Calculating solar radiation and 'cloudblue' factor

Kevin Buchan & Mike Rivington, Macaulay Land Use Research Institute, 2005

Contents:

More information:

http://www.macaulay.ac.uk/LADSS/

Calculating solar radiation and 'cloudblue' factor

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

$$\text{CalcRad3}\ (t_d, \text{latdeg}, \text{h0s}, \text{cloudblue})$$
$$\tau = 0.64 + 0.12 * \cos((t_d - 174) / 365 * 2 * \pi)$$
$$\lambda = \text{latdeg} * \pi / 180$$
$$\delta = -23.4 * \pi / 180 * \text{Cos}(2 * \pi * (t_d + 10) / 365)$$
$$\sin\phi = \text{Sin}(\lambda) * \text{Sin}(\delta) + \text{Cos}(\lambda) * \text{Cos}(\delta)$$
$$h = 2 / (15 * \pi / 180) * \cos^{-1}(-\text{Tan}(\lambda) * \text{Tan}(\delta))$$
$$\text{tauthing} = \tau^{(1 / \sin\phi)}$$
$$J_{0.p} = 1367 * \sin\phi / \pi / 2 * (1 + \text{tauthing})$$
$$J_{0.s} = 1367 * \sin\phi / \pi * \text{tauthing}$$
$$f_{blue} = (1 - \text{tauthing}) / (1 + \text{tauthing})$$
$$f_{cloud} = \text{cloudblue} * f_{blue}$$
$$c = 1 - \text{h0s} / h$$
$$J_0 = (\text{h0s} * J_{0.s} + h * J_{0.p} * (f_{blue} * (1 - c) + f_{cloud} * c)) / h$$
$$\text{rad} = \max(0, J_0 / 1000000 * h * 3600 * 2)$$

Symbols and Constants

Solar constant = 1367
π taken as 3.14159265
t_d = day of year
latdeg = latitude in degrees
λ = latitude in radians
h0s = sunshine hours per day
cloudblue = x factor (empirical parameter)
$J_{0.p}$ = potential irradiance at solar noon / mean daytime irradiance at canopy surface on clear day
$J_{0.s}$ = direct solar component of $J_{0.p}$
δ = solar declination angle

ϕ = solar elevation angle at local noon
h = daylight period in hours
τ = atmospheric transmissivity
f_{blue}= intensity of radiation from blue sky
f_{cloud} = intensity of radiation from cloudy sky
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 `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 `CalcFactFromSR` is valid by using it in a call to `CalcRad3` as before and comparing the returned SR with the original measured SR input.

Function: CalcFactFromSR

$$\text{CalcFactFromSR}(t_d, \text{latdeg}, \text{h0s}, \text{rad}, \text{minFact}, \text{maxFact})$$
$$\tau = 0.64 + 0.12 * \cos((t_d - 174) / 365 * 2 * \pi)$$
$$\lambda = \text{latdeg} * \pi / 180$$
$$\delta = -23.4 * \pi / 180 * \cos(2 * \text{Pi} * (t_d + 10) / 365)$$
$$\sin\phi = \sin(\lambda) * \sin(\delta) + \cos(\lambda) * \cos(\delta)$$
$$h = 2 / (15 * \pi / 180) * \cos^{-1}(-\tan(\lambda) * \tan(\delta))$$
$$\text{tauthing} = \tau^{(1 / \sin\phi)}$$
$$J_{0.p} = 1367 * \sin\phi / \pi / 2 * (1 + \text{tauthing})$$
$$J_{0.s} = 1367 * \sin\phi / \pi * \text{tauthing}$$
$$f_{blue} = (1 - \text{tauthing}) / (1 + \text{tauthing})$$
$$c = 1 - \text{h0s} / h$$
$$J_0 = \text{rad} / 2 / 3600 / h * 1000000$$
$$f_{cloud} = (((J_0 * h - \text{h0s} * J_{0.s}) / h / J_{0.p}) - (f_{blue} * (1 - c))) / c$$
$$\text{cloudblue} = f_{cloud} / f_{blue} \text{ ; where minFact} <= \text{cloudblue} <= \text{maxFact}$$

Average Best Fixed Factor

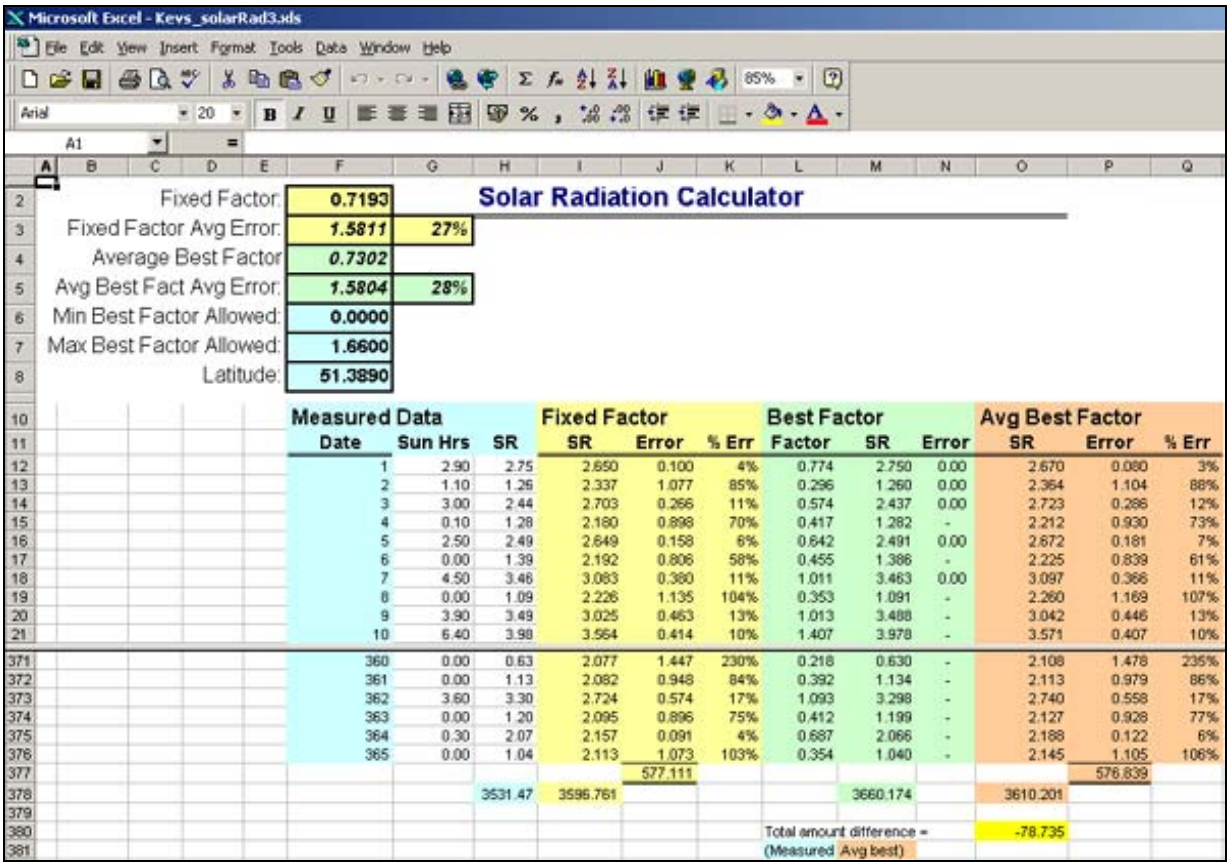
From the 'best factor' calculation, we can calculate the average factor over the year:

Average best factor = sum of all Best Factor SRs / 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).



Microsoft Excel - Kevs_solarRad3.xls

File Edit View Insert Format Tools Data Window Help

Arial 20 B I U 85%

A1 =

Solar Radiation Calculator

Fixed Factor:	0.7193		
Fixed Factor Avg Error:	1.5811	27%	
Average Best Factor	0.7302		
Avg Best Fact Avg Error:	1.5804	28%	
Min Best Factor Allowed:	0.0000		
Max Best Factor Allowed:	1.6600		
Latitude:	51.3890		

	Measured Data			Fixed Factor			Best Factor			Avg Best Factor		
	Date	Sun Hrs	SR	SR	Error	% Err	Factor	SR	Error	SR	Error	% Err
12	1	2.90	2.75	2.650	0.100	4%	0.774	2.750	0.00	2.670	0.080	3%
13	2	1.10	1.26	2.337	1.077	85%	0.296	1.260	0.00	2.364	1.104	88%
14	3	3.00	2.44	2.703	0.266	11%	0.574	2.437	0.00	2.723	0.286	12%
15	4	0.10	1.28	2.180	0.898	70%	0.417	1.282	-	2.212	0.930	73%
16	5	2.50	2.49	2.649	0.158	6%	0.642	2.491	0.00	2.672	0.181	7%
17	6	0.00	1.39	2.192	0.806	58%	0.455	1.386	-	2.225	0.839	61%
18	7	4.50	3.46	3.083	0.380	11%	1.011	3.463	0.00	3.097	0.366	11%
19	8	0.00	1.09	2.226	1.135	104%	0.353	1.091	-	2.260	1.169	107%
20	9	3.90	3.49	3.025	0.463	13%	1.013	3.488	-	3.042	0.446	13%
21	10	6.40	3.98	3.564	0.414	10%	1.407	3.978	-	3.571	0.407	10%
371	360	0.00	0.63	2.077	1.447	230%	0.218	0.630	-	2.108	1.478	235%
372	361	0.00	1.13	2.082	0.948	84%	0.392	1.134	-	2.113	0.979	86%
373	362	3.60	3.30	2.724	0.574	17%	1.093	3.298	-	2.740	0.558	17%
374	363	0.00	1.20	2.095	0.896	75%	0.412	1.199	-	2.127	0.928	77%
375	364	0.30	2.07	2.157	0.091	4%	0.687	2.066	-	2.188	0.122	6%
376	365	0.00	1.04	2.113	1.073	103%	0.354	1.040	-	2.145	1.105	106%
377					577.111						576.839	
378			3531.47	3596.761				3660.174		3610.201		
379												
380							Total amount difference =			-78.735		
381							(Measured Avg best)					

Figure 1: Solar Radiation Calculator