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Geog 595 Ecological Modeling
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Lab 5 Radiation Transfer Through Plant Canopies

(1) read the chapter again and the theory above, describe the theory of radiation transfer through plant canopies using your own words.

How photosynthetically active radiation (PAR) travels through a plant canopy:

Radiation from the sun reaches the top of any plant canopy in two components: direct beam radiation (Q_{ob}) and diffuse radiation (Q_{od}). If the canopy leaves absorb 100% of this light (the black leaf assumption), then the direct light reaching the ground is equal to the light at the top of the canopy, reduced by a term involving an extinction coefficient, and the LAI of the canopy: $Q_b(\theta) = Q_{ob}\exp(-K_b(\theta)L)$. The extinction coefficient is a function of the solar zenith angle and the ratio of average horizontal to vertical leaf projections on the ground; if leaves are oriented more horizontally, then more light will go extinct before reaching the ground. However, in reality the canopy leaves are green, not black, and so some of the light is scattered. The deeper down in the canopy we go, the more the light is scattered. This means we must further reduce the beam radiation by adding a term for leaf absorptivity, which is α.

The diffuse radiation component is a little harder to handle, and it is often not measured. To describe how much diffuse radiation reaches the bottom of a scattering canopy, the form of the equation is similar to that for direct radiation, $Q_d = Q_{od}\exp(-K_d\sqrt{\alpha}L)$. To get the extinction coefficient this time, we need to estimate the transmissivity of the diffuse radiation, but this estimation only requires knowledge of K_b.

It is difficult (computationally intensive) to model multiple scattering within a plant canopy. However, a good estimation of the direct and diffuse components of PAR reaching the ground can be made by thinking of the canopy as being composed of sunlit and shaded leaves. Since the shaded leaves are shaded (they are not lit directly by any light), their mean radiation intensity Q_{sd} equals the sum of the means of the diffuse and scattered radiation. However, the sunlit leaves are lit directly, so their mean radiation intensity Q_{sl} is equal to Q_{sd} plus the amount of direct radiation at the top of the canopy that does not go extinct ($K_b(\theta)Q_{ob}$). To find the means of the diffuse and scattered radiation, we assume that the mean diffuse radiation intensity decreases exponentially from canopy top to bottom, and that the mean scattered radiation intensity decreases linearly from top to bottom.

(2) *Assuming spherical leaf angle distribution, x=1 in Eq (3), run the model for LAI=1, 3, 5 and describe how the radiation intensity for sunlit and shade leaves changes with LAI. How total radiation intercepted by leaves in the canopy change with Lai in the canopy?*
(3) *Do the same as in (2), but assuming x=0, and 3, in Eq. (3).*

To answer these questions, I chose to use just one day of the data generated by our radiation.c program (May 5, 2001) to generate a set of six graphs on the following page. Each graph is of radiation intensity vs. hour of day, and has LAI=1, 3, and 5 as series. The top row of graphs (Figures 1-3) show the radiation intensity for sunlit (Q_{sl}) and shaded (Q_{sd}) leaves over a 24-hour period for increasing values of x. These graphs are all to the same scale. The bottom row (Figures 4-6) show the total radiation ($Q_{tot}=Q_{sl}+Q_{sd}$) intercepted by leaves in the canopy for increasing x-values, and all 3 of these graphs are to the same scale.

The results for x=1:

As LAI increases from 1 to 5, the radiation intensity for sunlit leaves decreases, regardless of what time of day it is (Figure 2). This can be seen by the decreasing height of the blue, yellow, and purple curves, which correspond to sunlit leaves. The radiation intensity for shaded leaves also decreases with increasing LAI. This can be seen by the decreasing height of the pink, cyan, and red curves, which correspond to shaded leaves.

As for the total radiation intercepted by leaves in the canopy (Q_{tot}), this also decreases with increasing LAI. This can be seen in Figure 5. The Q_{tot} for LAI = 1 is larger than Q_{tot} for LAI = 3, which is larger than Q_{tot} for LAI = 5.

Results for x=0 and x=3:

I find similar results for sunlit and shaded leaves as I did with x=1: As LAI increases from 1 to 5 , the radiation intensity for both leaf types decreases, regardless of time of day. I also find the same results for total radiation as for x=1: the total radiation intercepted by canopy leaves also decreases with increasing LAI.

Two interesting observations:

First, by plotting increasing x from left to right (Figures 1-3), I can also see that Q_{sl} for all values of LAI increases with increasing x, while Q_{sd} decreases with increasing x. This means that as x increases, the ratio of Q_{sl} to Q_{sd} increases even as the total radiation intercepted by the canopy (Figures 4-6) decreases. These findings make sense if there are more sunlit than shaded leaves as x increases, which is actually the case.

Since x is the ratio of the average projected areas of leaves on horizontal surfaces over vertical surfaces, as x increases, the leaf distribution within the canopy goes from being vertical (x=0) to horizontal (x=infinity). As more leaves become horizontal with increasing x, more beam radiation goes extinct, so more of this radiation is intercepted by the leaves and less is available to be scattered. Thus, with increasing x, there should be more sunlit than shaded leaves.

Second, as x increases, the total radiation at any single value of LAI decreases (Figures 4-6), moreso in the early and late hours of the day than around noon. This appears as a pinching of the ends of the graph at x=3 compared with when x=0. This is because around dawn and dusk, the sun is at low zenith angles. More horizontally distributed leaves (x=3) would cast longer shadows, causing less radiation to reach the shaded leaves.

How the Radiation Intensity Intercepted by Sunlit and Shaded Leaves Varies with Hour for LAI=1, 3, and 5
May 5, 2001

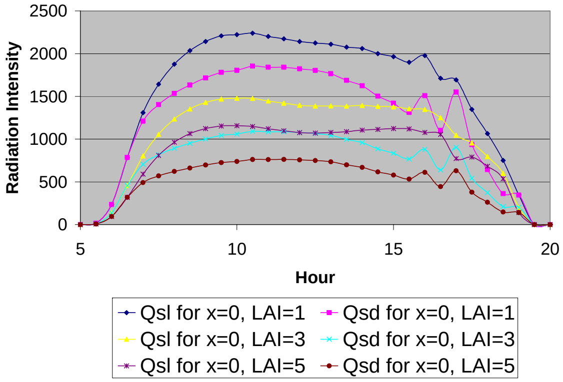

Figure 1: x=0, Q_{sl} and Q_{sd}

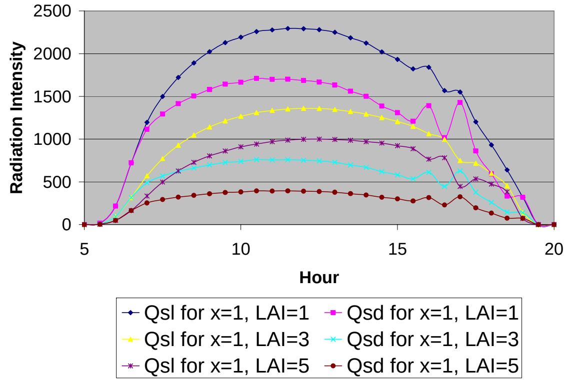

Figure 2: x=1, Q_{sl} and Q_{sd}

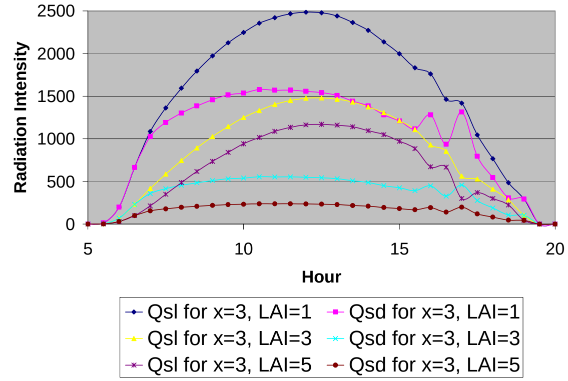

Figure 3: x=3, Q_{sl} and Q_{sd}

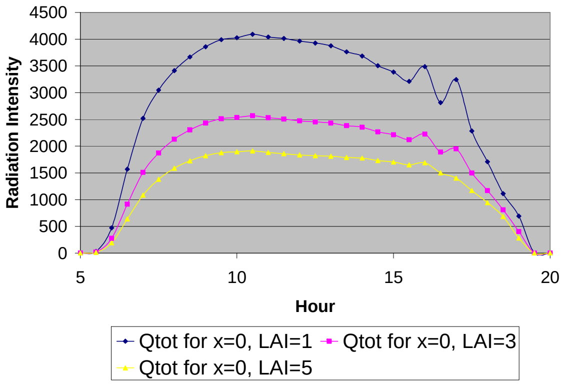

Figure 4: x=0, Q_{tot}

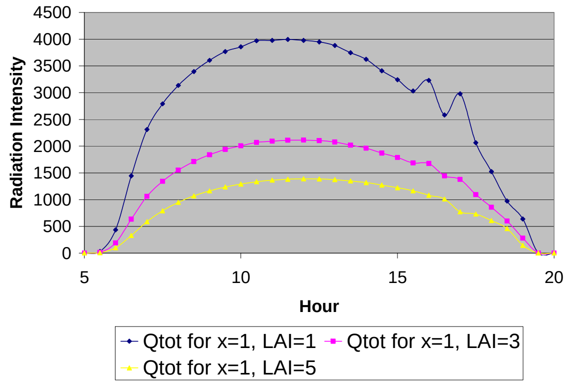

Figure 5: x=1, Q_{tot}

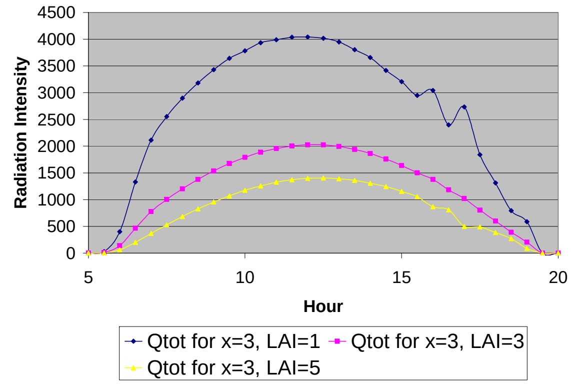

Figure 6: x=3, Q_{tot}