2727

Final Report on Grant USDA Forest Service Cooperative Agreement PNW No. 96-5038/ UNC#5-45885

EFFECT OF FOREST MANAGEMENT PRACTICES ON SOLAR HEAT ABSORPTION AT THE H. J. ANDREWS EXPERIMENTAL FOREST, OREGON.

David Greenland
Department of Geography
University of North Carolina - Chapel Hill

February 28, 1999.

"There is much in history to show that highly developed human cultures .... went down at the same time as their forests were lost" Rudolf Geiger, 1965. p. 361.

EFFECT OF FOREST MANAGEMENT PRACTICES ON SOLAR HEAT ABSORPTION AT THE H. J. ANDREWS EXPERIMENTAL FOREST, OREGON.

Contents

Summary
Outline of research program
    Introduction
    Detail of Work Concept
Tasks achieved
    The Spatial Data Base
        General Description
        Detailed Description of Formation
        The Actual ALCLIM Data Base
    Albedo Values
    Point Modeling Studies
    Preliminary analysis of the relation between radiation and diurnal temperature range
    Error Analysis
    Miscellaneous items
Conclusions
Plans for further work
References

SUMMARY

This study is a small step towards an overall goal to provide a working model of the H. J. Andrews Experimental Forest, Oregon at 120 m spatial resolution to link the values of all the surface energy budget variables (net radiation, latent and sensible heat flow, and ground heat flow) with real and potential changes of specific surface types. This part of the study involves procedures leading to the eventual estimation of absorbed solar radiation at the forest surface. This part of the research program is outlined and then discussed in some detail. The tasks achieved are described. These include the development of the spatial data base, the search for albedo values, the results from point modeling studies, preliminary analysis of the relation between radiation and diurnal temperature range, a preliminary error analysis and some miscellaneous items. The conclusions from the work are:

1) A GIS system can not be used for this work because of the need for complex mathematic manipulations within and across cells of the data base. The task of data base development for this project is not trivial but has now been achieved and documented.

2) There is a shortage of good albedo observations relevant to the forests such as the HJA. Pending specific NASA over flights, the best available data have to be employed.
3) Point modeling studies clearly demonstrate the importance of the focus of this investigation and, even more, the need for the completion of the spatially distributed radiation estimations under different forest manipulations.
4) Preliminary analysis of the relation between radiation and diurnal temperature ranges shows:
    a) Large day to day variability of radiation receipt at the HJA demands that modeling estimates be made on a daily basis and only then, if necessary, aggregated to larger time periods.
    b) A good relationship exists between daily radiation and diurnal temperature range especially when the relationships are made by seasonal groupings.
    c) The Bristow and Campbell relation between radiation and diurnal temperature ranges is strong and robust at the HJA. It is not yet certain whether the improvement in results it gives will be worth its application in the further development of this project.

The remaining steps outlined in the "detailed work concept" section below will be completed in the future. It is planned to develop this work in a modular fashion such that when new data and techniques become available, such as from over flight remote sensing, the results may easily be updated.

OUTLINE OF RESEARCH PROGRAM

Introduction

The forest landscape is composed of many different types of surface depending on the dominant species of trees and the management practices employed on the landscape. Each surface has a different reflectivity to, and absorptivity of, the incoming flows of solar radiation (K down). The ratio of reflected to incoming radiation is called the albedo of the surface. Forest management practices such as clear-cuts, and selective cuts as well as the stage of succession of grow back are associated with different values of surface albedo. An extreme case would be a forest of mature old growth Douglas Fir that might absorb 90% of the incoming solar radiation compared to a mixed grass and a bare soil surface which might absorb only 75%. *The general objective of this research was to examine ways to establish the range of values of solar heat absorption in a mid-latitude temperate rain forest.*

The research is focused on the H. J. Andrews Experimental Forest (HJA), near Blue River Oregon, which is one of the sites in the U. S. Long-Term Ecological Research Program. Previous research has estimated clear sky radiation on the slopes of this forest. The research performed under this grant has set the stage to complete the following tasks:

1) estimate the accuracy of the previous radiation estimates;
2) estimate the effect of cloud cover on the depletion of radiation compared to the clear sky estimates;
3) obtain best estimates of albedo for the different surfaces of the HJA based on measurements for similar surfaces appearing in the literature and LANDSAT reflectance measurements;
4) assign albedo values to all points on a radiation grid;
5) calculate the mean annual and spatial (averaged across the grid points) absorbed radiation for the grid;
6) repeat calculations at all grid points using albedo values representative of mature old growth, secondary regrowth (circa 120 yr. old) forest, grass, and bare soil;
7) apply the 1997 absorbed radiation estimates at 10 year intervals using a reconstructed surface appropriate to each of the intervals;
8) perform an error analysis to estimate the range of accuracy of the estimates made in the previous steps.

This report expands upon these tasks, discusses the work completed so far, and outlines the plan for completing the rest of the steps.

Detail of Work Concept

The research is focused on the H. J. Andrews Experimental Forest (HJA), near Blue River Oregon, which is one of the sites in the U. S. Long-Term Ecological Research Program. The HJA is triangular shaped with the short boundary on the eastern side and is about 15 km W to E and 10 km N to S with a total area of 6400 hectares. HJA has an elevation range from 420m (1378 ft) to 1630m (5346 ft). The area has complex terrain and is dissected by Lookout Creek and McRea Creek. The Forest has four benchmark meteorological observing sites at which a wide variety of meteorological measurements are taken. The sites are called Primary Meteorological Site (PRIMET, elevation 426m (1397 ft)), Central Meteorological Site (CENMET, elevation 1006m (3300 ft)), Vanilla Leaf Station (VANMET, elevation 1267m (4157 ft)), and Upper Lookout site (UPLO, elevation 1280m (4200 ft)).

The H. J. Andrews Experimental Forest (HJA) is a 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 (Fig. 1). The area is in the states of Washington and Oregon west of the watershed divide formed by the highest points of the Cascades. This area will be referred to as the Western Pacific Northwest (W PNW). The forest is currently one of 21 sites in the Long-Term Ecological Research (LTER) program sponsored by the National Science Foundation (Franklin et al., 1990). During the 1970s the Forest was a representative site in the Coniferous Forest Biome Project of the U.S. International Biological Program. It was originally established in 1948 as an Experimental Forest of the U.S. Forest Service. There is an immense legacy of research resulting from the participation of the Andrews Forest in these research programs (McKee et al., 1987, Blinn et al., 1988). Future participation in LTER ensures the continuing scientific importance of the site. Climatological information has been collected at the site since 1951 with a continuous, electronically sensed, record from May 1972. Until 1994, the observing system is composed of a primary meteorological station and a network of satellite temperature and precipitation recording stations. After 1994, four primary benchmark stations anchored the observing system.

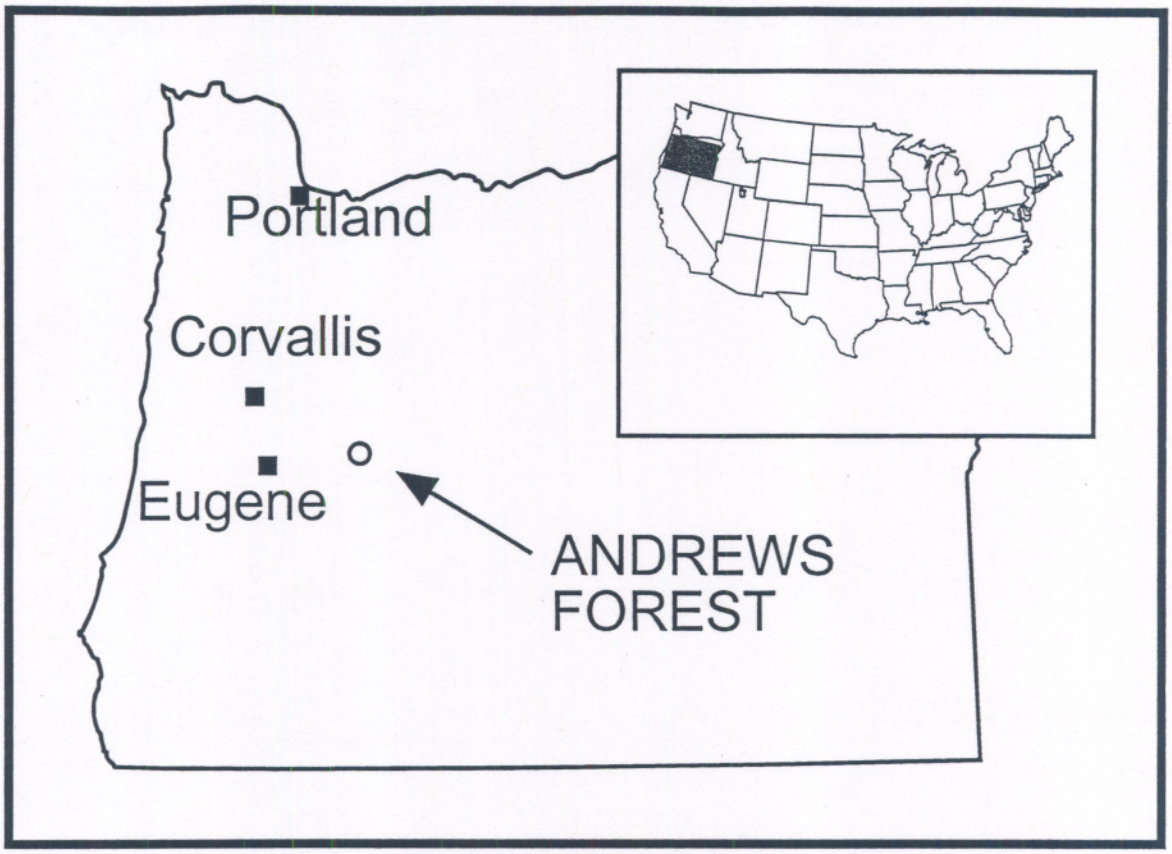


Fig. 1. Location map of the H.J. Andrews Experimental Forest.

A previous related study estimated the potential (clear sky) shortwave direct and diffuse solar radiation arriving at the slopes of the HJA (Greenland, 1996). A rectangular grid of 110x88 data points and elevation data from a Digital Elevation Model was used for these estimates. When the follow up work related to this research is complete the following steps will have been taken:

1) Using new and independent data from the Central Met and Upper Lookout sites the accuracy of the previous radiation estimates will be established.

2) There will be estimates of the effect of cloud cover on the depletion of radiation compared to the clear sky estimates. Data for the calendar year 1997 will be used. The estimates will be made as follows:

Observed daily totals of K down at the four observing sites will be used to scale the daily values of K down for grid points in four areas of the complete forest estimated to be represented by the K down values of these sites.

A subsidiary experiment will make estimates of cloudiness-related reduction of clear sky K down using the range of daily maximum and minimum temperatures. This approach is often used in cases where actual observations of cloud cover are not available and it will be important to test the accuracy of the method since it will likely be used when the results from the current study are scaled up to a larger geographic area. Following the approach of other workers (e.g. Running et al, 1987) the range between the maximum and minimum temperatures will be taken as an index of daily cloud cover. Using daily data for CENMET site and working on a month by month basis the day(s) with the lowest range will be assumed to have complete cloud cover while those with the largest range will be taken to have clear sky. Observed daily totals of K down, which are directly dependent on cloud cover, will be used to scale the temperature range to provide an index of cloud cover and, more specifically, how much to reduce the clear sky K down estimates.

3) The best estimates of albedo for the different surfaces of the HJA will be obtained based on measurements for similar surfaces appearing in the literature and LANDSAT reflectance measurements for PNW forests made by Dr. Warren Cohen.

4) The latest available data layer of forest type and land surface cover from the HJA GIS, and the results from step 3 above will be used to assign albedo values to all points on the radiation grid. I will then calculate the mean annual and spatial (averaged across the grid points) absorbed radiation for the grid, which will be used as representative of the whole forest. The calculations will be repeated at all grid points using albedo values representative of mature old growth, secondary regrowth (circa 120 yr. old) forest, grass, and bare soil. These four calculations, along with the original one of present day land cover, will give an estimate of the potential range of absorbed K down one might expect for the forest under different extreme scenarios.

5) I will then make an historical reconstruction of the HJA surfaces for about the last 50 years, and apply the 1997 absorbed radiation estimates at 10-year intervals using the reconstructed surface appropriate to each of the intervals. This procedure will provide an approximate history of the absorbed radiation at the Forest over the second half of the 20th century.

6) An error analysis will be performed to estimate the range of accuracy of the estimates made in the various scenarios. The climate of 1997 will be placed in its temporal perspective.

TASKS ACHIEVED

Work has been completed on several of the steps outlined above. The following steps have been taken.

The spatial data set has been established. A review of albedo values has been made and will be continued. Initial point modeling studies were completed of the effect of changing forest albedo. Preliminary analysis of the relation between radiation and diurnal temperature range has been made. Some error considerations have been made of the variables considered in this report. Several miscellaneous items have also been completed.

The Spatial Data Base

General Description

The spatial data base used for this study is the same as that employed to estimate the potential radiation receipt at the HJA (Greenland, 1996) and was derived as follows.

The spatial data base is grounded on Digital Elevation Model (DEM) data for an area which encompasses the H. J. Andrews Forest. Dr. Warren Cohen, Hazel Hammond, and Maria Fiorella kindly provided the data.

The elevation data in meters above mean sea level are in a file called BASEDEM. This is a text file of elevation data employed for the Andrews Forest area and the Andrews LTER GIS Atlas. Data points represent 30 m cells. Data come from UTM zone 10 and have the following coordinates: xmin, ymin: 558365, 4893415 xmax, ymax: 572075, 4903705. The file contains 343x457, i.e. 156,751 data points. The density of the BASEDEM grid was reduced to a matrix of 115 columns and 86 rows placed in an ASCII file called LOWRES in order to make computations and later data entry manageable. The cell size of LOWRES is 120 m. Another program uses data from the LOWRES file and provides data on the exact UTM coordinates that correspond with the row numbers and column numbers in the data matrix of the LOWRES file. The data are provided in the output file UTMOUT. The UTM coordinates of the approximate and the detailed boundary of the HJA are available. The rows of the LOWRES data file were reversed. This permits the contouring program, SURFER, to produce a map with north at the top of the page and allows for the fact that the original DEM data were stored from "the bottom up". A further file is used for input into SURFER to produce a topographic map spatially compatible with the output radiation data sets and maps. Removing the outer two rows and columns of data points from the original elevation data file produces the compatibility. This step is taken because the program that computes the potential radiation uses the data from the outer two rows for radiation computation but cannot actually compute radiation for the data in those rows.

The potential direct radiation estimates were placed in a series of files called DIR1221, DIR0151, DIR0214, DIR0315, DIR0415, DIR0515, and DIR062.1 These are output files of direct radiation for the days indicated in the last four digits of the filename e.g. 1221 is for Dec. 21. DIF1221, DIF0151, DIF0214, DIF0315, DIF0415, DIF0515 and DIF0621 are output files of direct plus diffuse radiation for the days indicated in the last four digits of the filename. All these files still have SURFER header information on them but would have to have a suffix .GRD added to the file names for entry into SURFER. All of these DIR and DIF files represent the output from the potential radiation program were renamed to preserve the integrity of their date.

Detailed Description of Formation

The spatial data base is grounded on Digital Elevation Model (DEM) data for an area which encompasses the H. J. Andrews Forest. The data were kindly provided by Dr. Warren Cohen.

As mentioned, the elevation data in meters above mean sea level are in a file called BASEDEM. This is a headerless ASCII text file of elevation data employed for the Andrews Forest area and the Andrews LTER GIS Atlas. Data points are space separated. They represent 30 m cells. The density of the grid was downgraded in order to make computations and later data entry manageable.

The density was reduced using a program called SKIP. This is a FORTRAN program that reduces the number of data points in BASEDEM to a matrix of approximately 100x100. The user is asked for number of rows and columns in BASEDEM file and the number of points to skip (skip factor) when producing the output file called LOWRES.

Consequently the actual elevation data used for the study are in a file called LOWRES. This is the ASCII file data output from SKIP. LOWRES contains a reduced size matrix in FORTRAN format F5.0. This file contains 115 columns and 86 rows of elevation data. 575 DOS columns and 86 DOS rows are used.

A program called UTM2 uses data from the LOWRES file and provides data on the exact UTM coordinates which correspond with the row numbers and column numbers in the data matrix of the LOWRES file. The data are provided in the output file UTMOUT (Table 1). So UTMOUT is the output from UTM2 and gives the UTM coordinates for each point on the LOWRES data matrix. This information will be required for adding the output radiation data to the Andrews or other GIS system but remember the DIRxxxx and DIFxxxx files have a matrix in which the two outer rows and columns of data from LOWRES have been removed from each side of the matrix. UTMOUNT is a very large file and should only be examined electronically. An example of its output is found in Table A1 below.

It is necessary to add the approximate boundary of the Andrews Forest to output graphics. The approximate boundary is given in a file called HJACOORD.utm (Table 2) while a detailed boundary is located by the UTM coordinates given in file HJAUTM (Table 3).

The ELDAT program uses LOWRES as data and produces a file called ELEVDATA which 1) has rows reversed (compared to as they were in LOWRES), 2) adds a header for the SURFER program, and 3) outputs the data in no more than 250 (DOS editor) columns. The reversal in step 1 makes the former bottom row the top row and the original second row from the bottom becomes the second row from the top etc. This permits the contouring program, SURFER, to produce a map with north at the top of the page and allows for the fact that the original DEM data were stored from "the bottom up"

It is necessary to remove the header from the ELEVDATA file and add ANRAD5 header data and then rename the file ANDAT3 before using ANDAT3 as a data file for ANRAD5 that is the main program computing potential insolation values and is based on the Williams Model.

Thus ELEVDATA is the file produced by the ELDAT program and ANDAT3 is the data file for the ANRAD5 program.

RADELEV is a data file of elevation points. The file is produced by the program ANRAD4E and is used for input into SURFER to produce a topographic map spatially compatible with the radiation data sets and maps produced by ANRAD5. The compatibility is produced by removing the outer two rows and columns of data points from the original ELEVDATA file. This step is taken because the ANRAD5 program uses the data from the outer two rows for radiation computation but cannot actually compute radiation for the data in those rows.

Thus ANRAD4E is the program that produces the RADELEV data set which is a matrix of topographic points similar to ELEVDATA but with the data for the two outer rows and columns of the matrix missing.

Table 1. Example of data in the UTMOUNT file that may be used to identify the UTM coordinates of the data points in the 115 columns by 86 rows of elevation data in the LOWRES elevation data file.

Position in LOWRES				UTM Coordinate			
ROW NUMBER	1	COL NUMBER	1	UTMY	4903705	UTMX	558365
ROW NUMBER	1	COL NUMBER	2	UTMY	4903705	UTMX	558485
ROW NUMBER	1	COL NUMBER	3	UTMY	4903705	UTMX	558605
ROW NUMBER	1	COL NUMBER	4	UTMY	4903705	UTMX	558725
ROW NUMBER	1	COL NUMBER	5	UTMY	4903705	UTMX	558845
ROW NUMBER	1	COL NUMBER	6	UTMY	4903705	UTMX	558965
ROW NUMBER	1	COL NUMBER	7	UTMY	4903705	UTMX	559085
ROW NUMBER	1	COL NUMBER	8	UTMY	4903705	UTMX	559205
ROW NUMBER	1	COL NUMBER	9	UTMY	4903705	UTMX	559325
ROW NUMBER	1	COL NUMBER	10	UTMY	4903705	UTMX	559445
ROW NUMBER	1	COL NUMBER	11	UTMY	4903705	UTMX	559565
ROW NUMBER	1	COL NUMBER	12	UTMY	4903705	UTMX	559685
ROW NUMBER	1	COL NUMBER	13	UTMY	4903705	UTMX	559805
ROW NUMBER	1	COL NUMBER	14	UTMY	4903705	UTMX	559925
ROW NUMBER	1	COL NUMBER	15	UTMY	4903705	UTMX	560045
ROW NUMBER	1	COL NUMBER	16	UTMY	4903705	UTMX	560165
ROW NUMBER	1	COL NUMBER	17	UTMY	4903705	UTMX	560285
ROW NUMBER	1	COL NUMBER	18	UTMY	4903705	UTMX	560405
ROW NUMBER	1	COL NUMBER	19	UTMY	4903705	UTMX	560525
ROW NUMBER	1	COL NUMBER	20	UTMY	4903705	UTMX	560645

Table 2. UTM Points defining the approximate perimeter of the Andrews Forest and the Primary Meteorology Station.

Points defining the perimeter of the Andrews Forest

1	558,851.600	4,894,641.000
2	559,517.800	4,896,517.000
3	562,305.400	4,899,165.000
4	566,425.400	4,902,723.000
5	568,336.300	4,903,320.000
6	569,318.100	4,901,987.000
7	569,072.700	4,900,742.000
8	570,019.400	4,899,147.000
9	571,351.800	4,898,218.000
10	571,807.600	4,895,623.000
11	571,123.900	4,894,466.000
12	568,967.400	4,894,554.000
13	566,548.100	4,894,361.000

14 564,619.600 4,895,220.000
15 562,024.900 4,895,150.000
16 560,429.400 4,893,922.000

Point location of the Primary Met Station:
559,447.440 4,895,455.000

Table 3. An example of the first few of 1280 UTM Points defining the perimeter of the Andrews Forest.

566327.12 4902367.00;
566346.44 4902428.50;
566343.12 4902471.00;
566349.12 4902504.50;
566365.25 4902550.00;
566395.69 4902610.00;
566439.75 4902659.00;
566516.94 4902696.00;
566588.38 4902717.00;
566675.12 4902734.00;

The Actual ALCLIM Data Base

Given the above information, the actual data base for the ALCLIM project is the elevation data grid in the file RADELEV and the direct plus diffuse potential radiation in the daily files DIFxxxx for which DIF0621 will serve as the prime working file. These files have been placed in a computer area that I call ALCLIM Disk 2. It is necessary to give a detailed description of them and their UTM Coordinate registration details. The registration details will be the same for both files and actually it is only necessary to work on DIF0621.

The Surfer header was removed from DIF0621 and was saved in Disk 2: Surferheader.txt
The Surfer header is as follows:

```
DSAA
 111   82
   1 111
   1  82
     17.45    38.33
```

This indicates the DIF0621 file has 111 columns and 82 rows.

The first ten data points in row one are:

```
30.12 28.36 29.35 34.11 36.20 36.98 36.06 34.63 34.54 34.24
```

The data thus are space delimited with explicit decimal points with implicit format F5.2
The data are in MJ/sq.m/day.

Identification of UTM coordinates of DIF0621

The original LOWRES file had data points in the 115 columns and 86 rows. But remember that ELDAT reversed the rows before they were operated upon to arrive at DIF0621. Excel file Rows in disk 2 contains the corresponding numbers of the LOWRES rows, the reversed ELEVDATA rows, and the corresponding DIF0621 row numbers. So counting from the top left hand corner of the matrix(ices), as far as the UTMOUT cipher is concerned, the starting point (top left hand corner) of DIF0621 will correspond to row 84 column 3 of the LOWRES data set and (using UTMOUT) will also correspond to the UTM coordinates x =558605 y = 4893745. By similar reasoning the ending data point (bottom right hand corner) of DIF0621), as far as the UTMOUT cipher is concerned, will correspond to row 3 column 113 of the LOWRES data set and (using UTMOUT) will also correspond to the UTM coordinates x = 571805 y = 4903465.

The points representing the approximate boundary of the HJA will be

17,1
3,8
8,24
32,46
66,76
82,81
90,82
88,82
96,46
107,38
111,16
105,7
87,8
67,1
51,13
29,13
16,2
3,8

and are found on ANRAD Data Management Surfer – file Perim1.bln

The UTM coordinates representing the PRIMET, VANMET, CENMET, and UPLO meteorological stations are:

PRIMET	559447	4895455
VANMET	567879	4902177
UPLMET	570358	4895048
CENMET	568541	4899039

These UTM coordinates were provided by Hazel Hammond (pers. Comm. July, 1998). The row and column numbers have been added using the UTMOUT program output.

Locational Information on HJA Benchmark Meteorological Stations

Station	Actual UTM Coordinate X	Y	Nearest ANRAD Grid Coordinate X	Y	Difference in meters X	Y	Grid Column Number	Grid Row Number
PRIMET	559447	4895455	559445	4895425	2	30	10	69
VANMET	567879	4902177	567845	4902145	34	32	80	14
UPLMET	570358	4895048	570365	4895065	-7	-17	101	73
CENMET	568541	4899039	568565	4899025	-24	14	86	40

Hazel Hammond also provided the latitude and longitude of these points observed via a GPS unit. These data are:

```
PRIMET   44-12-42.64   122-15-21.20
VANMET   44-16-17.85   122-08-58.17
UPLMET   44-12-25.96   122-07-09.81
CENMET   44-14-35.90   122-08-29.80
```

According to Ms. Hammond these should be good to within 10 meters.

The points representing the PRIMET, VANMET, CENMET, and UPLO meteorological stations will be

8,15,"Primet"
77,71,"Vanilla Leaf"

and the data file for Surfer to use this data is found on ANRAD Data Management Surfer – file Climsite.dat
The output from the file is as follows:

"Col No","Row No"
8,15,"Primet"
77,71,"Vanilla Leaf"

Also note that the ANRAD Data Management Surfer diskette contains Topog3.SRF – the Surfer file needed to draw the topographic map of the Andrews including the boundary and the two climate sites.

Albedo Values

An extensive search for published and observed albedo values has been undertaken.

The initial idea for this project came as a result of the work of Dr. Warren Cohen at the Forest Science Laboratory at Corvallis, Oregon. Cohen used LANDSAT data to identify the mean reflectance of eight different forest surface types in the six different wavebands of the LANDSAT Thematic Mapper (TM). The TM spectral bands are associated with the following wavelengths (in microns): 1 (0.45-0.52 Blue), 2 (0.52-0.60 Green), 3 (0.63-0.69) Red, 4 (0.76-0.90) Near-infrared, 5 (1.55-1.75) Mid-infrared, 6 (10.4-12.5) Thermal infrared, 7 (2.08 - 2.35) Mid-infrared. His work shows that as one goes from old growth forest through mature, clear-cut, young closed, and young open forest surfaces there is an increase in reflectance values in most wavebands but particularly in the longer near and mid-infrared wavelengths. These data can be used to scale albedo data taken from surface measurements. Cohen (pers. comm, 1998) reports that no further work has been done on this data set but that new remote sensing campaigns in the next few years may be more productive.

Swanson (pers. comm, 1992) has pointed out several implications of the fact that more manipulated forest land surfaces may have higher albedo values . First, the cutting of large areas of old growth forests in the W PNW in the last century must presumably have increased the overall reflectivity of large areas of the region. Second, any move to a shorter forest rotation system (e.g. cutting every 40 years as opposed to 100 years) would result in larger areas of young open and closed forest existing for longer periods of time and thus again increasing the overall reflectivity of the region. There will be many secondary effects as well. Some of these will act as positive feedbacks. For example, snow cover as seen from the air (or by incoming radiation) will last longer in clear-cuts than on, or in, the canopies of mature forest. Long ago Hare and Ritchie (1972) clearly demonstrated that a similar phenomenon acting on the tundra and open and closed Boreal forest in N.E. Quebec. Here the forest gaps at the tundra edge gave rise to the forest climate being markedly warmer than the tundra climate particularly in the spring when the snow lasted longer on the tundra surface and increased its albedo. Indeed, Sagan et. al. (1979) have gone as far as to suggest that human activity (primarily activities leading to desertification) in the past several millennia has increased the global albedo causing the present climate to be 1 to $2^{O}K$ cooler than during the Climatic Optimum, and an extrapolation of present rates of change of land use suggests a further decline of $1^{O}K$ in global temperature by the end of the next century. More specifically, and more importantly to the present proposal, actual radiation budget measurements relating to the effect of clearcutting were made by McCaughey in Quebec. At a site at Montmorency following the logging of Balsam fir, net radiation values decreased by 10% to 22% and the albedo values increased from 0.7 to 0.18 (McCaughey, 1978, 1981, 1982). A review of albedo values clearly indicates that forest clearings, or their equivalent surfaces, have a markedly higher albedo value than do coniferous forest surfaces (Table 4). The data in Table 4 were taken for different times of the year at different latitudes. Readers requiring more specific details should refer to the individual papers. The radiation balance of cleared Douglas Fir forest in southwest Oregon measured by Holbo and Childs (1987) is of particular importance in the present study. They measured albedo directly 1.2 m above the soil surface with the sensor oriented parallel to the local slope.

Table 4. Observed values of albedos for forest surfaces

Surface	Albedo	Source
Forested Surfaces:		
Coniferous forest	0.10 - 0.15	Rosenberg et al., 1983
	0.16	Monteith, 1973
	0.05 - 0.15	Oke, 1987
Pine forest various	0.08 - 0.20	Jarvis et al., 1976
	0.13 - 0.23	Federer, 1968
Jack pine	0.12	Harding and Pomeroy, 1996
Pine with snow	0.17	Federer, 1968
Douglas Fir	0.09	Jarvis et al., 1976, Gay, 1972 (quoted in Jarvis) Gay and Stewart, 1973 (quoted in Jarvis)
Balsam Fir	0.08	McCaughey,1981
Spruce (abies)	0.05-0.06	Jarvis et al., 1976
Black spruce	0.08	Sharratt, 1998
Red Spruce/Eastern Hemlock	0.09-0.11	Eck and Deering, 1992
Dense conifer forest (Sweden)	0.12-0.13	Odin and Perttu, 1966
Sparse conifer forest (Sweden)	0.10-0.11	Odin and Perttu, 1966
Deciduous forest at end of winter (Moscow)	0.24-0.30	Rauner (1961)
Cleared Surfaces:		
SW Oregon clearcut	0.22	Holbo and Childs, 1987
SW Oregon clearcut &burn (2 sites)	0.13	Holbo and Childs, 1987
SW Oregon shelterwood & burn	0.12	Holbo and Childs, 1987
SW Oregon shelterwood (2 sites)	0.21	Holbo and Childs, 1987
Field	0.18 -0.20	Federer, 1968
Field with snow	0.72	Federer, 1968
Grass	0.24	Monteith, 1973
Grass (Alaska)	0.19	Sharratt, 1998
Short grass	0.26	Oke, 1987
Heather	0.14	Monteith, 1973
Bracken (ferns etc)	0.24	Monteith, 1973
Gorse	0.18	Monteith, 1973
Mediterranean evergreen	0.21	Monteith, 1973 scrub (Maquis)
Cleared Balsam Fir	0.17	McCaughey, 1981
Cleared conifer forest (Sweden)	0.14-0.18	Odin and Perttu, 1966
Snow Covered Vegetated Surfaces		
Grass (Alaska)	0.60-0.84	Sharratt, 1998.

There seem to have been rather few forest surface albedo values, of the kind applicable to the Pacific Northwest Andrews forest, reported in the literature over the past few years. There are two reasons for this. One is that there has been a concentration on satellite remote sensing techniques. It should be noted that most satellite reflectance data are not directly useful for the kind of study reported here because the data come from once a day (or less) overpasses taken at one instant during daylight hours whereas albedo values need to be averaged over all daylight hours. The satellite data are also subject to atmospheric interference of various kinds. The second reason for the lack of albedo observations is that they require towers or very low flying platforms from which to be made. Albedo observations from the Wind River Crane, WA were requested for this study but have yet to be provided (Franklin, pers. comm. 1998). Albedo data were also requested from Dr. Tony Black at the University of British Columbia but no response was received. Data from the OTTER and BOREAS projects and Amazonian deforestation studies have yet to be searched for albedo values.

Point Modeling Studies

The question of what role an albedo change might play between the forested and clear-cut surface can be approached initially by simulation modeling. Application of a simple microscale climate model to the Andrews Forest indicates some of the range of microclimate variation that might be expected in this location associated with a change from mature forest to a clear-cut situation. The model used is an advanced version of the surface temperature equilibrium model first introduced by Myrup (1969).

Employing input data on air temperature, relative humidity, and wind velocity from Bierlmaier and McKee (1989) and standard values from the literature for other parameters, surface energy budget and soil temperature values were simulated for a summer, equinox, and winter situation for a forest are and a clear-cut area (Table 5). Mean daily air temperatures, relative humidities, and wind velocities were changed with season but all other variable values remained constant except for albedo. The albedos of the Douglas Fir forest, clear-cut (grass), and clear-cut (old snow in the winter) were taken as 0.09, 0.24, and 0.50 respectively.

Table 5. Simulated Daily Surface Heat Budgets, Evaporation, and Soil Temperatures for the Andrews Forest. Heat Fluxes are in MJ/m^2, Evaporation is in mm, Temperatures are degrees C. K = Incoming shortwave radiation, R_n = Net Radiation, LE = Latent Heat Flow, H = Sensible heat Flow, G = Substrate Heat Flow, E = Evaporation, Maximum and Minimum soil temperatures are listed for 6.25 cm and 50 cm depth.

	K	R_n	LE	H	G	E	6.25	50
Summer Solstice								
Forest	31.3	21.2	14.0	6.9	0.4	5.7	18.0/13.5	15.5/15.0
Clear-cut	31.7	16.8	12.9	3.7	0.2	5.2	18.2/12.8	14.8/14.2
Clear-cut with low roughness length	31.7	17.1	2.8	8.0	2.9	1.2	19.3/4.1	6.2/5.6
Spring Equinox								
Forest	19.1	10.0	2.9	6.7	0.4	1.2	9.4/3.5	5.1/5.0
Clear-cut	19.4	7.3	2.4	4.6	0.3	1.0	8.9/3.5	4.9/4.8
Winter Solstice (with high soil moisture)								
Forest	6.9	-0.8	0.0	-0.3	-0.5	0.0	2.0/-1.8	0.6/0.6
Clear-cut (with snow cover)	7.1	-3.4	-0.8	-1.9	-0.7	-0.3	1.0/-1.8	0.5/0.5

As expected, in all cases the effect of the higher albedo in the clear-cut is to lower the net radiation. Although the present study concentrates on alterations to the radiation balance some discussion on the effects on the other variables is of interest. Accompanying higher albedos there is also a decrease of evaporation and latent and sensible heat fluxes in the clear-cut compared to the forest. The decrease is rather small but could be important when scaled up to a large geographical area. In winter, condensation of water vapor onto the snow surface is indicated.

The model employed here is really not designed for use with tall forest vegetation. In order to have comparisons with only the albedo variable altered, a roughness length of 4.0 m (representing the forest) was used in all simulations. However, when the roughness length value is placed at a more realistic 10 cm for the clear-cut (Table 5, Summer, Clearcut with low roughness length), the result is a greatly reduced latent heat and evaporation value for the clearcut and a very large soil temperature gradient and flow of heat into the soil. The simulation suggests two possibilities. First, it may not just be the alteration of albedo between forest and clear-cut alone that will cause a change in the climate, but the structural alterations of the surface morphology may also have an equal or greater effect on the turbulent, as opposed to the radiant, heat fluxes. Second, we learn that there may be a trade off when moving between a forested and clear-cut environment between cooling due to a reduction in net radiation and heating due to a reduction of the cooling effect of evaporative heat loss. Which of these processes is most important might well be a scale problem that can be answered by future research.

Preliminary analysis of the relation between radiation and diurnal temperature range

A major research project in itself is to establish the relationship for the HJA locations between solar radiation (K down) receipt and the diurnal temperature range. The latter is used as an index of cloud cover and subsequently to scale the model estimated solar radiation for a given day for the 'actual' amount as reduced by cloud presence. The importance of doing this for the HJA is evident when the daily radiation values are plotted (Fig. 2).

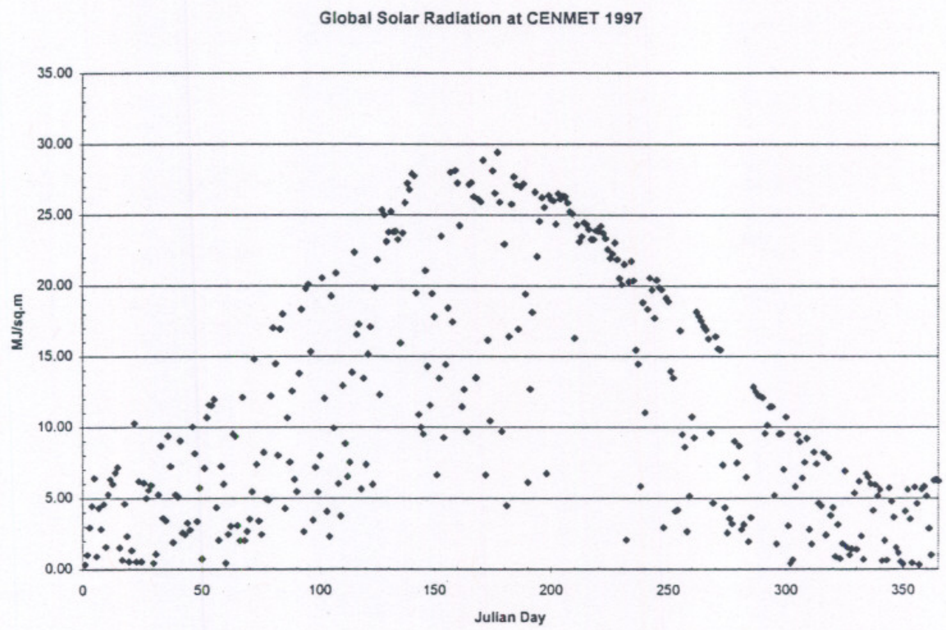


Fig. 2. Observed daily global solar radiation at the CENMET site during 1997.

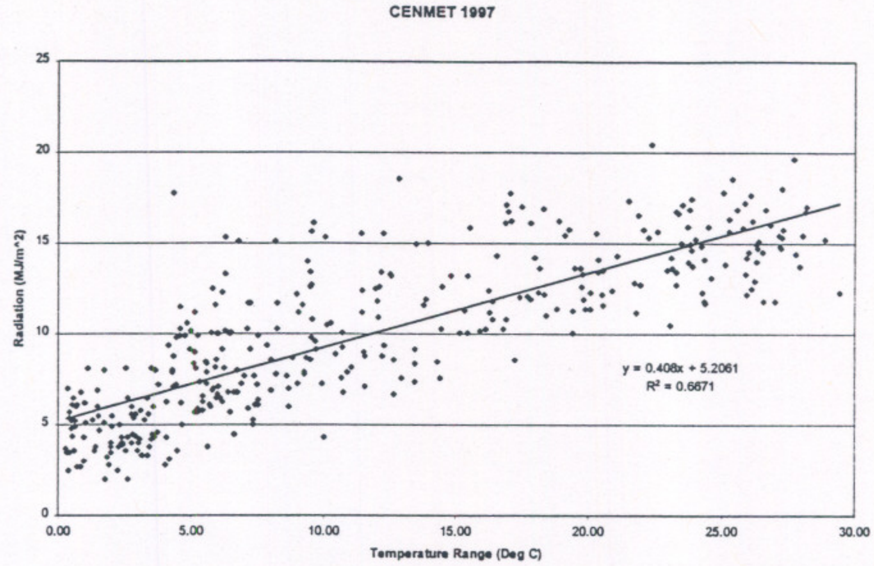


Fig. 3. The relationship between daily radiation data and diurnal temperature range at CENMET during 1997.

The relationship between these daily radiation data and diurnal temperature ranges for the whole year is shown in Fig. 3. A fairly good relationship with an r^2 value of 0.67 is seen. There is also considerable scatter. Future predictions will be made better by using individual regressions for each season for each benchmark meteorological site. Table 6 shows r^2 and standard error of estimate (SEE) values apply to the CENMET site for the seasons defined as winter (Dec, Jan, Feb), spring (Mar, April, May), summer (June, July, Aug), and fall (Sept, Oct, Nov):

Table 6. r^2 and standard error of estimate (SEE) values apply to the CENMET site.

Season	r^2	**SEE** in MJ/m^2
Winter	0.58	3.56
Spring	0.73	16.40
Summer	0.74	11.5
Fall	0.68	10.36

These values would give fairly good estimates of daily radiation simply by using the calculated regression equations. However, Running et al, (1987) use a more sophisticated relationship developed by Bristow and Campbell (1984) between atmospheric transmittance and daily temperature range.

The Bristow and Campbell procedure is empirically based using data from three sites in the state of Washington. Transmittance, T_t, is given by an empirical equation

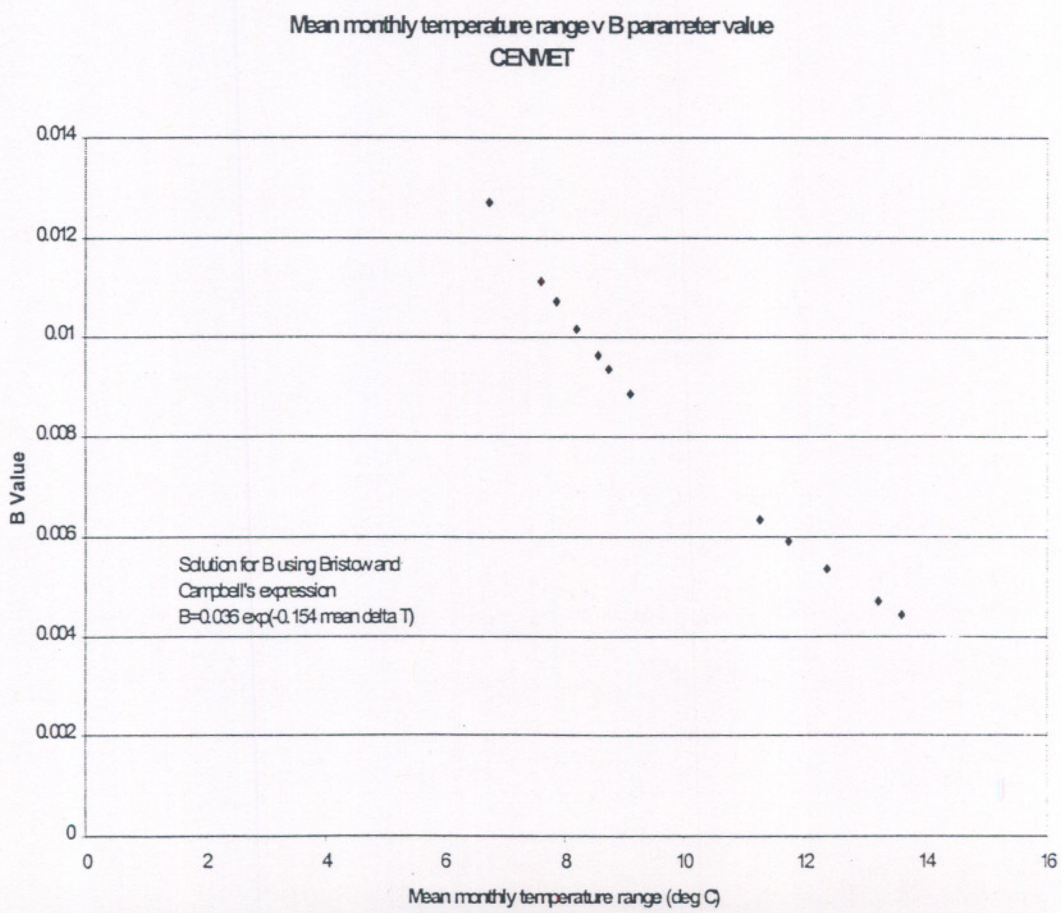
$$T_t = A\,(1 - \exp\,(-B\,\Delta T^{C})$$

where A, B, and C are empirical coefficients. Bristow and Campbell found it adequate to hold C constant at 2.4, A at 0.70 and to vary only B in order to distinguish between seasonal data. They compute the daily temperature range using

$$\Delta T_j = T_{max\,j} - (T_{min\,j} + T_{min\,j+1})\,/\,2.$$

The applicability of this technique for HJA is being investigated. A good stable relationship was found between the value of B and the mean monthly temperature range at CENMET (Fig. 4). This investigation will be taken further in a later study. However, after an error analysis is performed it is likely that the simple daily temperature versus radiation regression broken into seasonal groups will be adequate for this study.

Fig. 4. Relationship was found between the value of B and the mean monthly temperature range at CENMET



Error Analysis

The actual values of observed radiation and albedo in the studies quoted in the present study are believed to be accurate in the orders quoted by Holbo and Childs (1987). These authors suggest $K\downarrow$ can be measured to an accuracy of less than 2% of the maximum daily value averaging about 14 W/m^2 (in Oregon) while their $K\uparrow$ values are accurate to less than 14%. The error of the resulting quotient ($K\uparrow / K\downarrow$) for observed albedo would be approximately the difference between the two i.e. 12% (Topping, 1955).

Miscellaneous Items Completed

Many miscellaneous items have also been completed on this project. They include the following:

Correspondence continues with Ms. Hazel Hammond concerning the provision of digital land use data from the HJA GIS.

HJA radiation data have been obtained from Mr. Don Henshaw. Apart from analysis of the relation between radiation and diurnal temperature range, these data will be used in the future to assess the accuracy of earlier modeled radiation values.

There has been a need to update or replace software during the course of this project. Currently new versions of Word, Excel, Fortran, Minitab, and Freehand have been obtained.

CONCLUSIONS

My overall conclusion is that the completion of the overall project demands a much larger amount of work than originally anticipated. This work will be performed according to the plan in the next section.

Specific conclusions are as follows:

1) A GIS system can not be used for this work because of the need for complex mathematic manipulations within and across cells of the data base. The task of data base development for this project is not trivial but has now been achieved and documented.
2) There is a shortage of good albedo observations relevant to the forests such as the HJA. Pending specific NASA over flights the best available data have to be employed.
3) Point modeling studies clearly demonstrate the importance of the focus of this investigation and, even more, the need for the completion of the spatially distributed radiation estimations under different forest manipulations.

4) Preliminary analysis of the relation between radiation and diurnal temperature ranges shows:

a) Large day to day variability of radiation receipt at the HJA demands that modeling estimates be made on a daily basis and only then, if necessary aggregated to larger time periods.
b) A good relationship exists between daily radiation and diurnal temperature range especially when the relationships are made by seasonal groupings.
c) The Bristow and Campbell relation between radiation and diurnal temperature ranges is strong and robust at the HJA. It is not yet certain whether the improvement in results it gives will be worth its application in further development of this project.

PLANS FOR FURTHER WORK

The remaining steps outlined in the "detailed work concept" section above will be completed in the future. It is difficult to anticipate how long this will take. Each step provides unanticipated difficulties and will be made with as much care as possible. Only in this way will we have the required confidence in the replicability and accuracy level of the work. It is planned to develop this work in a modular fashion such that when new data become available, such as from over flight remote sensing, the results obtained in this study may easily be updated.

This work also remains part of a larger project in which the final goal is to provide a working model of the HJA, at the spatial resolution identified here, to link the values of all the surface energy budget variables (net radiation, latent and sensible heat flow, and ground heat flow) with specific surface types and their real and potential changes. Since this goal was identified in the early 1990s increasing attention has been given to the two-way interaction between the ecosystem and the atmosphere. The HJA provides a perfect real world laboratory for such investigations. It is apparent now that the results and overall goal will not be achieved easily. However the insights gained along the way justify the continued effort.

REFERENCES

Bierlmaier, F.A., and McKee, A 1989. Climatic summaries and documentation for the primary meteorological station, H. J. Andrews Experimental Forest, 1972-1984. USDA Forest Service, Pacific Northwest Research Station. Portland, OR. General Technical Report. PNW-GTR-223 26 pp.

Blinn, T., Swanson, F.J., and McKee, A. 1988. Research Publications of the H. J. Andrews Experimental Forest, Cascade Range, Oregon, 1988 Supplement. General Technical Report. PNW-GWT-223. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 26 p.

Bristow, K. L. and G. S. Campbell. 1984. On the relationship between incoming solar radiation and daily maximum and minimum temperature. Agricultural and Forest Meteorology. 31:159-166. (S600.A27).

Eck, T. F. and D. W. Deering. 1992. Canopy albedo and transmittance in a spruce-hemlock forest in mid-September. Agricultural and Forest Meteorology. 59:237-248.

Federer, C.A. 1968. Spatial variation of net radiation, albedo and surface temperature of forests. Journal of Applied Meteorology 7:789- 795.

Franklin, J. F., Bledsoe, C. S., and Callahan, J. T. 1990. Contributions of the Long-Term Ecological Research Program. BioScience. 40(7)509-523.

Gay, L.W. 1972. Energy flux studies in a coniferous forest ecosystem. in Proceedings - Research on coniferous forest ecosystems - A Symposium. ed. J.F. Franklin, L.J. Dempster, and R.H. Waring. pp 243-253. Pacific and Northwest Forest and Range Experimental Station. Portland. Oregon.

Geiger, R. 1965. The Climate Near The Ground. Harvard Univ. Press. Cambridge. Mass. 611 pp.

Greenland, D. 1996. Potential Solar Radiation at the H. J. Andrews Experimental Forest. Interim Report on research performed under USDA Forest Service, Pacific Northwest Research Station, Cooperative Agreement No. PNW 93-0477. 39 pp.

Hare, F.K. and Ritchie, J.C. 1972. The Boreal Bioclimates. Geographical Review. 62(3)333-365.

Harding, R. J. and J. W. Pomeroy. 1996. The energy balance of the winter Boreal landscape. Journal of Climate. 9(11)2778-2787.

Holbo, H.R., Childs, S.W., and McNabb, D.H. 1985. Solar radiation at seedling sites below partial canopies. Forest Ecology and Management 10:115-124.

Holbo, H.R., and Childs,S.W. 1987. Summertime radiation balances of clearcut and shelterwood slopes in southwest Oregon. Forest Science 33:504-516.

Jarvis, P.G., James, G.B. and Landsberg, J.J. 1976. Coniferous Forest. in Vegetation and the Atmosphere. Ed. J.L. Monteith. Vol 2. Academic Press. London. pp. 171-240.

McCaughey, J.H. 1978. Estimation of net radiation for a coniferous forest, and the effects of logging on net radiation and the reflection coefficient. Canadian Journal of Forest Research 8:450-455.

McCaughey, J.H. 1981. Impact of clearcutting on coniferous forest on the surface radiation balance. Journal of Applied Ecology 18:815-826.

McCaughey, J.H. 1982. Spatial variability of net radiation and soil heat flux density on two logged sites at Montmorency, Quebec. Journal of Applied Meteorology. 21:777-787.

McKee, A., Stonedahl, G. M., Franklin, J. F., Swanson, J. 1987. Research publications of the H. J. Andrews Experimental Forest, Cascade Range, Oregon, 1948 to 1986. General Technical Report. PNW-GWT-201. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 74 p.

Monteith, J.L. 1973. Principles of Environmental Physics. Edward Arnold. London. 241 pp.

Myrup, L.O. 1969. A numerical model of the urban heat island. Journal of Applied Meteorology. 8:908-918.

Odin. H. and K. Perttu. 1966. Radiation measurements near the forest limit in northern Sweden. Reports No.2. Meteorologiska Institutionen vid Kungl. Universitet Uppsala. 24 pp. (in Swedish with English summary).

Oke, T.R. 1987. Boundary Layer Climates. 2nd ed. Methuen. London. 435 pp.

Rauner, Yu. L. 1961. On the heat budget of a deciduous forest in winter. Izv. Acad. Sci. USSR, geographical series, #4, pp. 83-90.

Rosenberg, N.J., Blad, B.L., and Verma, S. 1983. Microclimate:The Biological Environment. Wiley. New York. 495 pp.

Running, S. W., Namani, R. R. and Hungerford, R. D. 1987. Extrapolation of synoptic meteorological data in mountainous terrain and its use for simulating forest evapotranspiration and photosynthesis. Candaian Journal of Forest Resources. 17:472-483.

Sagan, C., Toon, O.B., and Pollack, J.B. 1979. Anthropogenic albedo changes and the Earth's climate. Science. 206(4425)1363-1368 (Dec 21,1979).

Sharratt, B. S. 1998. Radiative exchange, near-surface temperature, and soil water of forest and cropland in interior Alaska. Agricultural and Forest Meteorology. 89:269-280.

Topping, J. 1955. Errors of observation and their treatment. Reinhold Publishing Corp. New York. 118 pp.