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

Lalit KUMAR[1] and Anirudh SINGH[2].

[1]University of New England, Armidale, NSW, Australia
[2] University of the South Pacific, Suva, Fiji

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 α
  - solar declination δ_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 δ_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)

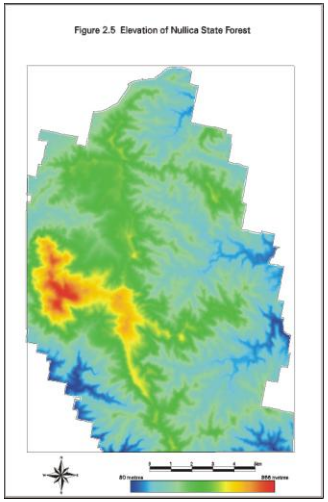


Figure 2.5 Elevation of Nullica State Forest

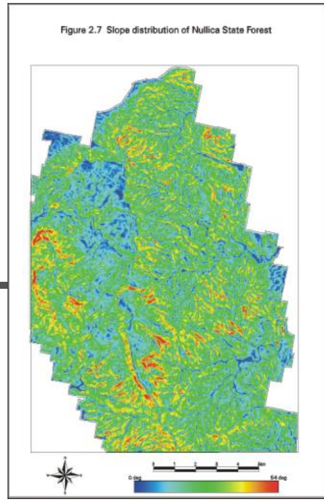


Figure 2.7 Slope distribution of Nullica State Forest

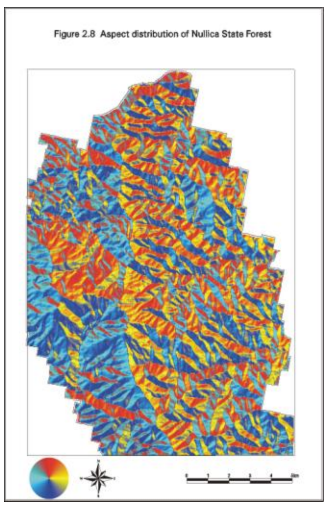


Figure 2.8 Aspect distribution of Nullica State Forest

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: $\delta_s = 23.45 * \sin (360^o * (284 + N)/365)$

Solar flux: $I_o = S_o * (1 + 0.0344 * \cos (360^o * N/365))$

$I_p = I_s * \cos i$ where $\cos i = \sin \delta_s (\sin L \cos \beta - \cos L \sin \beta \cos a_w) + \cos \delta_s \cos h_s (\cos L \cos \beta + \sin L \sin \beta \cos a_w) + \cos \delta_s \sin \beta \sin a_w \sin h_s$.

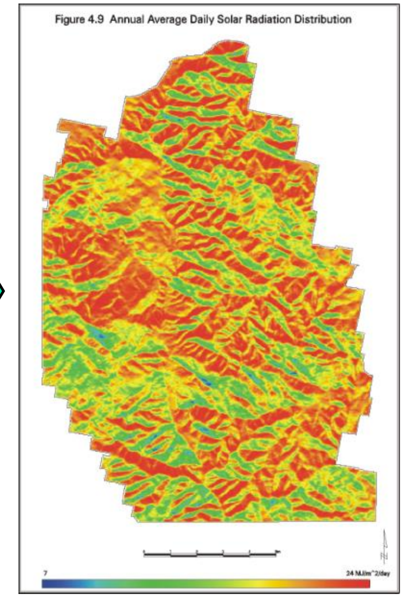


Figure 4.9 Annual Average Daily Solar Radiation Distribution

Initial model testing

- Algorithm first used to compute potential shortwave radiation at Nullica State Forest (latitude 36.5^{o} 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

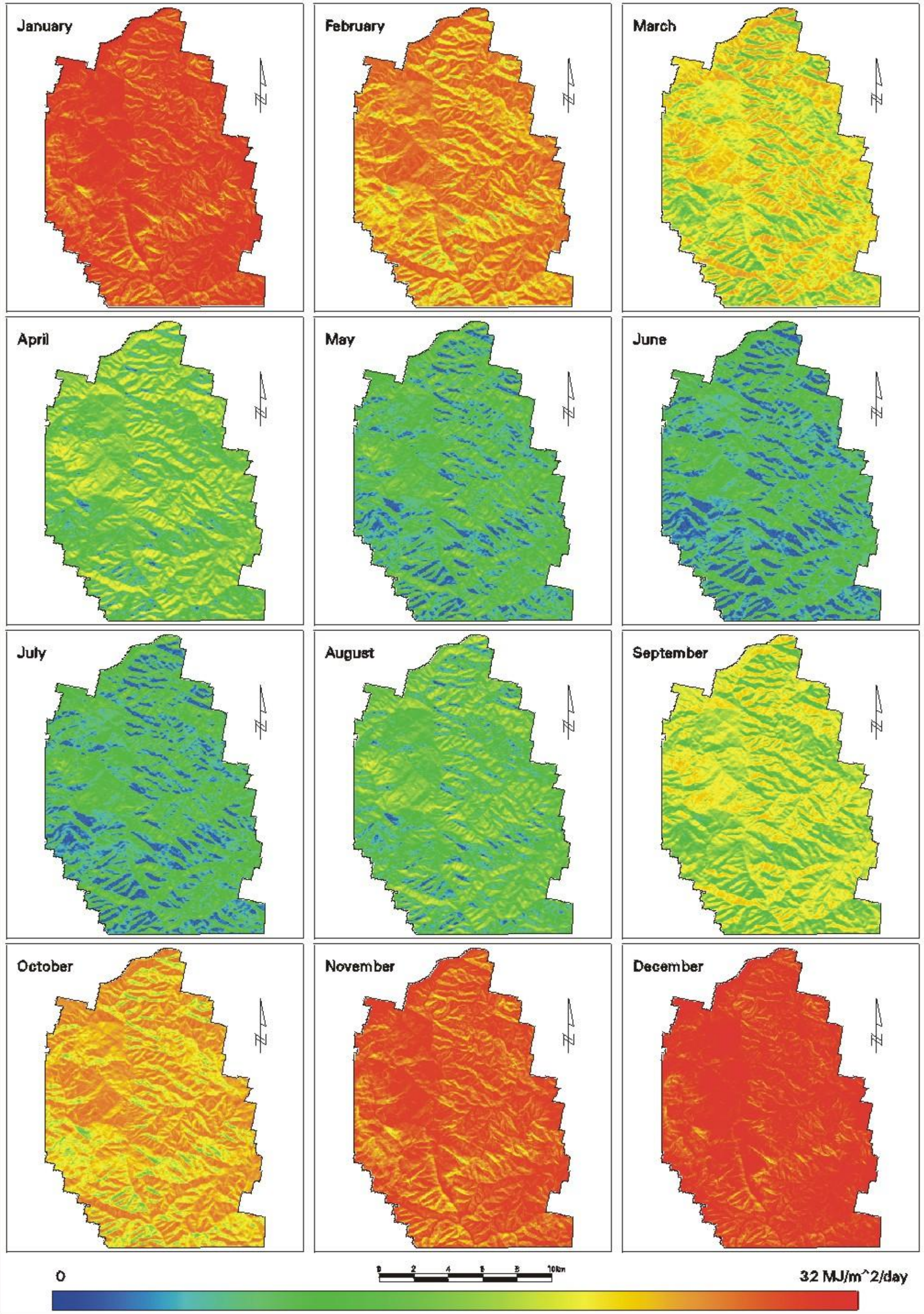


Figure 4.8 Seasonal Average Daily Solar Radiation Distribution

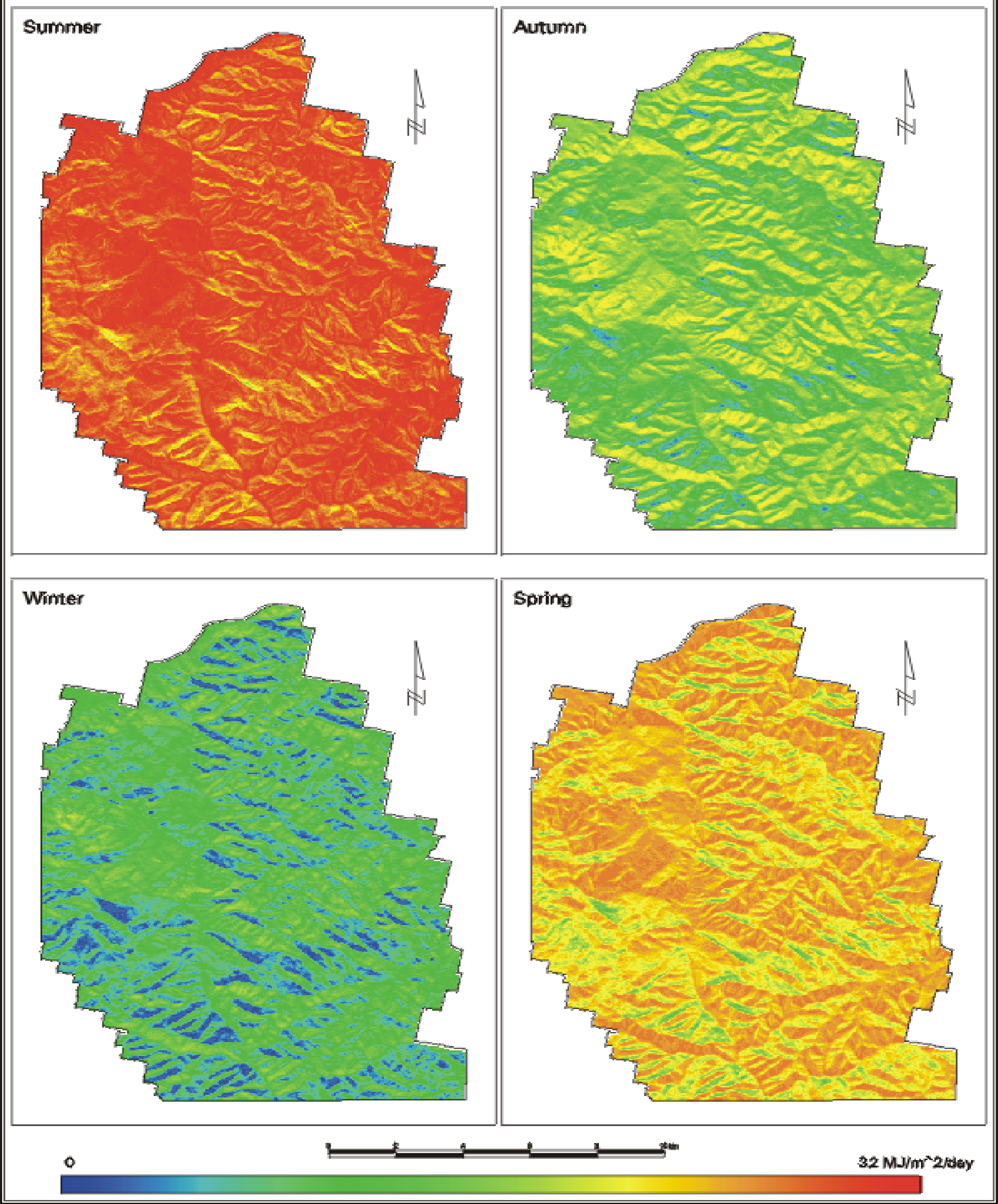
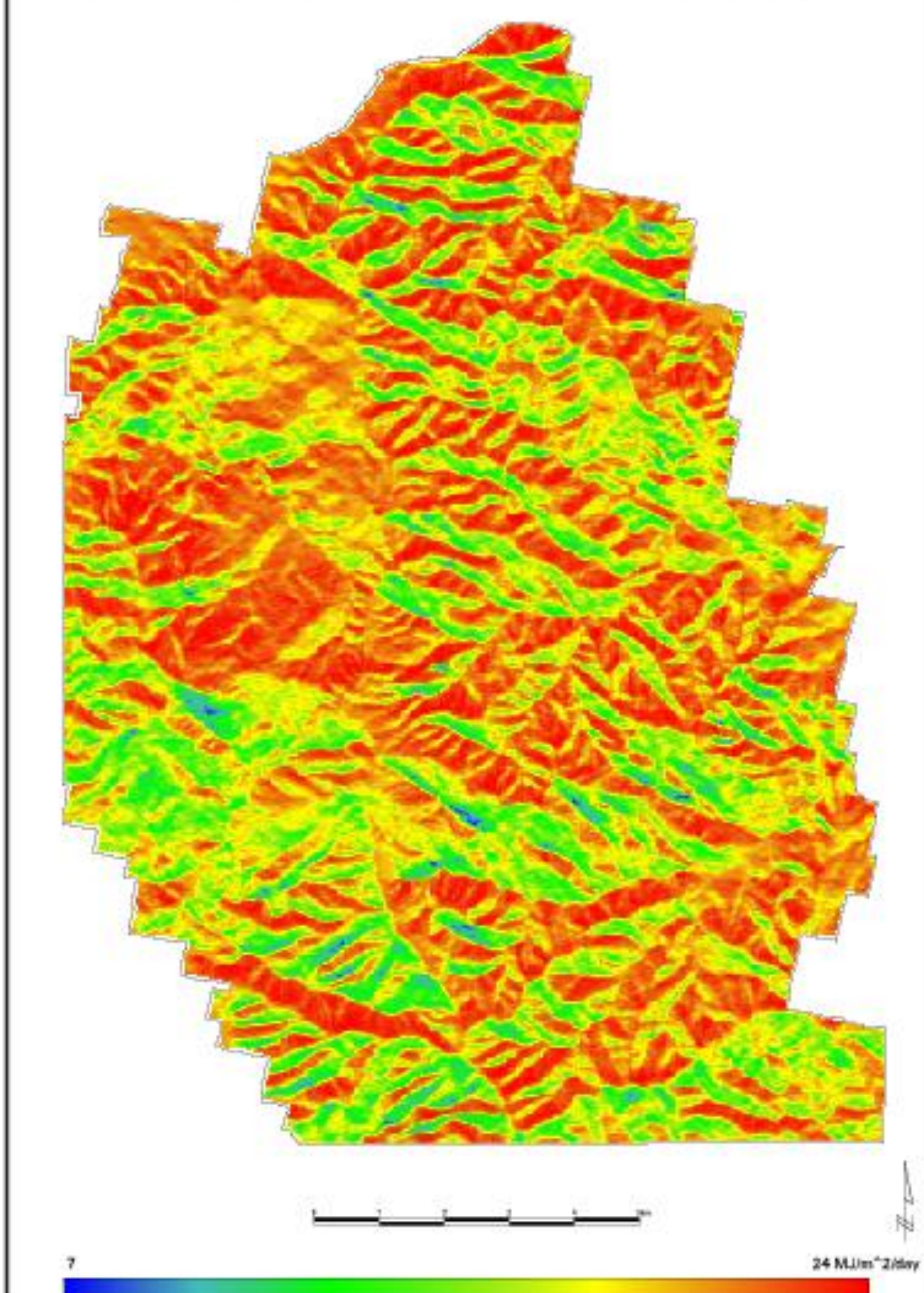


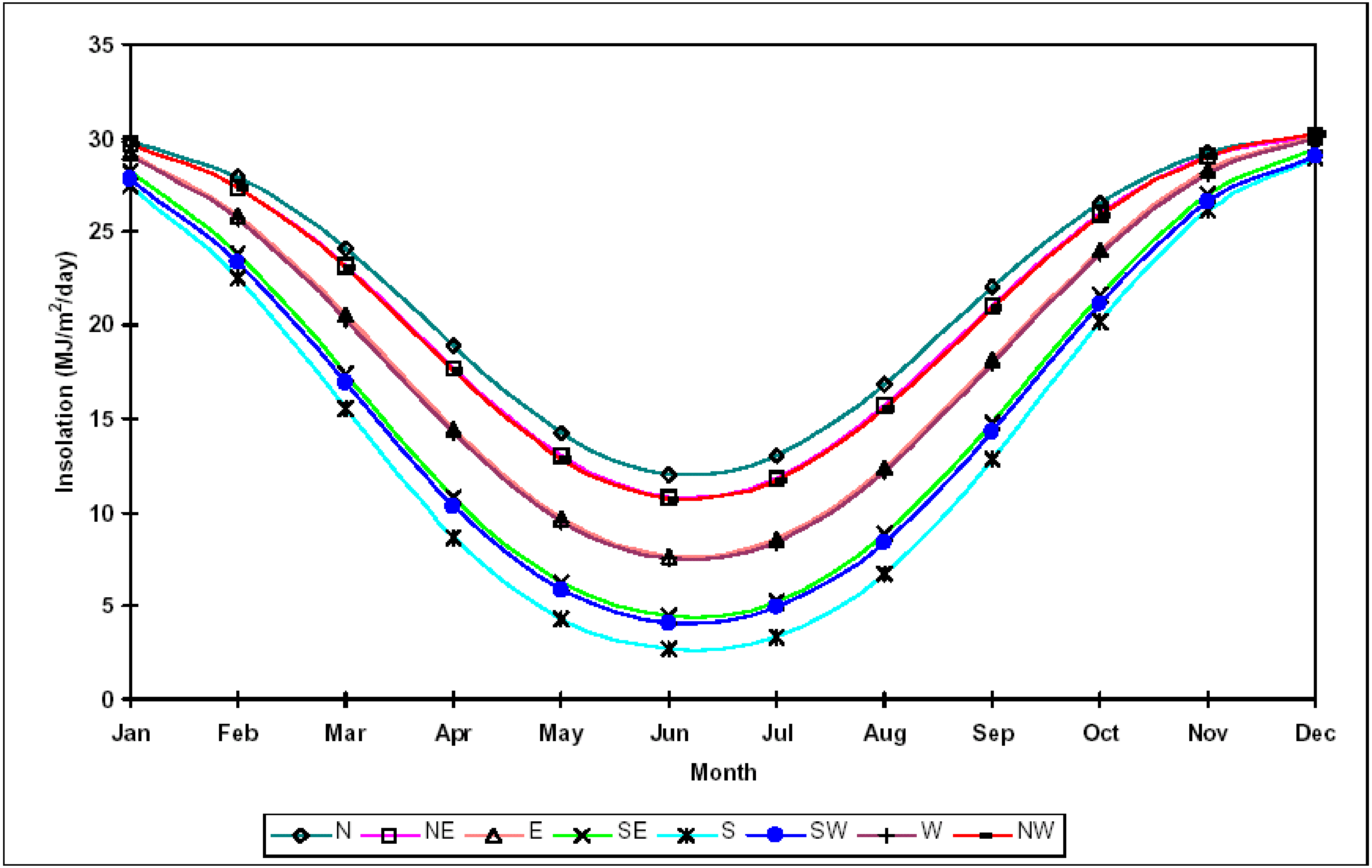
Figure 4.9 Annual Average Daily Solar Radiation Distribution



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.

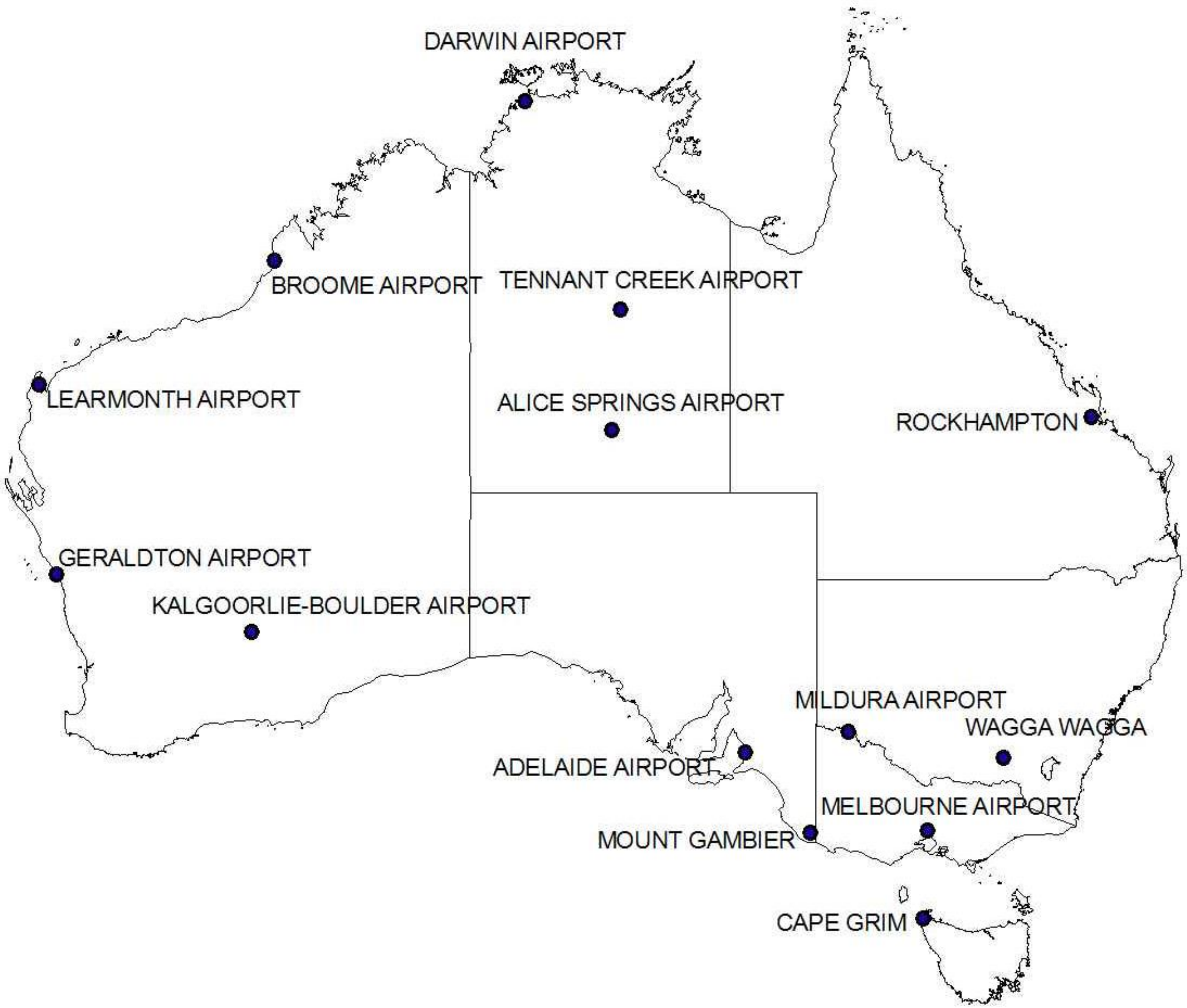


35
30
25
20
15
10
5
0
Insolation (MJ/m²/day)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
N
NE
E
SE
S
SW
W
NW

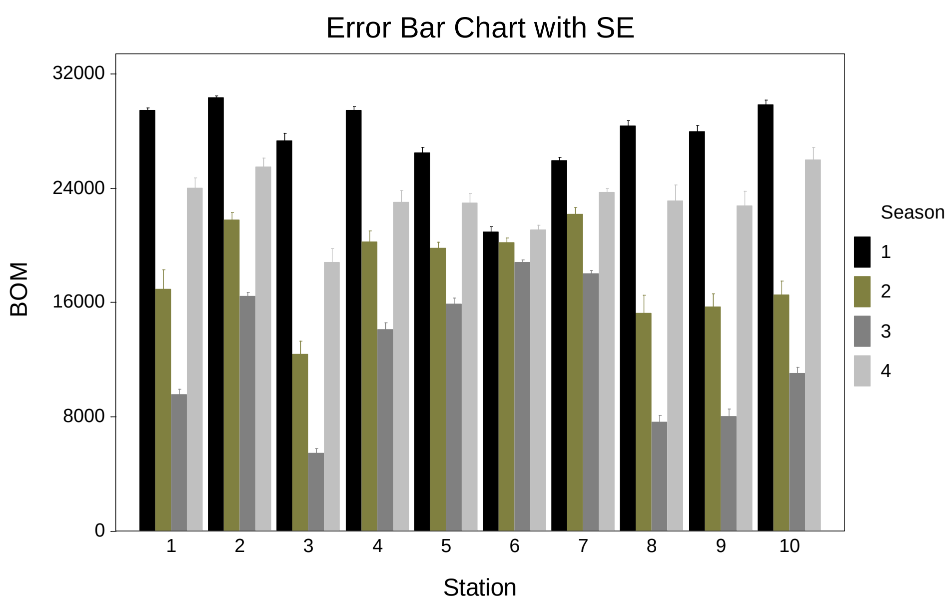
Correlating modelled radiation with actual data

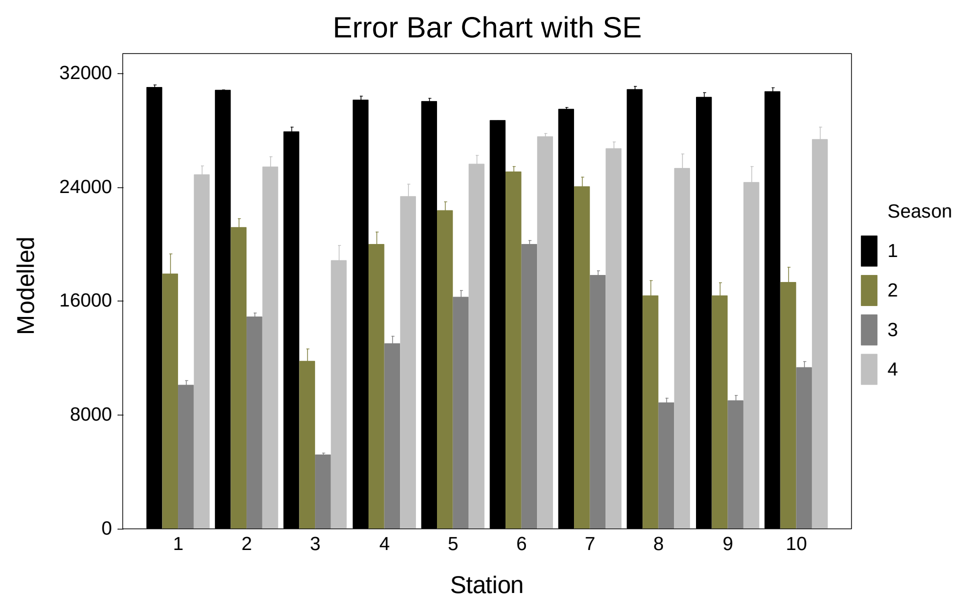
- The predictions of the potential direct (and diffuse) solar radiation for large areas was tested by correlating them with the actual data collected by BoM at 14 stations across Australia
- Hourly data was collected and clear sky records separated from cloudy days.
- Model used to calculate seasonally-integrated solar insolation
- Simple regression analysis used to derive relationships between the recorded and the modelled data.

Meteorological station data used in this study



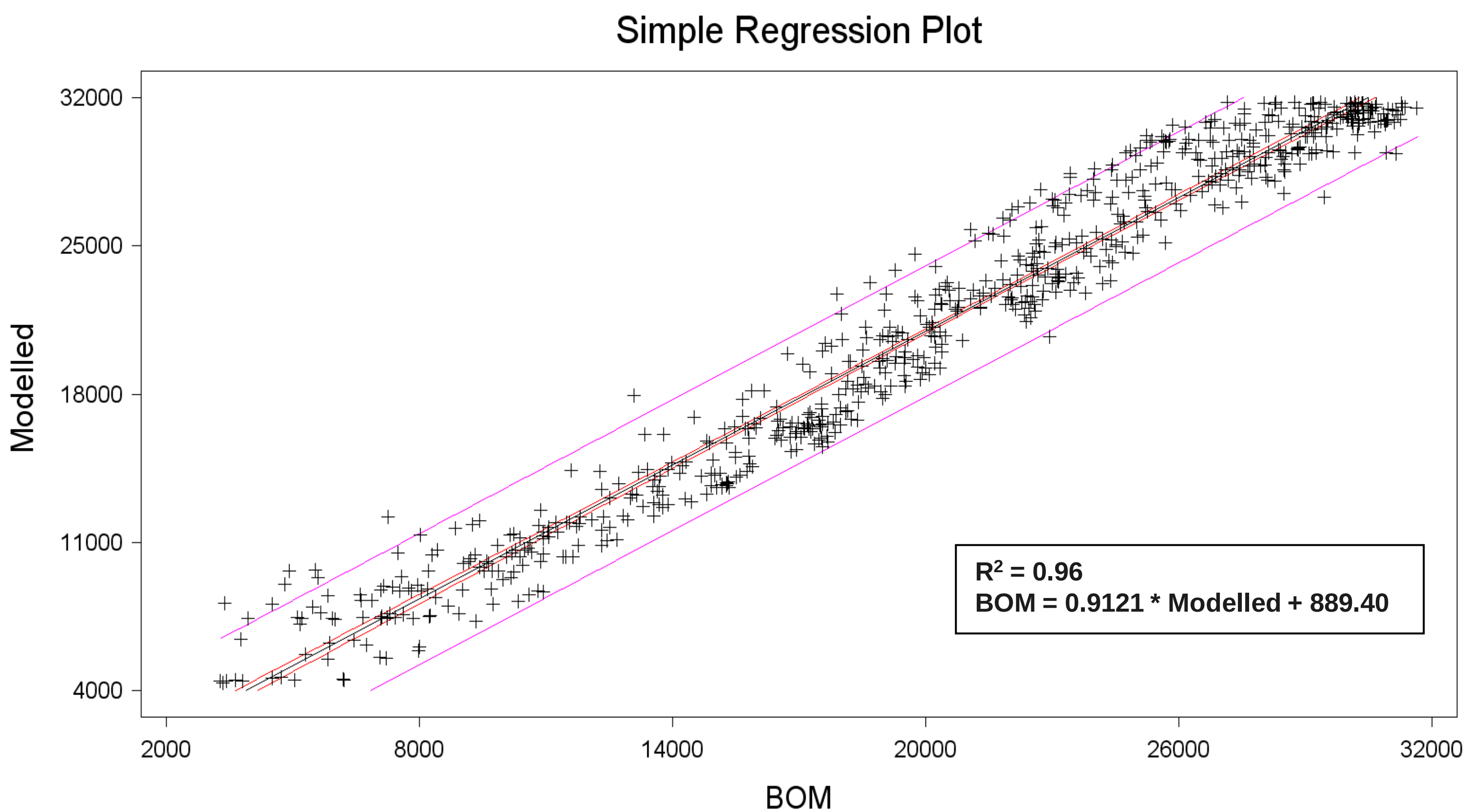
Bar chart showing the Bureau of Meteorology and Modelled seasonal solar radiation



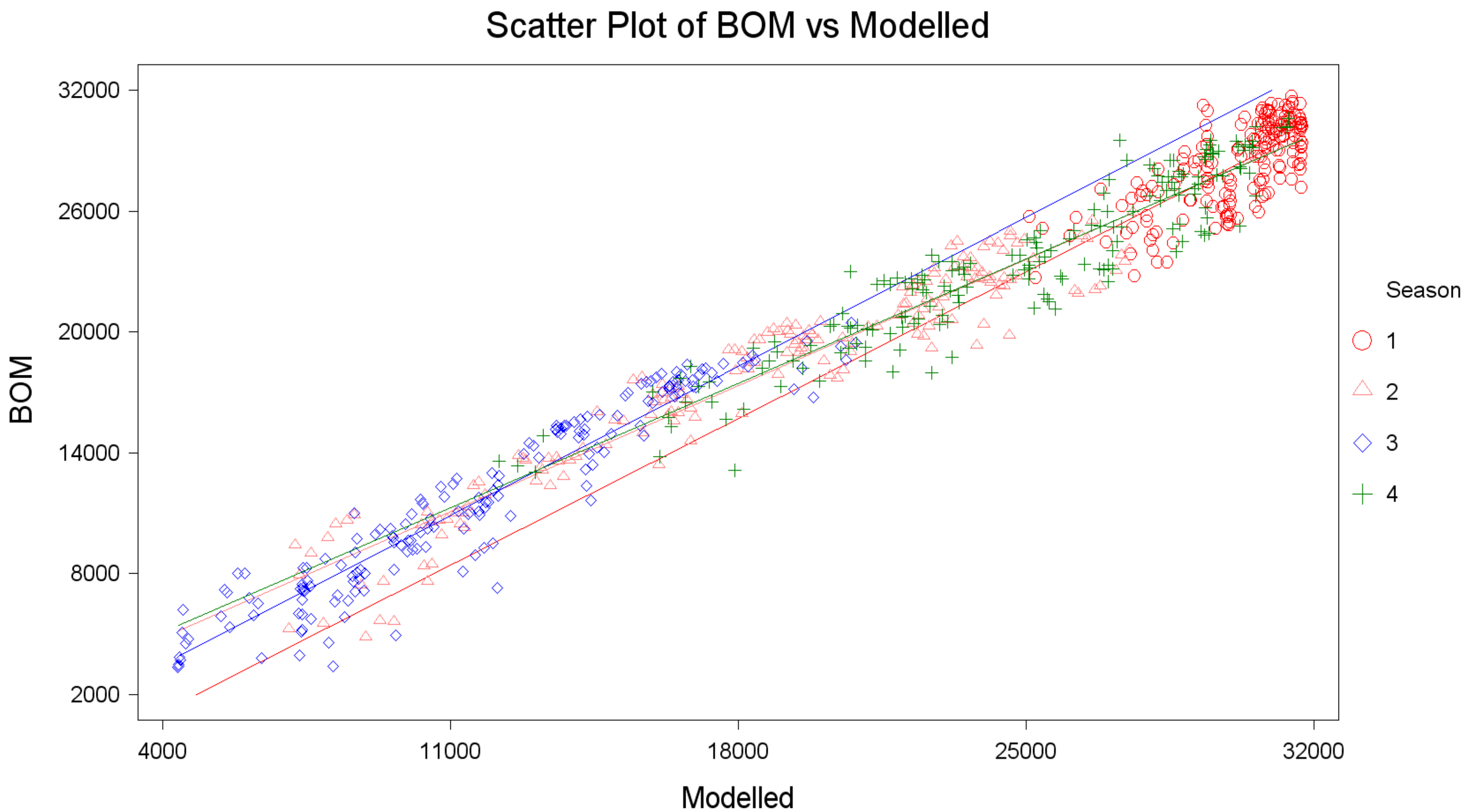


1 – Summer, 2 – Autumn, 3 – Winter, 4 – Spring

Regression plot with 95% confidence intervals marked



Scatter plot by seasons



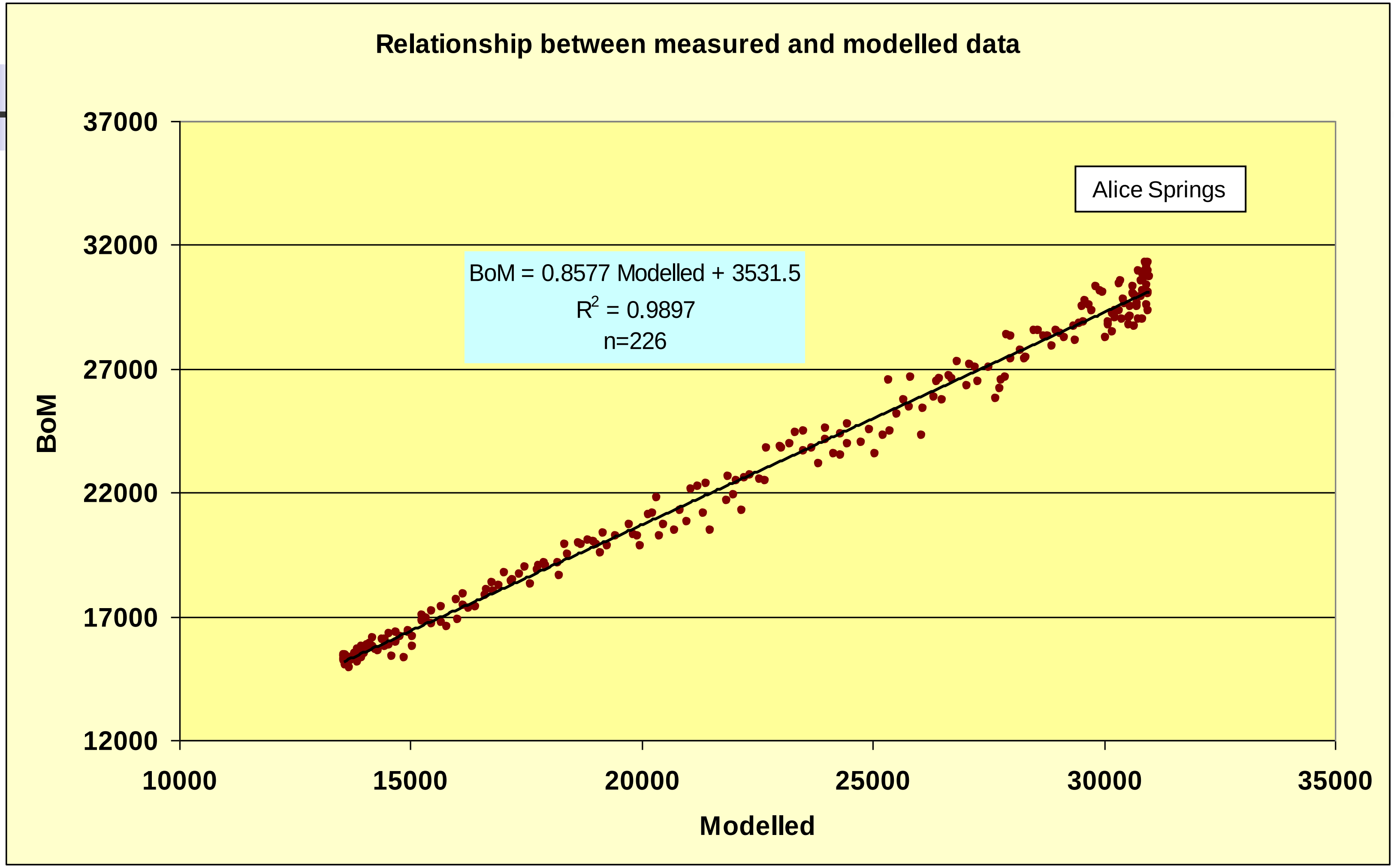
1 – Summer, 2 – Autumn, 3 – Winter, 4 – Spring

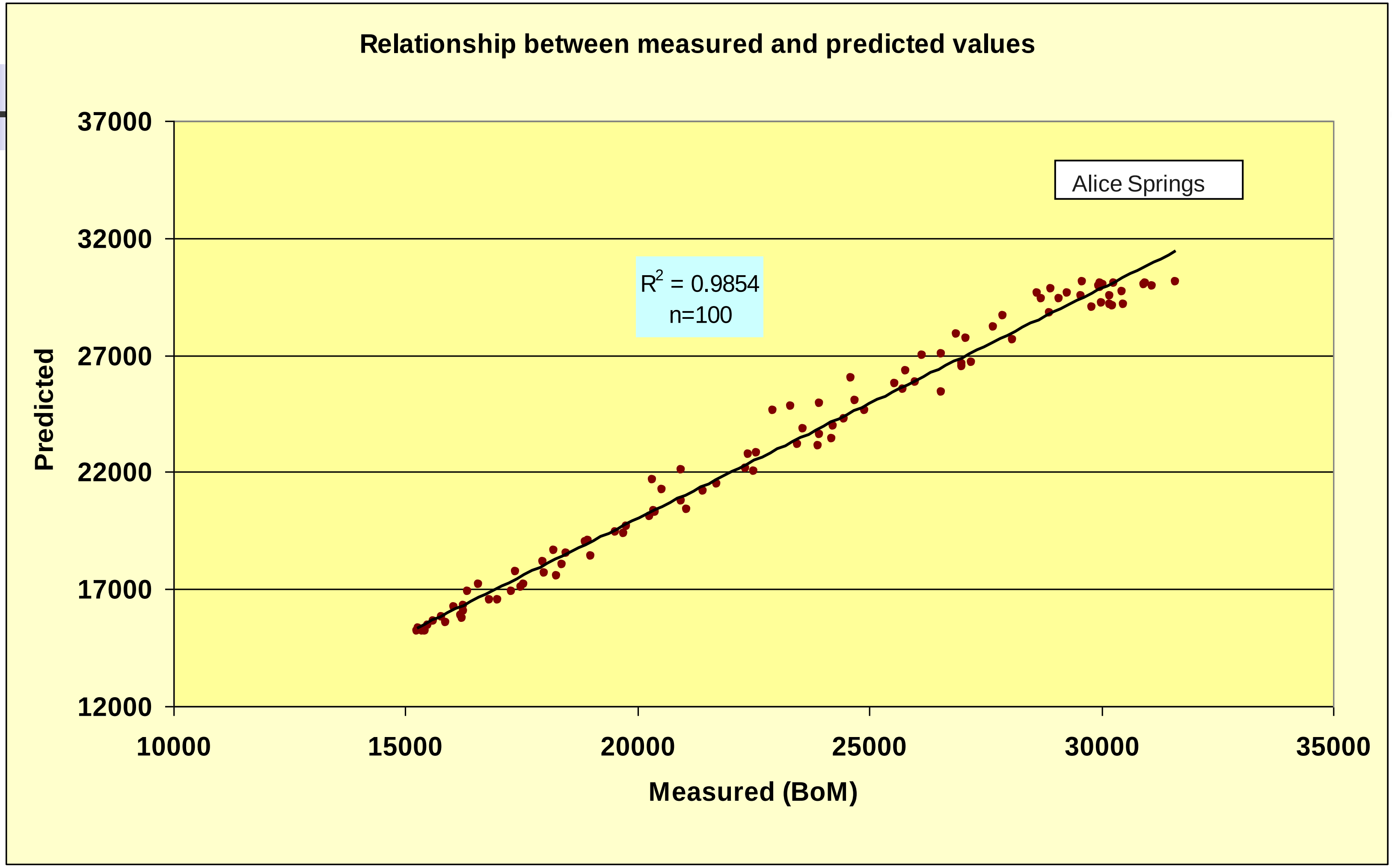
Results ……

- 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
37000
32000
27000
22000
17000
12000
BoM
10000
15000
20000
25000
30000
35000
Modelled
Alice Springs
BoM = 0.8577 Modelled + 3531.5
R2 = 0.9897
n=226


Relationship between measured and predicted values
Alice Springs
R^2 = 0.9854
n=100
Predicted
37000
32000
27000
22000
17000
12000
10000
15000
20000
25000
30000
35000
Measured (BoM)

Results ……

- 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

Uses in Micrometeorolgy

- In micrometeorology, the net radiation R_N on a surface is given by
- $R_N = [S_t - \rho\, S_t] \quad + \quad [L_d - L_u]$

net shortwave net longwave

where ρ 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!