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Geog595 Ecological Modeling, Spring 2007
Due: Friday April 27, 2007

Lab 8 Integrative Modeling of Energy, Water and Carbon Fluxes of Terrestrial Ecosystems

1. *Based on the main.c program and the functions used in the program, use your own words and necessary Equations (most already appeared in previous labs) to describe how energy flows from the sun, to the top of the canopy, through the canopy, and then used by transpiration and photosynthesis.*

The 4 Steps From Sunlight to Biomass

1. Energy flows from the sun to the top of a plant canopy

In Lab 4, we learned that light from the sun reaches the very top of Earth's atmosphere with a flux density of 1367.0 W/m², a value that is called the solar constant. This total radiation is divided up into two components, longwave and shortwave. The shortwave radiation is further divided into two components, NIR and wavelengths between 400-700 nm (PAR, which is usable by plants). The amount of direct solar radiation reaching the ground varies due to atmospheric transmittance τ , the solar zenith angle θ , and the amount of atmosphere the light must travel through (atmospheric optical number m):

$$S_b = S_0 \tau^m \cos(\theta).$$

The diffuse radiation reaching the ground is $S_d = 0.3(1 - \tau^m)S_0 \cos(\theta)$.

However, much of the Earth's land surface is vegetated, and therefore a considerable amount of this direct and diffuse radiation is intercepted by plant canopies.

2. Energy flows through the plant canopy

In Lab 5, we learned how PAR travels through a plant canopy. PAR reaches the top of any plant canopy in two components: direct beam radiation (Q_{ob}) and diffuse radiation (Q_{od}). The further the direct radiation travels through the canopy, the more it is scattered. To describe the radiation that reaches the ground, we need to know the extinction coefficient K_b , the LAI L of the canopy, and the leaf absorptivity α . The diffuse radiation reaching the canopy bottom can be similarly described as $Q_d = Q_{od} \exp(-K_d \sqrt{\alpha} L)$, where K_d depends on the transmissivity of the diffuse radiation through the leaves and can be estimated from K_b .

The multiple scattering that occurs within a plant canopy is too computationally intensive to model, but the direct and diffuse components of PAR reaching the ground can be estimated if the canopy is thought of as being divided into sunlit and shaded leaves. The shaded leaves are lit indirectly, and have a mean radiation intensity Q_{sd} equal to the

sum of the means of the diffuse and scattered radiation. The sunlit leaves are lit directly, and have a mean radiation intensity Q_{sl} equal to Q_{sd} plus the amount of direct radiation at the top of the canopy that does not go extinct ($K_b(\theta)Q_{ob}$).

3. The intercepted energy powers evapotranspiration

In Lab 6, we used the Ball-Berry model to calculate stomatal conductance, which was incorporated into the Penman-Monteith equation in Lab 7 to calculate evapotranspiration. The sunlit and shaded components of radiation influence the photosynthetic rate A , which is a part of the Ball-Berry equation. Thus, these components also affect evapotranspiration.

$$\text{Ball-Berry equation: } g_{sc} = kA \frac{h_s}{C_s}$$

$$ET = ((s * R_{net}) + (\rho * CP * vpd * g_a)) / (\gamma * (1.0 + g_a / g_s) + s)$$

In this lab, ET was described in main.c as being dependent on sunlit and shaded LAI, as well as evapotranspiration from sunlit and shaded leaves:

$$ET_{total} = 2.0 * (\text{sunlitlai} * ET_{sunlit} + \text{shadedlai} * ET_{shaded})$$

When we go to calculate the sunlit and shaded ET, we find we need as inputs the sunlit and shaded net radiation R_{net} . The sunlit and shaded R_{net} uses as inputs the longwave and shortwave radiation intercepted by the sunlit and shaded leaves, respectively, as well as the longwave radiation reaching the forest floor. Both PAR and NIR are counted as shortwave radiation.

$$R_{net_sunlit} = \text{aswr_sunlit} / 4.55 - L_{net_sunlit} + L_{net_floor} * (1.0 - \exp(-\text{ext_coeff}[0].Kd * lai)) / lai;$$

$$R_{net_shaded} = \text{aswr_shaded} / 4.55 - L_{net_shaded} + L_{net_floor} * (1.0 - \exp(-\text{ext_coeff}[0].Kd * lai)) / lai;$$

4. The intercepted energy also powers photosynthesis

The sunlit and shaded components of net radiation also influence the calculation of photosynthetic rate (psn) by the Farquhar model. This is expected, since the photosynthetic rate represents how fast PAR is being converted to biomass. We see in main.c that the total psn is divided into sunlit and shaded components, which are respectively derived from the sunlit and shaded components of the canopy intercepted PAR:

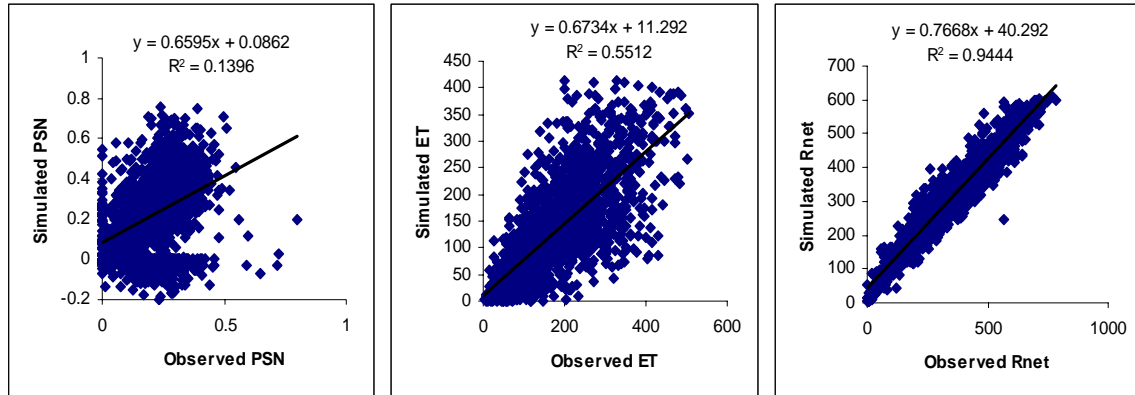
$$\text{psn_total} = 2.0 * (\text{sunlitlai} * \text{psn_sunlit} + \text{shadedlai} * \text{psn_shaded});$$

$$\text{psn_sunlit} = \text{compute_leuning_farquhar_psn}(\text{psnin}, \text{canopy_intercepted_par}[0].\text{sunlit}/2.0, \text{vpd}, \text{fsoil_theta});$$

$$\text{psn_shaded} = \text{compute_leuning_farquhar_psn}(\text{psnin}, \text{canopy_intercepted_par}[0].\text{shaded}/2, \text{vpd}, \text{fsoil_theta});$$

Thus, we see how the sets of equations we covered in this class allow us to model how sunlight drives two key ecological processes, evapotranspiration and photosynthesis.

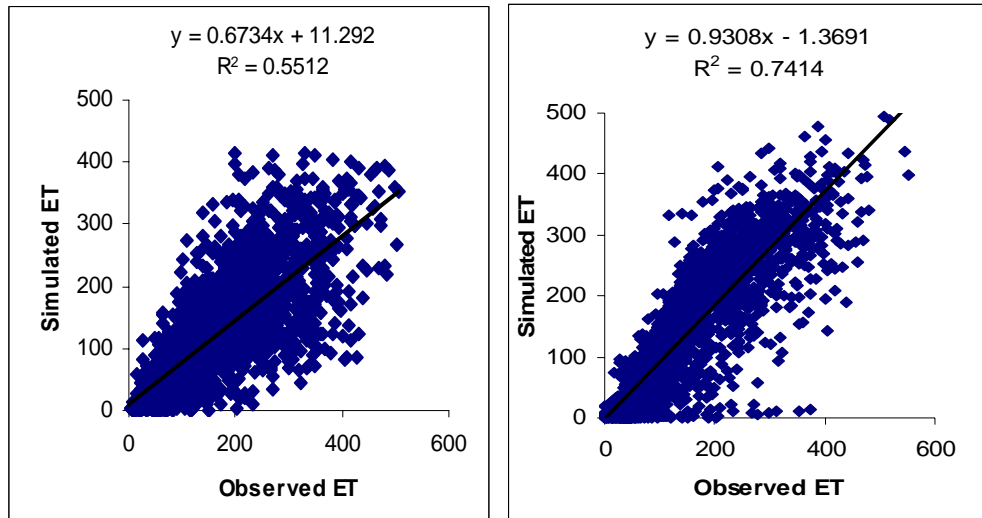
- Run the SCALE model for 2001 and compare the simulated net radiation, evapotranspiration and net photosynthesis with the tower observations for 2001 with three scatter plots. Describe how well they compare with the observation. If they do not compare well, what might be the problem.



The SCALE model output gave data for times when no corresponding data was available from the tower01 observational data. After deleting all non-matching data between the two sets, the above plots were created from the remaining 1678 data points. We see that for photosynthetic rate (PSN), evapotranspiration (ET), and net radiation (Rnet), the model underestimates each of the observed values. The best relationship between simulated and observed values occurs with Rnet, with the highest R^2 of 0.9444. Simulated and observed ET have a less strong relationship, but there is hardly any relationship between simulated and observed photosynthetic rate.

The difference in R^2 values between ET and Rnet could be a result of error propagation in the model. To explain, the Penman-Monteith equation for calculating ET uses Rnet, so any errors in Rnet will propagate to the ET results. Also, it could be that the variables controlling net radiation are better described than those controlling ET in the Penman-Monteith model. The difference between PSN and the other two values could be due to not having the full range of variables controlling photosynthetic rate included in the model. Photosynthetic rate is probably the least understood of these three values.

- Compare the results of ET modeled by SCALE with that obtained from lab 6 and see how well the results from the integrative model compare with those from the simulation in lab 6. How would you explain the difference in the comparison with the observed data by the two models?



Left: Results from this lab. **Right:** Results from Lab 7 (using the best model for ET, the Leuning model).

In Lab 6, the observed photosynthesis rate was used as an input into the Leuning model for ET. Thus, there should be no error in the photosynthesis rate because it was observed. However, in this lab, the photosynthesis rate was simulated. Thus, there is some error introduced, and this likely contributes to the lower R^2 value between simulated and observed ET in this lab compared to the last lab.

Nedit Makefile – tells how all the programs will be related together to make one executable. Need tabs on every $[\text{CC}]$ line, and no spaces on the line before.

Rm -f SCALE

Touch *.c (selects all the programs with time stamps more recent - program modifies just the one file that was edited).

Make (automatically looks for the make file).

SCALE -h (tells how to use the program).

SCALE -f r1-TdrSoil...(runs the program).

Last 3 output columns: Net radiation (W/m^2), ET (W/m^2), photosynthesis ($\text{mmol}/\text{m}^2/\text{s}$)

Rhessys model – has ~300 subprograms (o files).

Met2001 is the input file. Tower01 is the output file we compare with. We don't need the r1 file. Tower: AN-LE-Rnet; model output: Rnet-LE-AN (was; now it's been changed).

Make: makes all the files. Do the touch *.c to make all the files more recent than the .o files, so that the compiler will compile all the files. Otherwise, it will just compile the ones that have been updated.

(do simulation for 2001. Know where the data from the previous lab is – need to get the data in the same way. R1-TdrTsoil...May2Sep2001.txt – for validation. Go to main.c to see what columns are what. This file is like the tower file for Lab 7, but there the 0's have been removed. If we use r1-1 for the input, tower01-1 is the validation. If r1-2, tower01-2. If r1-01, use tower. To get rid of the last 2 columns (already done for us, do `awk '{print $1,$2,$3,$4,...,$12,$}' r1-Tdr...VdsAnRnet-May2Sep2001-1.txt` > ../lab8/met2001.dat. Then `head -5 r1...May2Sep2001` – this will show what the file looks like (the first 5 columns). The last 2 columns should be missing.) In tower01, An (mg/m²/s – mmol *0.012 – 12 g C for one mol) – LE – Rnet. Different order than in the r1 files. Put simulated and observed on a 1:1 line. An has already been scaled by 0.012.

scatter plots:

simulated net radiation w/ tower01 column 3

sim evapotranspiration w/ tower01 ET

sim net photosynthesis w/ tower01 psn

- (1) (Lab 6 – we used the observed photosynthesis as input to make the ET. There should be no error in the photosynthesis b/c it was observed. But, for this lab, the photosynthesis was simulated. Do 2 scatter plots, with observed vs. simulated for each. One plot for lab6, one plot with this lab.