Estimating Fine Scale Ground Solar Radiation From GIS Modelled Data And Historical Meteorological Records

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Introduction

This talk shows how GIS-based models can be used to predict potential direct (and diffuse) solar radiation received over large areas of interest.

The presentation

- Describes a simple model to calculate potential solar radiation
- Finds the correlation between this prediction and actual BoM-recorded solar radiation data at 14 stations all over Australia
- Uses this correlation function to compare predictions with actual data collected by BoM
- Suggests potential applications for this model
Why model solar radiation in a GIS?

- Difficult to extrapolate radiation measured at one point to other areas in a mountainous terrain (unlike rainfall)
- Store as a layer in a database for use with other layers
- Can account for decrease in radiation due to adjacent topography (hill shading)
- Quick and easy
Calculating direct (shortwave) solar radiation

- Find position of sun in the sky:
  - solar azimuth angle \( a_s \)
  - solar altitude angle \( \alpha \)
  - solar declination \( \delta_s \)

- Find solar flux outside the atmosphere \( S_o \)
- Attenuation during transmission - optical air mass (air mass ratio), water vapour and aerosol content of atmosphere

Required data:
- Slope of receiving surface
- Aspect of receiving surface
- Elevation of site
Inputs to model

- Latitude (negative for south of equator)
- Name of input DEM
- Name of output grid
- Day to start calculations (Julian date)
- Day to end calculations (Julian date)
- Time interval (in minutes)
Method of calculation

- For given DEM, calculate:
  - aspect grid
  - slope grid

- For first day of calculations, calculate:
  - solar declination $\delta_s$
  - sunrise time
  - sunset time
  - flux outside the atmosphere

- Use data on elevation, slope and aspect to calculate $I_P$, the component of the direct radiation striking the surface (with a slope and aspect)
Solar altitude: \( \sin \alpha = \sin L \sin \delta_s + \cos L \cos \delta_s \cos h_s \)

Solar azimuth: \( \sin a_s = \cos \delta_s \sin h_s / \cos \alpha \)

Solar declination: \( \delta_s = 23.45 \times \sin (360^\circ \times \frac{(284 + N)}{365}) \)

Solar flux: \( I_o = S_o \times (1 + 0.0344 \times \cos (360^\circ \times N/365)) \)

\( I_p = I_s \times \cos i \) where \( \cos i = \sin \delta_s (\sin L \cos \beta - \cos L \sin \beta \cos a_w) + \cos \delta_s \cos h_s \) 
\( \cos L \cos \beta + \sin L \sin \beta \cos a_w + \cos \delta_s \sin \beta \sin a_w \sin h_s. \)
Algorithm first used to compute potential shortwave radiation at Nullica State Forest (latitude 36.5° S) near Eden, NSW.

Site is rugged, with elevation ranging from 9 to 880 m.

Total area of 16406 ha was divided into 182288 grid cells each of area 30m x 30m.

Solar radiation calculated every 30 mins, and then integrated to yield daily values.

Monthly results are displayed in next slide – note summer months highest, winter months almost zero. Also effect of shadowing esp in winter months.
Figure 4.7 Monthly Solar Radiation Distribution

January

February

March

April

May

June

July

August

September

October

November

December

0 32 MJ/m²/day
Figure 4.8 Seasonal Average Daily Solar Radiation Distribution

Summer

Autumn

Winter

Spring

3.2 MJ/m²/day
Figure 4.9 Annual Average Daily Solar Radiation Distribution
Effect of seasons and aspects

Model shows

- Winter months receive about half the insolation compared to summer months.
- Northerly aspects (N, NE, NW) receive the highest radiation as compared to the south-facing slopes.
Correlating modelled radiation with actual data

- The predictions of the potential direct (and diffuse) solar radiation for large areas was tested by correlating them with the actual data collected by BoM at 14 stations across Australia.

- Hourly data was collected and clear sky records separated from cloudy days.

- Model used to calculate seasonally-integrated solar insolation.

- Simple regression analysis used to derive relationships between the recorded and the modelled data.
Meteorological station data used in this study
Bar chart showing the Bureau of Meteorology and Modelled seasonal solar radiation

1 – Summer, 2 – Autumn, 3 – Winter, 4 – Spring
Regression plot with 95% confidence intervals marked

Simple Regression Plot

\[ R^2 = 0.96 \]
\[ \text{BOM} = 0.9121 \times \text{Modelled} + 889.40 \]
Scatter plot by seasons

1 – Summer, 2 – Autumn, 3 – Winter, 4 – Spring
Much better results were obtained using single stations alone.

Each station data was split into two groups:
- One to develop a regression equation
- And a second set to test the predictive power

Following graphs are examples for Alice Springs.
Relationship between measured and modelled data

BoM = 0.8577 \cdot \text{Modelled} + 3531.5

R^2 = 0.9897

n=226

Alice Springs
Relationship between measured and predicted values

$R^2 = 0.9854$

$n=100$

Alice Springs
Overall the projected values differed by an average of around 2% (2.04%) from the Bureau of Meteorology data. (Maximum deviation was 4.8% and the median was 1.69%).

This suggests that, with appropriate verification, GIS modelled data can be used in lieu of field recorded data for areas where field data is not available or would be too expensive to record.

Regression equations developed using meteorological stations close by seems to perform better than pooled data from all stations.
In micrometeorology, the net radiation $R_N$ on a surface is given by

$$R_N = [S_t - \rho S_t] + [L_d - L_u]$$

where $\rho$ is the albedo, $S_t$ is shortwave radiation down, $L_d$ and $L_u$ are longwave radiation down and up resp.

The model can be used to calculate $S_t$ for any location under specific conditions.
Uses in Renewable Energy Resource Assessment

- Solar energy an important form of renewable energy
- Solar PV technology still expensive, finite life-span
- Need to assess solar energy resources at a location to determine viability of installing equipment (e.g. through simple payback analysis)
- GIS-modelled potential direct solar radiation can be used to predict annual solar energy resource at a specific site. The model reveals that this can vary dramatically from site to site.
Thank you

for your attention!