Calculating solar radiation and ‘cloudblue’ factor

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More information:

http://www.macaulay.ac.uk/LADSS/
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Predicting Solar Radiation

Predictors for solar radiation have been developed because there is often a lack of representative solar radiation data in most countries. Cloudiness, atmospheric transmissivity, latitude and orientation of the Earth relative to the Sun, time of day, slope and aspect of the surface determine the spatial and temporal distribution of irradiance incident on a surface. A number of methods exist for conversion of sunshine duration to solar radiation. Each has a range of data input requirements.

CalcRad2 and CalcRad3 (Functions for Calculating Solar Radiation using Empirical Fixed Factor) are functions that use sunshine duration to predict solar radiation. The model accounts for latitude, solar declination and elevation, day length and atmospheric transmissivity on a daily basis and has only daily sunshine duration (hours) as input.

Woodward et al. (2001) determined an empirical fixed factor (FF) of 1.11 for New Zealand. Rivington et al (2002) optimised FF for three test sites. Daily FF values were fitted using measured solar radiation values for each day per year for each complete year within the data set (Calculating Best Fixed Factor from Measured Solar Radiation). The average of all years can then be used (Average Best Fixed Factor).

This method imposes a base-line amount of diffuse radiation, variable with h, such that an input of zero sunshine hours will still produce a value of irradiance.

Functions for Calculating Solar Radiation using Empirical Fixed Factor

The original CalcRad2 function (Woodward et al. 2001) uses formulae for estimating potential and daily irradiance, transmissivity, radiation intensity, solar declination, solar elevation, solar radiation and sunshine hours. See also Johnson (1995) for further information:

The function includes a hard coded fixed factor of 1.11 – an ideal value for New Zealand. However, to allow this value to be more easily modified for use in other parts of the world, the function was modified for our requirements so that the fixed factor could be calibrated for a specific location and passed in as an argument. The new function is CalcRad3(A, B, C, D) where:

A: day of year
B: latitude
C: sunshine hours
D: fixed factor

Function: CalcRad3

CalcRad3 (t_d, latdeg, h0s, cloudblue)

\[
\begin{align*}
\tau &= 0.64 + 0.12 \times \cos((t_d - 174) / 365 \times 2 \times \pi) \\
\lambda &= \text{latdeg} \times \pi / 180 \\
\delta &= -23.4 \times \pi / 180 \times \cos(2 \times \pi \times (t_d + 10) / 365) \\
\sin\phi &= \sin(\lambda) \times \sin(\delta) + \cos(\lambda) \times \cos(\delta) \\
h &= 2 \times (15 \times \pi / 180 \times \cos(-\Tan(\lambda) \times \Tan(\delta))) \\
\text{tauthing} &= \frac{1}{1 + \text{tauthing}} \\
J_p &= 1367 \times \sin(\phi) \times / \pi / 2 \times (1 + \text{tauthing}) \\
J_s &= 1367 \times \sin(\phi) \times \pi \times \text{tauthing} \\
f_{\text{blue}} &= (1 - \text{tauthing}) / (1 + \text{tauthing}) \\
f_{\text{cloud}} &= \text{cloudblue} \times f_{\text{blue}} \\
c &= 1 - h0s / h \\
J_s &= (h0s \times J_s + h \times J_p) \times (f_{\text{blue}} \times (1 - c) + f_{\text{cloud}} \times c)) / h \\
\text{rad} &= \max (0, J_s / 1000000 \times h \times 3600 \times 2)
\end{align*}
\]

Symbols and Constants

Solar constant = 1367
\pi taken as 3.14159265
t_d = day of year
latdeg = latitude in degrees
\lambda = latitude in radians
h0s = sunshine hours per day
cloudblue = x factor (empirical parameter)
J_p = potential irradiance at solar noon / mean daytime irradiance at canopy surface on clear day
J_s = direct solar component of J_p
\delta = solar declination angle
\( \phi \) = solar elevation angle at local noon
\( h \) = daylight period in hours
\( \tau \) = atmospheric transmissivity
\( f_{\text{blue}} \) = intensity of radiation from blue sky
\( f_{\text{cloud}} \) = intensity of radiation from cloudy sky
\( \text{rad} \) = solar radiation
\( J_0 \) = mean daily irradiance
\( c \) = proportion of sky covered by cloud

**Calculating Best Fixed Factor from Measured Solar Radiation**

In order to fit daily FF values the CalcRad3 function was modified so that measured radiation would be specified as input and the function would calculate and return the FF value. This new function is \( \text{CalcFactFromSR}(A, B, C, D, E, F) \), where:

- \( A \): day of year
- \( B \): latitude
- \( C \): sunshine hours
- \( D \): measured SR
- \( E \): min best factor limit
- \( F \): max best factor limit

It can be verified that the ‘best factor’ returned from \( \text{CalcFactFromSR} \) is valid by using it in a call to \( \text{CalcRad3} \) as before and comparing the returned SR with the original measured SR input.

**Function: CalcFactFromSR**

\[
\begin{align*}
\tau &= 0.64 + 0.12 \times \cos((t_d - 174)/365) \times 2 \times \pi \\
\lambda &= \text{latdeg} \times \pi/180 \\
\delta &= -23.4 \times \pi/180 \times \cos(2 \times \pi \times (t_d + 10)/365) \\
\sin \phi &= \sin(\lambda) \times \sin(\delta) + \cos(\lambda) \times \cos(\delta) \\
h &= 2 / (15 \times \pi/180) \times \cos^{-1}(-\tan(\lambda) \times \tan(\delta)) \\
taunting &= \tau^{\frac{1}{\sin \phi}} \\
J_{s.p} &= 1367 \times \sin \phi / \pi / 2 \times (1 + taunting) \\
J_{s.s} &= 1367 \times \sin \phi / \pi \times taunting \\
f_{\text{blue}} &= (1 - taunting) / (1 + taunting) \\
c &= 1 - h0s / h \\
J_0 &= \text{rad} / 2 / 3600 / h \times 1000000 \\
f_{\text{cloud}} &= (((J_s - h0s \times J_{s.p}) / h / J_{s.p}) - (f_{\text{blue}} \times (1 - c))) / c \\
\text{cloudblue} &= f_{\text{cloud}} / f_{\text{blue}} \; \text{; where minFact} \leq \text{cloudblue} \leq \text{maxFact}
\end{align*}
\]

**Average Best Fixed Factor**

From the ‘best factor’ calculation, we can calculate the average factor over the year:

\[
\text{Average best factor} = \text{sum of all Best Factor SRs} / \text{days in year}
\]

This value can be used as a good FF value for that location.
Solar Radiation Calculator

The CalcRad3 and CalcFactFromSR functions are VB Scripts contained within the solar radiation calculator (Figure 1).

![Solar Radiation Calculator](image)

Figure 1: Solar Radiation Calculator