<your lastname>.R).