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Potential Solar Radiation at H.J. Andrews Experimental Forest, Oregon

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ABSTRACT: Potential (clear-sky) radiation receipt is modeled for the slopes of the H.J. Andrews Experimental Forest Long-Term Ecological Research site in the foothills of the southern Cascade mountains of central Oregon. The modeling method developed by Williams is selected and applied to the forest area for the times of the solstices and equinox as well as mid-month times in January, February, April, and May in order to completely characterize the seasonal change of potential radiation at the location. The method uses an 82×111 point grid with a 120-meter spacing interval. Resulting maps reveal areas of the forest with extremely steep gradients of potential radiation. These steep gradients have higher absolute values in summer compared to winter. The south- facing slopes that have the highest potential radiation values tend to be at the highest elevations. There are places that receive no direct radiation as far into the year as February. Standard deviation values of potential radiation across the Andrews show the maximum spatial variability to occur in February. There is a decrease in the ratio of diffuse to direct plus diffuse potential radiation from 0.66 at December 21 to 0.23 at June 21. It seems that Lookout Creek approximately divides the Andrews Forest into an area of relatively high potential radiation to the north of the creek and relatively lower potential radiation values to the south of the creek. Potential radiation values seem to be associated with the Andrews GIS data layers of debris flows and predominant tree species zones.

The Andrews Forest

H.J. Andrews Experimental Forest is a 6400-hectare forest of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and Pacific silver fir (*Abies amabilis* Doug. ex Forbes) located in, and typical of, the central portion of the western slope of the Cascade mountain range of Oregon (Figure 1). The forest has a complex topography (Figure 2) and ranges in elevation from 410 to 1630 meters (1350 to 5340 feet). The research site is one of 18 sites in the Long-Term Ecological Research program currently sponsored by the National Science Foundation.

Objective

The purpose of this study is to produce maps of seasonal potential insolation (*ie*, solar radiation receipt under clear sky conditions) for H.J. Andrews Experimental Forest. These maps will have value for:

- Making future estimates of heat energy input to the various slopes of the forest.
- Establishing relationships between solar input and net primary productivity.

In: C.M. Isaacs and V.L. Tharp, Editors. 1997. *Proceedings of the Thirteenth Annual Pacific Climate (PACLIM) Workshop, April 15-18, 1996.* Interagency Ecological Program, Technical Report 53. California Department of Water Resources.

- Identifying areas of greatest potential heat input — a process that has implication for driving mesoscale wind circulations in the area, and possibly also for establishing areas of potential forest fire initiation danger.

The Williams Model

The Williams *et al* (1972) model, selected for this study, is based on work by Garnier and Ohmura (1968) who estimated potential global solar radiation (K↓) on slopes by:

$$K{\downarrow} = S_x\, p^m \cos(i) + D_h \cos^2(s/2) + \alpha\,(S_h + D_h)\sin^2(s/2) \tag{1}$$

where: S_x is incoming shortwave radiation at the top of the atmosphere; *ie*, extraterrestrial radiation
p is the mean zenith angle path transmissivity
m is the optical depth
D_h is the diffuse radiation on a horizontal surface
α is the albedo of the surface
S_h is the direct radiation on a horizontal surface

The first and second terms represent S (direct radiation) and D (diffuse radiation), respectively, and the third term represents D_{tr} (terrain reflected radiation). Garnier and Ohmura suggested using actual site measurements to determine the value of p at the site and that p should be approximated by sec Z_s (zenith angle). This suggestion was followed in this study. The second and third terms assume an isotropic distribution of D. The third term was not used in practice or in this study.

cos (i) is given by:

$$i = \cos^{-1}\{\cos(s)\cos(Z_s) + \sin(s)\sin(Z_s)\cos(A_z + A_s)\} \tag{2}$$

where: s is the slope of the surface
A_z is the solar azimuth
A_s is the slope azimuth (aspect)

Williams *et al* (1972) provide estimates of K↓ for complex terrain that treat the terrain as a matrix of elevation points and allow for the shading of an individual point, where appropriate, by those points surrounding it. Their estimate of D is given by:

$$D = (I_o / d^2)(0.91 - p^m)\cos(Z_s)\cos^2(s/2) \tag{3}$$

The 0.91 represents the proportion of radiation that has not been absorbed by atmospheric constituents. This model corrects the value of m for the elevation of the observation point. Daily total values are produced using integration of 20-minute values of Z_s and a grid of 82×111 points over the Andrews area with a 120-meter grid spacing.

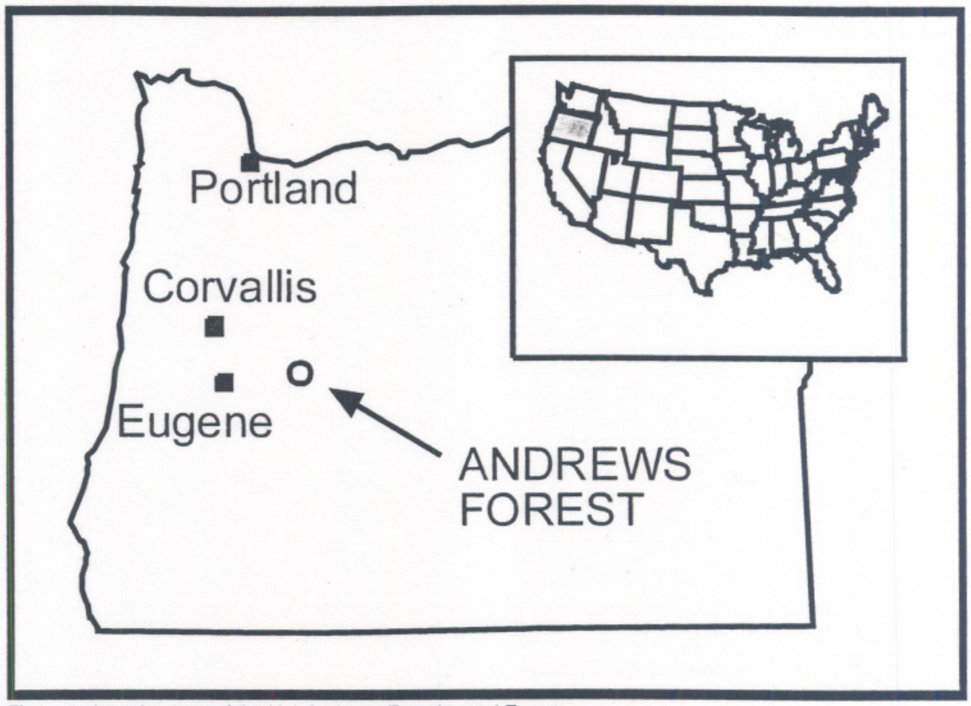


Figure 1. Location map of the H.J. Andrews Experimental Forest.

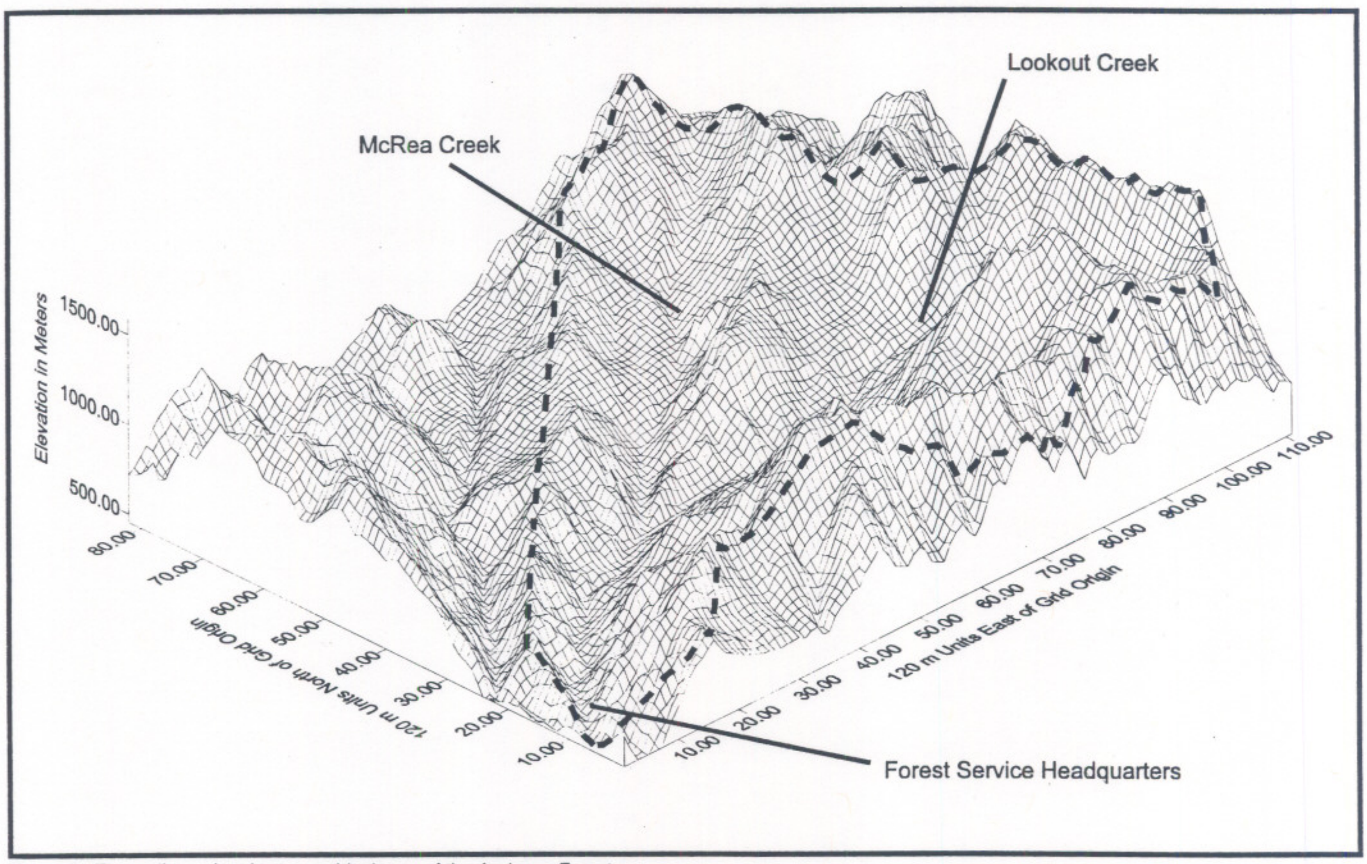


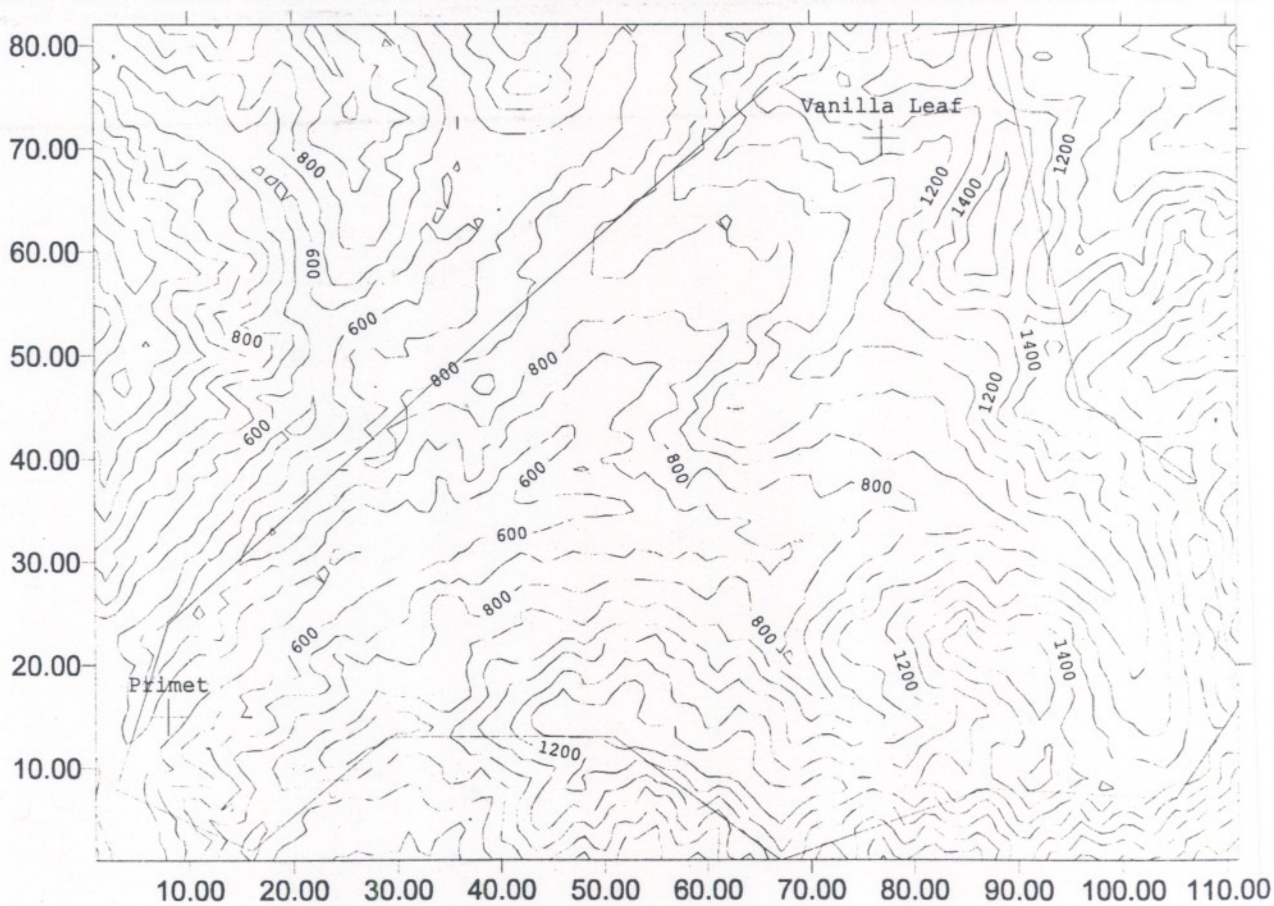
Figure 2. Three dimensional topographical map of the Andrews Forest.

Results

Provided here is a contour map of the Andrews topography (Figure 3) and an example of the potential direct and diffuse radiation values for April 15 (Figure 4). The latter figure may not reproduce well, and interested persons should contact the author if they require further details. Complete results and maps are documented in Greenland (1996). Based on the complete set of maps in Greenland 1996, the principal results are as follows.

Potential direct and diffuse radiation received at the Andrews Forest is spatially and temporally highly variable.

Results we might expect include the higher values of potential radiation in summer than in winter and on south-facing compared to north-facing slopes and the greater relative importance of diffuse, compared to direct, radiation in the winter months.



Axis units are 120 m (e.g 10 = 120x10 m from lower left hand corner of the map)
North is to the top of the map. Countours are in m above msl. Straight lines indicate the approximate boundary of the Andrews Forest.

Figure 3. Contour topographical map of the Andrews Forest.

More surprising results include the identification of areas of steep potential radiation gradients and the greater receipt of potential radiation at the higher elevations than the lower ones. It could also be argued that Lookout Creek approximately divides Andrews Forest into an area of relatively high potential radiation to the north of the creek (with the exception of the north-facing slopes of McRea Creek Valley) and relatively lower potential radiation values to the south of the creek. This pattern holds throughout the change of seasons.

Counter-intuitive results also include the fact that the greatest amount of spatial variability of potential radiation occurs in late winter and early spring.

Potential radiation values seem to be associated with the spatial distributions shown on the Andrews GIS data layers of debris flows (flows are absent in low potential radiation value areas) and predominant tree species zones. In the latter case, one of the Andrews GIS layers shows the distribution of predominant tree zones (*ie*, areas dominated by one or more species). This

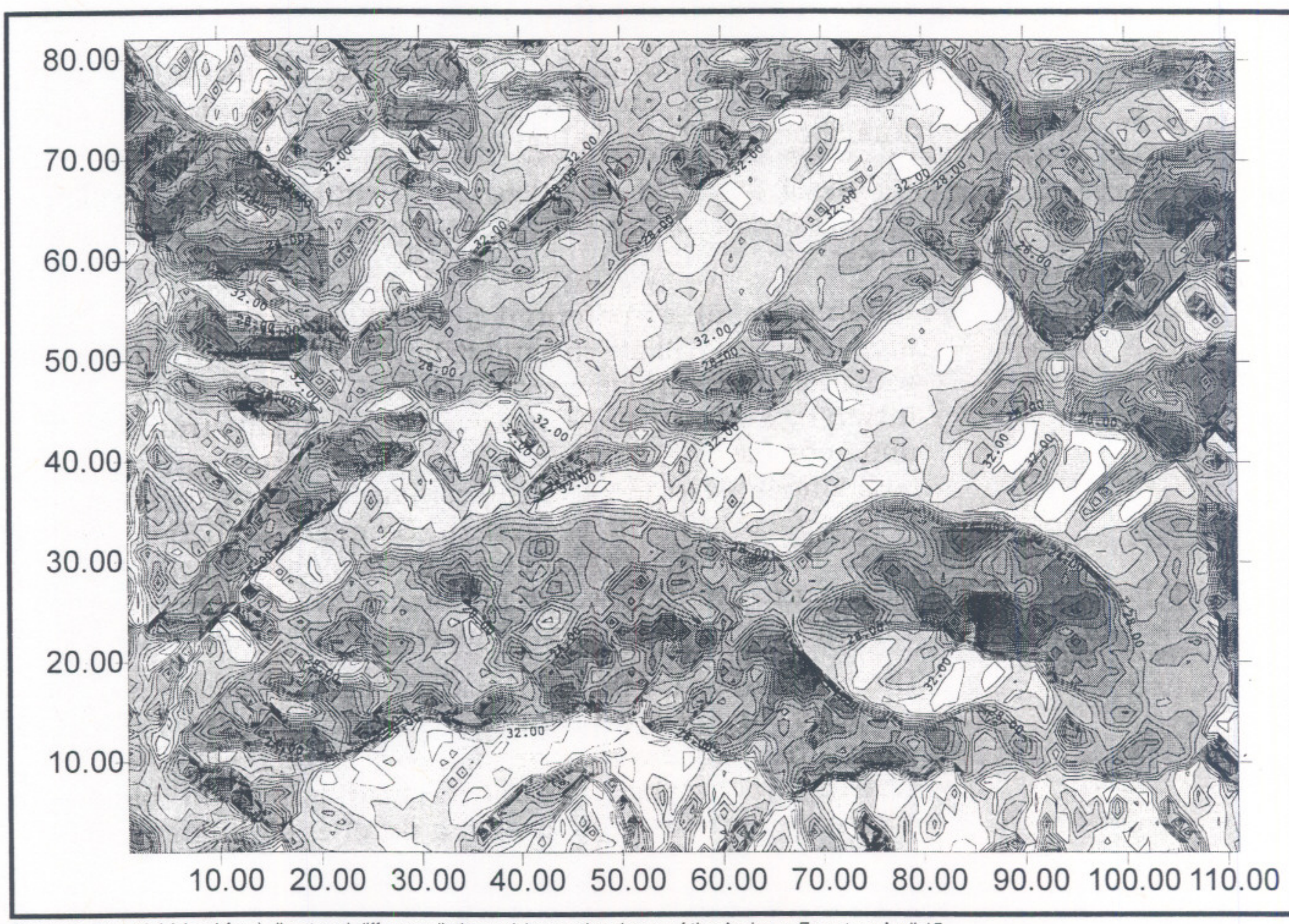


Figure 4. Potential (cloud-free) direct and diffuse radiation arriving on the slopes of the Andrews Forest on April 15.

Axis units are 120m (eg 10=120x10m from lower lefthand corner of map).
North is to the top of the map. Isolines are in MJ/sq.m/day. Isoline interval is 1 MJ/sq.m/day.
Highest and lowest isoline values are 33 and 13 MJ/sq.m/day, respectively.
Lighter shading indicates more potential solar radiation.

GIS layer indicates that Pacific silver fir is mainly distributed at higher elevations. The current study demonstrates that within these higher elevations, Pacific silver fir occurs in areas of less than highest maximum possible potential solar radiation. There may also be relationships acting in concert with other processes and the distributions of other variables such as precipitation (precipitation is highest and potential radiation is low south of Lookout Creek. Forest fire frequency is least in this location).

Future Work

This study in many ways represents a beginning. Solar radiation is itself the beginning of a cascade of energy flow through the atmospheric system and the ecosystem. Future work should continue to follow the cascade to successive levels. Specifically the following steps will be of value.

- Spatial analysis of the data will be continued by using geostatistical techniques. In particular, a semivariogram analysis will not only give greater information on the key spatial scales on which potential radiation varies.
- It is important to establish the effects of clouds and aerosols in attenuating the amount of potential radiation to determine finally how much radiation arrives at the surface.
- Values of absorbed radiation will be estimated and will likely be related even more closely to other biophysical variables of the forest.
- Establishment of potential global solar radiation ($K\downarrow$) and albedo values will aid in establishment of other variables of the radiation and surface energy balance. These variables include incoming and outgoing longwave radiation, substrate heat flow, and sensible and latent heat flow. These are the fundamental components of the physical climate and are the important linking factors to the ecosystem. Saunders and Bailey (1994) noted that "the energy budgets of sloping surfaces remain a largely untouched research problem, and nowhere is this more important than in mountainous regions".
- The processes modeled in the above items must be integrated with key variables available from remote sensing technology. When this has been done, a powerful set of tools will be available to provide researchers with important bioclimatic information that can be used at a number of different scales.

Acknowledgments

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