Programs to Estimate the Solar Radiation for Ecosystem Models

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## Introduction

The following manuscript documents the calculations used in two programs that we have developed to estimate the solar radiation input to a site based on its latitude, elevation, aspect,  slope, and cloud cover.  The effects of topographic shading are not included in this version of these programs.  The first program, SolarRad, is used for a single location.  The second program, SolarImg, is used for a multiple locations in a grid.  Both programs are coded in C and can be used either in a DOS or a UNIX environment.

Both programs input and output the same variables.  SolarRad inputs the latitude, elevation, aspect, and slope from one file (Locat.drv), whereas SolarImg inputs the elevation, aspect, and slope variables from different files containing a  grid of values.  Latitude is assumed to be constant in SolarImg, and therefore the geographic extent of the grid being represented should be held to less than 1 degree latitude.  Both programs require either monthly cloud cover data or climatic data to predict monthly cloud cover.  It is assumed that the climatic data applies to the entire area being considered.  SolarRad outputs a single file (Radiate.drv) that contains the monthly data, whereas SolarImg outputs a grid for each month.  The data that are output for both programs are mean daily direct, diffuse, and total solar radiation.  The SolarRad program also outputs the azimuth angle of the sun at sunrise and the maximum solar altitude from the horizon for each month as well as the annual average of these and the radiation parameters.

These programs have several potential uses.  The first is to supply estimates of solar radiation required to run simulation models (Urban 1993, Harmon et al. in review).  The second is to combine with other climatic data such as temperature to estimate other climatic variables such as Potential Evapotranspiration (Jensen and Haise 1963).  The Sun angle data can also be used to determine the effect of topographic shading, the passage of light through canopies (Urban 1993) or the effects of one patch of trees on another (Harmon et al in review).

## Overview

The calculations follow the method of Bonan (1989) and Nikolov and Zeller (1992).  Solar radiation and sun angle data can be calculated for any day of the year.  Unless one is interested in calculating daily values, we recommend that the day representing the mean daily value for a month be used (Table 1).

Table 1.  Days of the month that give the mean daily solar radiation after Klein (1977).

| Month | Date | Julian Day |
|---|---|---|
| January | 14 | 17 |
| February | 16 | 47 |
| March | 16 | 75 |
| April | 15 | 105 |
| May | 15 | 135 |
| June | 11 | 162 |
| July | 17 | 198 |
| August | 16 | 228 |
| September | 15 | 258 |
| October | 15 | 288 |
| November | 14 | 318 |
| December | 10 | 344 |

The general flow of calculations in the programs is as follows:

1)  Estimate the amount of radiation entering the top of the atmosphere (see ExtraTerrestrial Radiation Function).

2)  Estimate the cloud cover based on monthly precipitation and temperature if these data are not directly available (see Cloud Function).

3)  Estimate the effect of season, latitude, elevation, and cloud cover on the transmission of solar radiation to a horizontal (i.e., non-sloping) surface (see Transmission Function).

4)  Based on the transmission of solar radiation, estimate the partitioning of solar radiation into direct and diffuse radiation (see Partition Function).

5)  Determine the effect of the slope of the site on the amount of diffuse radiation received (see Diffuse Tilt Function).

6)  Determine the effect of the slope of the site on the amount of direct radiation received (see Direct Tilt Function).

7)  Add the diffuse and direct radiation received by the surface (see Total Radiation Function).

8) Determine the azimuth angle of the sun at sunrise and the maximum solar altitude (see Sun Angle Function).

The details of each function are described more fully below.  We have followed certain naming conventions in the following equations.  Whenever a variable can apply to different time periods we have italicized the prefix.  Therefore any variable that contains Mon can apply to any month, and any variable that contains Hour can apply to any hour of the day.

**Convert Function.**

The purpose of this function is to convert all the angles that are expressed as degrees into radians by multiplying by 0.01745 radians/degree.   This conversion is computed for the latitude and slope steepness.  All other conversions to radians (e.g., aspect) are done within the formulae.

**ExtraTerrestrial Radiation Function.**

This function calculates the amount of radiation received at the top of the atmosphere for a given month.  The average daily radiation received by a horizontal surface above the atmosphere is estimated from the solar declination on a given day, the latitude, and sunrise/sunset hour angle.  The solar declination (MonSolarDec in radians) on a given day of the year is:

MonSolarDec= 0.4093 * sin (6.283*(284+MonJulian)/365)

where MonJulian is the Julian day of a month that gives the mean monthly solar radiation.  Note that in the right hand side of this equation Julian days are converted to radians and that the days of the year are offset to give correct seasonal phasing.  The sunrise/sunset hour angle for each month (MonHourAngle) is given by:

MonHourAngle =  arccos[- tan (Lat) * tan (MonSolarDec)]

where Lat is the latitude in degrees.  The solar radiation received at the top of the atmosphere (MonSolarRadTop) for a given Julian day (MonJulian) is:

MonSolarRadTop=(SolarConstant/3.1416)*[1+0.033*cos(6.197*MonJulian)]
              *[cos (Lat)*cos(MonSolarDec)*sin(MonHourAngle)
              +MonHourAngle*sin(Lat)*sin(MonSolarDec)]

Julian days are converted to an angle in radians by multipliying by 6.197 (6.283 radians *360 degrees/365 days per year).  The solar constant (SolarConstant) varies from source to source; we have set SolarConstant to 2880 cal cm-2 day-1 as in Bonan (1989).

**Cloud Function.**

The purpose of this function is to calculate the mean monthly cloud cover.  If these type of data are available, then they will be read directly from the file named Cloud.drv.  As

cloud data are rarely available, therefore we leave the option of calculating cloud cover from the temperature range and the amount of precipitation following the method of Urban (1994).  The first step is to calculate the saturation vapor pressures at the minimum (MonTempMin), the mean 24 hour (Temp24), and mean daytime (MonTempDay) temperature for each month:

MonEvapSatTempMin =  6.1078*exp [(17.269*MonTempMin)/(237.3+MonTempMin)]

MonEvapSatTemp24 = 6.1078* exp [(17.269*MonTemp24)/(237.3+MonTemp24)]

MonEvapSatTempDay = 6.1078* exp [(17.269*MonTempDay)/(237.3+MonTempDay)]

TempMin and Temp24 are taken from the Climate.drv file.  The mean daytime temperature (MonTempDay) is calculated from the mean 24 hour temperature (MonTemp24) and the mean maximum temperate (MonTempMax):

MonTempDay= 0.212* (MonTempMax-MonTemp24) +MonTemp24.

MonTemp24 and MonTempMax are read from the Climate.drv file.  The mean monthly relative humidity (MonRelHumid) is then calculated from the ratio of the monthly saturation pressures at the minimum and daytime temperatures:

MonRelHumid= 100*MonEvapSatTempMin/MonEvapSatTempDay.

The evaporative demand (MonEvap) increases with the relative humidity and the vapor saturation pressure at the mean temperature:

MonEvap= MonRelHumid * MonEvapSatTemp24

The monthly proportion of cloud cover (MonCloud) is then estimated as

MonCloud= 1.0 - 0.1155*(MonEvap/(MonPrecip*10))0.5

where MonPrecip is the monthly precipitation in cm from the Climate.drv file.  Because there are combinations of evaporative demand and precipitation that may give negative numbers, MonCloud is restricted to be a number greater than or equal to zero.

**Transmission Function.**

This function estimates the effect of clouds and elevation (as it influences the depth of the atmosphere) on the amount of radiation hitting a horizontal surface.  The radiation received at the top of the atmosphere is attenuated by the time it reaches the earth's surface.  Although some (Buffo et al 1977) have applied a constant factor, we estimate transmissivity based on latitude, elevation, and  mean monthly cloud cover as suggested by Nikolov and Zeller (1992).  The first step is to estimate the effect of latitude on transmissivity, with the assumption that as latitude increases, the

transmissivity decreases.   Several constants are calculated from latitude (Lat, which is in degrees):

CosLatConstant=1.0 - (1.3614 * cos (Lat))

This constant is then used to calculate two other constants used to estimate amount of radiation transmitted through the atmosphere:

TransConstant1= 32.9835- (64.884 * CosLatConstant)

and

TransConstant2 = 0.715 - (0.3183 * CosLatConstant)

These two transmission constants are used to estimate the amount of solar radiation actually received at the ground surface at sea level (MonSolarRadSeaLevel).

MonSolarRadSeaLevel= -TransConstant1+(TransConstant2 *MonSolarRadTop) -
(0.3259*MonSolarRadTop*MonCloud)

where MonCloud is the proportion of cloud cover (i.e., complete cloud cover = 1) and MonSolarRadTop is the radiation received at the top to the atmosphere.

In addition to the effect of latitude and cloud cover, transmission is assumed to increase with increased elevation.   The first step is to calculate the amount of radiation that is absorbed by the atmosphere at sea level:

MonMaximimRadAbsorbed = MonSolarRadTop - MonSolarRadSeaLevel

The next step is to calculate the fraction of this radiation that is not absorbed if the elevation is higher than sea level:

MonFractTrans = 1.0 -exp [-0.000067* (Elev/AvgSineSolarAltAngle)

where Elev is elevation in meters, and AvgSineSolarAltAngle is the average sine of the solar altitude angle as calculated below.  This equation is a simplification of the one presented by Nikolov and Zeller (1992).

The amount of total radiation reaching the surface each month (MonSolarRadSurf) is:

MonSolarRadSurf=MonSolarRadSeaLevel+(MonFractTrans*MonMaximimRadAbsorbed

**Partition Function.**

This function partitions the total amount of radiation that is received by a horizontal surface into direct and diffuse radiation.  The total solar radiation received at the earth's

surface is separated into direct beam (MonSolarDirect) and diffuse radiation (MonSolarDiffuse) by the method of Klein (1977). First one must calculate the fraction of solar radiation that is received at the ground surface for each month (MonFractRecived):

MonFractRecieved= MonSolarRadSurf/MonSolarRadTop

The fraction of solar radiation received as diffuse light each month (MonFractDiffuse) is an inverse function of the fraction of total radiation that is received:

MonFractDiffuse= 1.0045 + (0.0435*FractRecived) -(3.522 MonFractRecived2)
        + (2.6313*MonFractRecieved3)

This relationship appears to be good for a range of MonFractRecieved of 0.15-0.75. If FractRecieved is greater than 0.75 then MonFractDiffuse is set equal to 0.166.

The amount of direct radiation received by a horizontal surface without topographic shading (MonDirSolRad) will be:

MonDirSolRad= (1-MonFractDiffuse)*MonSolarRadSurf

The amount of diffuse solar radiation received by a horizontal surface without topographic shading (MonDiffuseSolRad) is:

MonDiffuseSolRad=MonFractDiffuse*MonSolarRadSurf

**Diffuse Tilt Function.**

This function adjusts the amount of diffuse radiation received by a site to account for the fact that on a tilted surface not all the sky is visible. For diffuse solar radiation the amount of energy received is directly proportional to the fraction of the sky that is not obscured:

MonDiffuseSolRadSlope=MonDiffuseSolRad*cos2(Slope/2)

where Slope is the site steepness in percent slope as stored in the Locate.drv file.

**Direct Tilt Function.**

This function estimates the effect of a tilted surface on the amount of direct radiation received following the method of Keith and Kreider (1978) and Liu and Jordan (1963). The effect of a sloping surface on direct solar radiation requires the daily average of the solar incidence angle (MonSolarIncAngle) and the daily average solar altitude angle (MonSolarAltAngle) for each month. To solve these one must compute hourly solar incidence and altitude angles, then compute an average. The first step is to calculate

the solar hour angle (SolHourAngle) for each hour of the day using a 24 hour clock, where Time is the time since midnight:

SolHourAngle=0.2618*(Time-12)

The sine of the solar altitude angle for a given hour of the day for a month is:

HourMonSineSolarAltAngle=sin(Lat)*sin(MonSolarDec)
                + cos(Lat)*cos(MonSolarDec)*cos(SolHourAngle)

For horizontal surfaces the cosine of the solar incidence angle is:

HourMonCosSolarIncAngle=HourMonSineSolarAltAngle.

For tilted surfaces facing directly south (180 degrees) with a slope of Slope:

HourMonCosSolarIncAngle=sin[Lat-0.01745*Slope]*sin(MonSolarDec)
                    + cos(Lat-0.01745*Slope)
                    *cos(MonSolarDec)*cos(SolHourAngle)

For tilted surfaces other than those facing south (180 degrees) the cosine of the solar incidence angle is:

HourMonCosSolarIncAngle=cos(AzimAngleSouth-AzimAngleWall)*
                cos(arcsin (HourMonSineSolarAltAngle))*sin(Slope)
                + HourMonSineSolarAltAngle*cos(Slope)

The azimuth angle of the sun from the south is given by:

MonAzimAngleSouth=arcsin[cos(MonSolarDec)*sin(SolHourAngle)/
Cos(arcsin(HourMonSineSolarAltAngle)]

The wall azimuth angle is defined as:

AzimAngleWall=0.01745*(180-Aspect)

To calculate how the direct solar radiation of a tilted surface deviates from the horizontal it is necessary to calculate the daily means of HourMonSineSolarAltAngle (AvgSineSolarAltAngle) and HourMonCosSolarIncAngle (MonAvgCosSolarIncAngle) for the period the sun is above the horizon and in front of the surface.  This means that only the hours which meet the following conditions should be used to compute the averages: when arcsin(HourMonSinSolarAltAngle) is more than 0 radians and arccos(HourMonCosSolarIncAngle) is less than 1.5708 radians.

The mean daily direct solar radiation recieved each month by a sloping surface (MonDirectSolRadSlope) is:

MonDirectSolRadSlope=MonDirectSolRad*MonAvgCosSolarIncAngle
/MonAvgSineSolarAltAngle.

## Total Radiation Function.

This function calculates the total radiation received as the mean daily amount for each month.  The total solar radiation received is:

MonSolRad=MonDirectSolRadSlope + MonDiffuseSolRadSlope

## Sun Angle Function.

This function calculates the azimuth angle of the sun at sunrise (SunriseAzimAngle) in degrees from south and the solar altitude angle when the sun is directly south (SolarAltAngleSouth) in degrees from the horizon for each month.  It also calculates the yearly average value of these variables, weighted by the mean daily radiation received each month.  The azimuth angle of the sun at sunrise for each month in degrees is given by:

MonSunriseAzimAngle= 57.3 *MonHourAngle

where MonHourAngle is the hour angle in radians from south at sunrise.  This is calculated above (see ExtraTerrestrial Radiation Function).  The solar altitude angle when the sun is directly south (MonSolarAltAngleSouth) in degrees from the horizon for each month is calculated as:

MonSolarAltAngleSouth = arcsin (sin(Lat)*sin(MonSolarDec)
+ cos(Lat)*cos(MonSolarDec)

where MonSolarDec is calculated by the ExtraTerrestrial Radiation Function.

The annual mean of these angles is calculated as a weighted average based on the mean monthly total radiation:

AvgSunriseAzimAngle =Sigma (MonSunriseAzimAngle*MonSolRad)
/TotalAnnualSolRad

and

AvgSolarAltAngleSouth =Sigma (MonSolarAltAngleSouth*MonSolRad)
/TotalAnnualSolRad

where TotalAnnualSolRad is the sum of all the mean daily radiation values for each month.  A weighted average is used so that the months that contribute the greatest amount of radiation have the greatest effect on the yearly average.

**Running the Programs**

SolarRad

To run this program type in SolarRad and hit enter.  The program will then ask for the name of the site (this must match one found in the Locat.drv file), and whether you are going to read a file containing the cloud cover data or if you are going to estimate the cloud cover from climatic data.  The program with then make the calculations and write the results to a file called Radiate.drv.  If you wish to save the results from a previous run, you must rename this file before running the program again.

SolarImg

To run this program type in SolarImg and hit enter.  The program then asks you to supply the names of the files containing the elevations (m), slopes (percent), aspects (degrees from north), the types of files these are (choice include ASCII, 16 bit binary, floating point binary, SVF, and ERDAS).  ASCII files have been tested most frequently and most likely to give good results.  Use other types at your own risk.  If the files containing elevation, slope, and aspect data are not SVF or ERDAS types, then the user must supply the number of rows and columns in the files.  The program then requests the latitude in degrees and requests the number of months that the estimates should be made.  If one month is selected, then one is asked to supply the Julian day for that month.  If 12 months are selected then the days presented in Table 1 are used.  The program then asks if the cloud cover is to be entered from a file (Clouds.drv) or if it is to be estimated from climatic data (Climate.drv).  The program then asks what type of radiation data should be output (direct beam, diffuse or total).  The output files are named by the month and have the extensions .tot, .bea, and .dif for the total, direct beam, and diffuse radiation data.  If 12 months are selected then two additional grids are output: mean daily direct beam and total radiation (Year.bea and Year.tot)

**Input/Output Files**

SolarRad files

The single cell version of the program requires that the user input data on the monthly climate (Climate.drv) or cloud cover (Cloud.drv), and the physical characteristics of the site (Locate.drv).  Although most users will want to run each month of the year, the Climate.drv and Cloud.drv files may be altered to include the climate and cloud data for a single month.  The program then outputs the mean daily radiation and sun angle information for each day of the month and for the year.  The details of each file are described below.

Climate.drv

This input file contains the climatic information required to calculate the effects of climate on cloud cover.  This file is used by both the single cell and grid versions of the model.  If the user only wishes to calculate radiation inputs for a single month, then only the temperature and precipitation data for a single month need to be entered.

The variables in order of their appearance in the file are as follows:

Model Number:  ML04 indicates this file is input for SolarRad or SolarImg.

Input File Number:  indicates the type of file, we have abitararly assigned the Climate.drv file tha value 12.

Month: a 3 character abbreviation of the month of the year staring with January and ending with December.  The first letter of each month must be capitalized as shown in the example file.

TempMin: the mean monthly minimum temperature (C).

TempMax:  the mean monthly maximum temperature (C).

Temp24:  the mean monthly temperature for the entire 24 hour day (C).

Prec: the mean monthly total precipiation (cm).

Example Climate.drv file:

```
ML04 12 Jan  -1.50  3.2   0.3  39.0
ML04 12 Feb  -0.20  7.0   2.7  27.0
ML04 12 Mar   0.10  9.4   3.8  27.0
ML04 12 Apr   1.70 14.6   7.4  14.0
ML04 12 May   4.40 19.3  11.7  11.0
ML04 12 Jun   7.30 23.3  14.9   6.0
ML04 12 Jul   9.00 28.7  18.3   1.0
ML04 12 Aug   8.60 28.0  17.4   4.0
ML04 12 Sep   6.30 24.1  13.5   8.0
ML04 12 Oct   3.40 15.8   8.1  18.0
ML04 12 Nov   0.70  7.5   3.5  34.0
ML04 12 Dec  -0.90  3.6   1.1  41.0
```

Clouds.drv

If there are monthly estimates of cloud cover, then the user can include these data in the Clouds.drv file.   If the user only wishes to calculate radiation inputs for a single month, then only the cloud data for a single month need to be entered.

Model Number:  ML04 indicates this file is input for SolarRad or SolarImg.

Input File Number:  11 indicates this is the Clouds.drv file

Month: a 3 letter abbreviation for the month of the year staring with January and ending with December.  The first letter of each mopnth needs to be capitalized as shown in the example file.

Cloud: the proportion of the sky covered with clouds for each month.

Example Cloud.drv file:

```
ML04 11 Jan  0.70
ML04 11 Feb  0.70
ML04 11 Mar  0.60
ML04 11 Apr  0.60
ML04 11 May  0.50
ML04 11 Jun  0.30
ML04 11 Jul  0.20
ML04 11 Aug  0.20
ML04 11 Sep  0.30
ML04 11 Oct  0.40
ML04 11 Nov  0.60
ML04 11 Dec  0.70
```

Locat.drv

This file is used by the single cell version (SolarRad) and is used to define the location and site characteristics of the area where solar radiation and sun angles are to be estimated.  More than one site name can be stored in this file.  If the user wishes to keep the cloud or climatic data the same for a set of sites, then is only necessary to enter the particular site name when prompted by the program.

The variables in order of their appearance in the file are as follows:

Model Number:  ML04 indicates this file is input for STANDCARB.

Input File Number:  16 indicates this is the Locat.drv file.

SiteName: the name of the particular site being simulated.

SoilText:  the soil texture class of the site.

Ecoregion:  the ecoregion that the site occurs in.  This determines the species of trees that will be present.

California Coast Range (CACR)
California Cascades-west side (CACW)
Oregon Cascades-west slope (ORCW)
Oregon Cascades-east slope (ORCE)
Oregon Coast Range (ORCR)
Washington Cascades-west slope (WACW)
Washington Cascades-east slope (WACE)

Latitude:  the latitude of the site to the nearest degree (degree).

Elevation:  the elevation above mean sea level of the site (meters).

Aspect:  the compass direction that the site is sloping toward (degrees from north).

SlopeSteep:  the steepness of the site in percent.

SoilDepth:  the depth of the soil for rooting of plants (cm).

Rocks:  the percentage of the soil profile that has fragments of rock >2mm diameter (%).

Example Locat.drv file:

```
ML04  16  defaultsite  loam   CACR  40   300  180  0  100  5
ML04  16  testsite1    loam   ORCW  44   100  180  0  100  5
ML04  16  testsite2    loam   ORCW  44  1000  180  0  100  5
ML04  16  testsite3    loam   ORCW  44  3000  180  0  100  5
```

Radiate.drv

This file is output by the SolarRad program.  It contains the radiation and sun angles data for each month and the mean for the year.  This file is overwritten each time the program is run.  If the user wishes to save output from a paritcular site, the file should be renamed before the program is run again!!

The variables in order of their appearance in the file are as follows:

Model Number:  ML04 indicates this file is from the SolarRad program.

Input File Number:  13 indicates this is the Radiate.drv file

Month: a 3 character abbreviation for the month of the year staring with January and ending with December.  Also there is a name Year which indicates the daily mean during the year for radiation and the yearly weighted average for the sun angles.

DifSolRad: mean daily diffuse solar radiation for a given month and site (cal cm-2 day-1). To calculate the monthly radiation multiply this number by the number of days in the month. For the year, this is the daily mean for the year. To calculate the yearly radiation multiply the year value by 365.

DirSolRad: mean daily direct solar radiation for a given month and site (cal cm-2 day-1). To calculate the monthly radiation multiply this number by the number of days in the month. For the year, this is the daily mean for the year. To calculate the yearly radiation multiply the year value by 365.

SolRad: mean daily total solar radiation for a given month and site (cal cm-2 day-1). To calculate the monthly radiation multiply this number by the number of days in the month. For the year, this is the daily mean for the year. To calculate the yearly radiation multiply the year value by 365.

SunriseAzimAngle: the azimuth angle of the sun at sunrise for each month (degrees from south). The year value is the weighted average, weighted by mean daily total radiation received each month.

SolarAltAngleSouth: solar altitude angle when the sun is directly south (degrees from the horizon). The year value is the weighted average, weighted by mean daily total radiation received each month.

Example of the Radiate.drv file

Model, card, Month, DifSolRad, DirSolarRad, SolRad
SunriseAzimuthAngle, AltAngleSouth

ML04 16  Jan  75.63   30.13 105.76   68.34   25.08
ML04 16  Feb  110.80   57.34 168.14   77.17   33.04
ML04 16  Mar  156.03   89.96 245.99   87.67   43.58
ML04 16  Apr  203.91   47.37 351.28   99.22   55.42
ML04 16  May  236.78   99.01 435.79  109.19   64.79
ML04 16  Jun  240.49 272.79 513.28  114.32   69.09
ML04 16  Jul  156.07 515.59 671.66  111.99   67.18
ML04 16  Aug  196.07 271.42 467.49  103.37   59.46
ML04 16  Sep  169.66 152.64 322.30   92.15   48.22
ML04 16  Oct  124.37   75.85 200.22   80.61   36.40
ML04 16  Nov   84.10   36.94 121.04   70.68   27.09
ML04 16  Dec   66.28   24.46   90.74   65.74   22.95
ML04 16 Year  151.68 156.13 307.81   99.30   55.01


SolarImg files

This version of the file is for a grid of locations, each cell in this grid can have a different elevation, slope, and aspect. The latitude is assumed to be constant within the grid of cells, and the cloud cover or climatic data used to estimate this is also assumed to apply to the entire grid. These files (Climate.drv and Cloud.drv) are exactly like those used for the single site version. Examples of the grid input files for ASCII data are presented below.

Elev.img

This file contains the elevation in meters of each cell in the grid. This is an example of a 5 column by 5 row grid.

```
 10  100  200 200 300
100  100  200 200 300
200  200  200 200 200
300  300  200 200 200
400  400  200 200 200
```

Slope.img

This file contains the slope in percent of each cell in the grid. This is an example of a 5 column by 5 row grid.

```
15  30 15 0  0
30  30 15 0  0
30  30  0 0  0
30  30  0 0  0
30  30  0 0  0
```

Aspect.img

This file contains the aspect in degrees from north of each cell in the grid. This is an example of a 5 column by 5 row grid.

```
0   0  180 180 180
0   0  180 180 180
0   0  180 180 180
0   0  180 180 180
0   0  180 180 180
```

Total Radiation Files

All files containing the total radiation are output with the extension .tot with the units of cal cm-2 day-1. Each month forms the other part of the file name. Example: Jan.tot.

Direct Beam Radiation Files

All files containing the direct beam radiation are output with the extension .bea with the units of cal cm-2 day-1. Each month forms the other part of the file name. Example: Feb.bea.

Diffuse Radiation Files

All files containing the total radiation are output with the extension .dif with the units of cal cm-2 day-1. Each month forms the other part of the file name. Example: Dec.dif.

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