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Validation of Methods Used in the APVI Solar Potential Tool

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Abstract

The APVI Solar Potential Tool is an online tool for estimating the potential for electricity generation from PV on building roofs in Australian cities. The tool accounts for solar radiation and weather at the site; PV system area, tilt, orientation; and shading from nearby buildings and vegetation.

This paper discusses the validation tests undertaken for design of the algorithms and selection of the software tools used in the development of the Australian PV Institute's (APVI) Solar Potential Tool. Three primary tests were undertaken investigating (1) the accuracy of APVI's Solar Potential Tool in comparison to measured outputs of AC power from PV systems with and without shading; (2) an analysis of the accuracy of NREL's System Advisor Model (SAM) in comparison to measured outputs of AC power for PV systems with and without shading; and (3) an analysis of the accuracy of ArcGIS's Solar Radiation tool to estimate insolation on shaded and unshaded surfaces.

The validation tests revealed that (1) APVI's Solar Potential Tool is able to model the AC output of PV systems, capturing the effects of shading from surrounding buildings and vegetation, at both the monthly and annual levels; (2) NREL's SAM models the daily output of PV systems with a low level of uncertainty (< 4.5% when onsite measurements of irradiance are available) in addition to modelling the hourly impact of shading when used in conjunction with ArcGIS's Skyline or Area Solar Radiation tools; and (3) a linear correction can be applied to ArcGIS's estimates of insolation, resulting in a Pearson correlation coefficient of 0.991 between the linear corrected ArcGIS results and insolation as reported by SAM.

1. Introduction

The availability of and interest in web-based solar irradiation and photovoltaic (PV) mapping tools at city and building surface scales has increased significantly over the past decade. The maps to date have primarily been developed to expand interest in PV and to educate the general public about its benefits and costs [1]. Since irradiance maps and PV output calculators for building surfaces enable remote PV site assessment, these tools have also generated a strong interest from installers within the solar community. At the city scale, irradiance and PV maps have found additional uses such as the assessment of PV deployment in network areas [2] and the integration of solar energy into cities' emergency planning strategies [3].

The increase in the prevalence and use of solar irradiation and PV mapping tools for city and building applications highlights the need for a review of the methodologies and assumptions used to build these maps and their associated level of accuracy for predicting irradiance, estimating potential PV system size and associated PV performance. Reviews of existing solar maps presented in the literature [4, 5] list the methodologies used by a range of maps to estimate irradiance, categorise the performance of different roof surfaces and other features available on the maps. It should be noted that most of the existing solar irradiation and PV maps do not provide detailed documentation of the methodologies and assumption used in the development of the maps. For the APVI Solar Potential Tool, documentation of its methodology and assumptions were deemed important so users of the tool can critically assess its outputs. Details on the data sources and specific calculation used within the Tool were reported in [6]. This paper discusses the three primary validation tests undertaken during the development phase of the Solar Potential Tool. The three tests were:

1. An analysis of the accuracy of APVI's Solar Potential Tool in comparison to measured outputs of AC power;
2. An analysis of the accuracy of NREL's System Advisor Model (SAM) in comparison to measured outputs of AC power; and
3. An analysis of the accuracy of ArcGIS's Solar Radiation Tool to estimate insolation.

2. APVI Solar Potential Tool in Comparison to Measured PV System Data

This section presents a comparison between the monthly estimates of AC power from the APVI Tool, to the measured values of AC power for two PV systems that were located on SMA's Sunny Portal [7, 8]. The first example is a 5.1 kWp flush mounted PV array located on the roof of Darlington Public School in Sydney. Figure 1 presents an aerial image of the PV system (Figure 1a), along with screen shots of the insolation heat map (Figure 1b) and winter solstice midday shadow layers (Figure 1c) from the Solar Potential Tool. These images indicate that the system may suffer from partial shading during the morning in winter due to nearby trees. Within the Solar Potential Tool, a polygon was drawn over the area where the PV system is roughly located (green polygon in Figure 1b in comparison to the location of the PV system in Figure 1a), whilst a value of 5.1 kW was entered into the "Flush mounted system size" field.

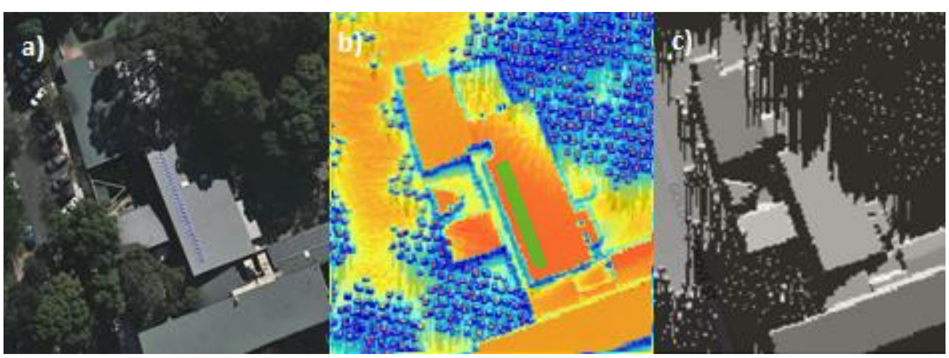

Figure 1: a) Aerial image of Darlington PS PV System; b) Insolation heat map kWh/m^2/day; c) Winter solstice midday shadows.

Figure 2 graphs the expected AC energy output from the Solar Potential Tool, which utilises a typical mean year (TMY) weather file in its calculation, in comparison to the measured values of AC output from Sunny Portal [7] for 2012 and 2013. The estimate of expected average annual AC energy output from the Solar Potential Tool was 6,305 kWh in comparison to the reported annual outputs of 6,198 and 6,349 kWh in 2012 and 2013 respectively. The results for this example indicate that the Solar Potential Tool, utilising a TMY weather file for Sydney, provided a reasonable estimate of the AC output of this PV system for both 2012 and 2013.

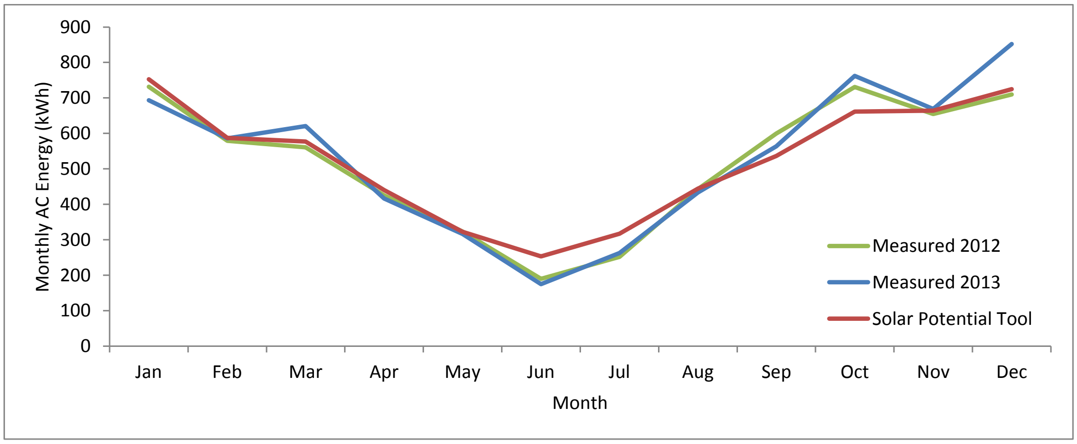

Figure 2: Monthly AC output in kWh measured for the years 2012 and 2013 in comparison to the APVI Solar Potential Tool

The second example is a 14.28 kWp rack mounted PV system located on the roof of Building 17 at the Australian National University in Canberra. Figure 3 presents an aerial image and screen shots from the Solar Potential tool for this PV system. The tilt angle and orientation of the PV system was unknown, however as Figure 3 demonstrates the orientation of the PV system is aligned with the roof orientation (43° East of North). Figure 3d) indicates that the system's tilt angle may coincide with the tilt angle of the white triangular structures that are located on the building's roof (estimated to be 34° by the Solar Potential Tool). It should be noted that any estimation of a PV system configuration (size, tilt, orientation or performance derating) will increase the level of uncertainty of simulated PV performance in comparison to its measured performance.

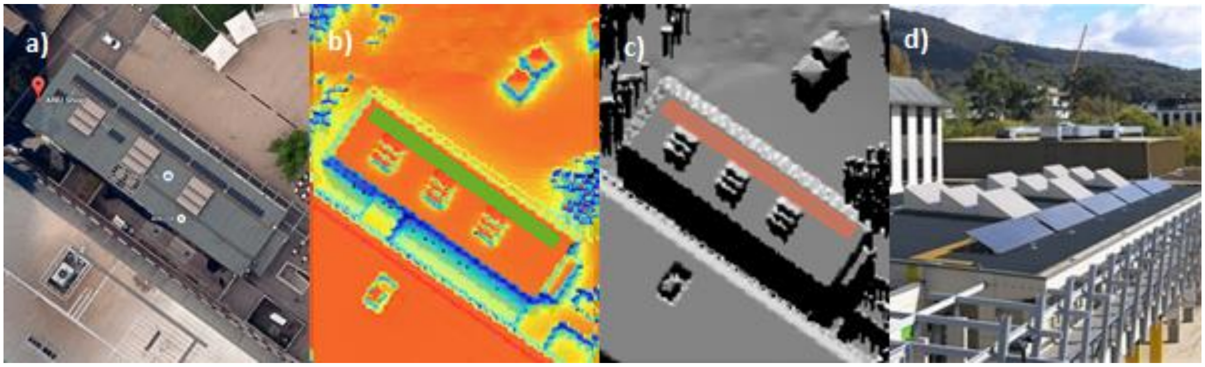

Figure 3: a) Aerial image of ANU Building 17 PV System; b) Insolation heat map kWh/m^2/day; c) Winter solstice midday shadows; d) Image of ANU building 17 PV systems as portrayed on SMA's Sunny Portal

The measured outputs of monthly AC energy from Sunny Portal [8] are presented in Figure 4 in comparison to the Solar Potential Tool's estimates of monthly AC energy using a TMY weather file for Canberra. A complete year of data was not available on Sunny Portal for this system. However multiple part years' data were available and have been presented. The results in Figure

4 illustrate that the system has quite a variable output from year to year, which would partially be due to variations in the local weather conditions from year to year. In addition the variation in measured performance of this system may also be due to performance degradation or reliability issues, particularly given that this system had only partial years' of data available. Taking these issues into consideration, Figure 4 indicates that the estimates of monthly AC energy from the Solar Potential Tool, which utilises a TMY weather file in its calculation, falls within the measured annual variation of the PV system, providing a reasonable average estimate of the PV system's performance.

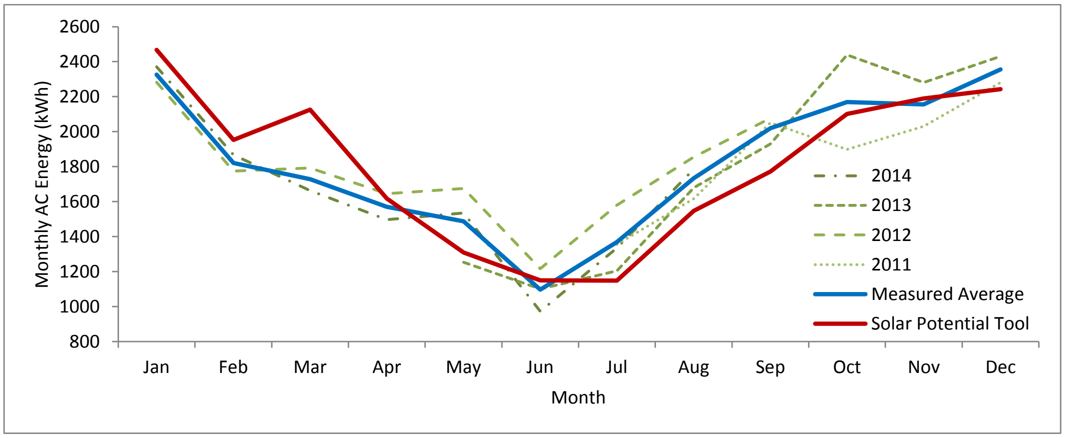

Figure 4: Monthly AC output in kWh measured for the years 2011 to 2014 in comparison to the Solar Potential Tool

3. NREL's SAM in Comparison to Measured PV System Data

This section presents a validation of NREL's System Advisor Model (SAM) to estimate the AC output of shaded and unshaded PV systems in Australian urban environments. SAM was utilised as the platform to estimate the AC output of PV systems due to the high level of documentation and published material on the performance of the algorithms incorporated within SAM. Primarily however, SAM was chosen as the PV modelling software package due to the inclusion of its software development kit, which enables SAM to be programmed for batch processing or programmed in conjunction with other software packages like ArcGIS. In addition to the presented analysis, NREL has also undertaken a number of case studies and validations of SAM which have demonstrated the software's ability to model the performance of PV systems with a low level of uncertainty [9].

The first example presented is an unshaded 1.37 kWp flush-mounted PV array located in Alexandria, Sydney. Figure 5 presents the modelled versus measured PV performance of the array using a) onsite measured plane of array (POA) irradiance data and b) measured irradiance data from a PV system located approximately 2.97 km away, in the suburb of Glebe, Sydney. The results indicate that SAM is able to model the performance of the PV system with a very low level of uncertainty (daily normalised root mean squared error (NRMSE) = 4.58%) when onsite measurements of irradiance are available as input into the software. For comparative purposes modelling results from SAM utilising a measured irradiance dataset from the suburb of Glebe were also presented in Figure 5. These results showed an increase in the level of modelling uncertainty and bias (daily NRMSE = 8.52%, normalised mean bias error (NMBE) = 1.26%) in comparison to the modelling scenario utilising onsite measured irradiance.

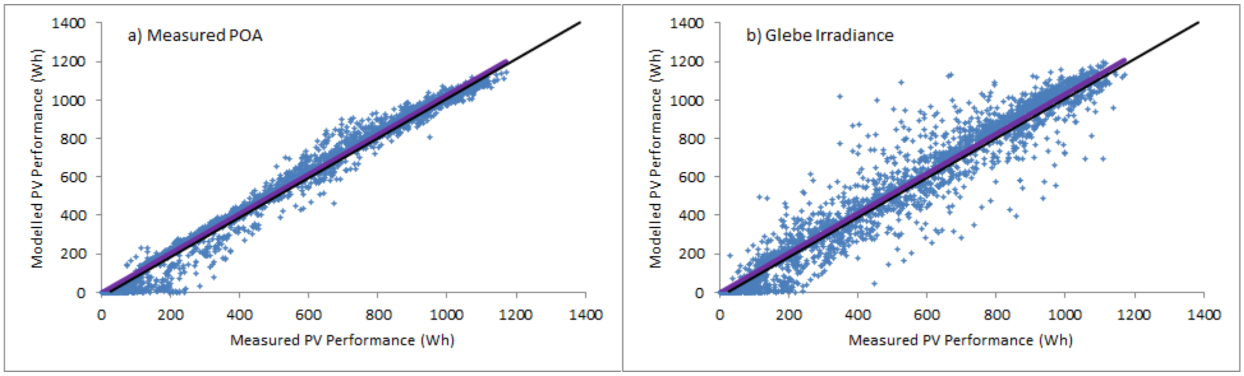

Figure 5: Measured vs. modelled AC power for a PV system located in Alexandria using a) onsite measured POA and b) POA irradiance measured in Glebe

The second example presented is a partially shaded 12.6 kWp rack mounted PV system (tilt = 15°, orientation = 6°) located on the roof of the St Andrews Cathedral School within Sydney's CBD. The system suffers minor shading effects due to surrounding buildings, as depicted by the equidistance viewshed presented in Figure 6. As per the first example, the system was modelled in SAM using both onsite measured plane of array (POA) irradiance and the measured irradiance dataset from Glebe. The modelled results in comparison to the measured PV performance again indicated a low level of modelling uncertainty (daily NRMSE = 4.03%) when onsite measured POA irradiance was available as input into SAM. In comparison, the simulation results using the Glebe irradiance dataset again resulted in a higher level of uncertainty (daily NRMSE = 15.05%) in addition to a higher level of bias (daily NMBE = 10.94%). The high level of modelling bias for this system, when using the Glebe irradiance dataset as input, in comparison to the results of the Alexandria PV system, is partially due to shading of the St Andrew's PV system which was not modelled within the SAM simulation, but is accounted for by data from the POA irradiance sensor, which experiences the same shading.

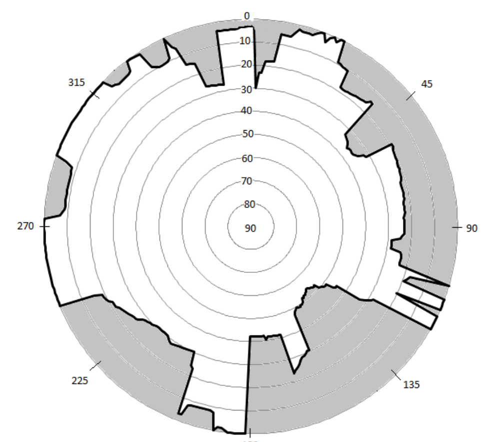

Figure 6: ArcGIS viewshed for the St Andrew's PV System

A second simulation in SAM, using the Glebe irradiance dataset as input, was undertaken incorporating the shading profile generated by the ArcGIS Solar Radiation Graphic tool, as presented in Figure 6. The results of this simulation saw a reduction in the level of modelled uncertainty and bias (daily NRMSE = 10.18% and NMBE = 6.5%) in comparison to the simulation result without the shading profile included (daily NRMSE = 15.05% and NMBE = 10.94%). Although the 2nd simulation results still contained a level of bias, Figure 7 illustrates how the inclusion of the shading profile corrected the hourly simulated PV performance during a time period where the St Andrews PV system was shaded by surrounding buildings. The likely explanation for the remaining level of bias in the simulation results is that the shading profile incorporated within the simulation was generated for a single static point on the array (centre position). The Solar Potential Tool, however, assesses the shading impact for each 1 m^2 of building surface and then determines the average impact of shading over the entire area being assessed by the user, so we would expect the level of bias to be reduced.

The validations tests run on NREL's SAM indicated that the program could model the daily output of PV systems with a low level of uncertainty (< 4.5%) when onsite measurements of irradiance were available as input into the simulation. In addition the tests revealed that the program could model the hourly impacts of shading when used in conjunction with ArcGIS's Solar Radiation tools.

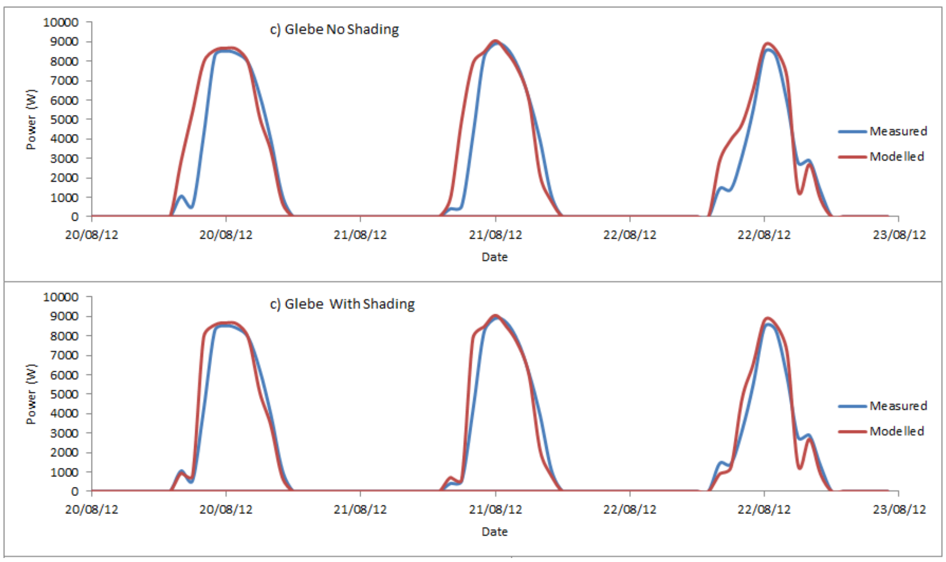

Figure 7: Measured vs. modelled AC power with and without shading modelled

4. Calculation of Monthly and Annual Insolation – ArcGIS versus SAM

This section presents the results of an analysis to determine the best combination of settings for Australian conditions within the ArcGIS Spatial Analyst solar radiation tool. ArcGIS was used as the processing tool to calculate the level of insolation, tilt and orientation at each analysis point (1 point/m^2 of roof surface). ArcGIS was chosen as the software package to calculate these parameters as it is currently one of the premier geospatial software packages available, and the review of the existing online solar irradiation and PV maps indicated that ArcGIS was the primary tool utilised in their development. As ArcGIS uses either the simplified uniform or overcast sky models with constant values for some radiation parameters throughout the year, calibration was required in order to obtain good agreement with NREL's SAM, which uses typical meteorological year weather files to better reflect variations in solar radiation across a year.

The default settings for the ArcGIS solar radiation tool were used for the majority of the inputs. The diffusivity and transmittivity settings of this tool were, however, investigated by varying the inputs of diffusivity (0.2-0.7) and transmittivity (0.3-0.7) for a total of 30 possible combinations, whilst holding all other input parameters at their default settings. The analysis was undertaken for 281 points across the suburb of Darlinghurst in Sydney and for 400 points across a 1km^2 area in Brisbane CBD. The results from ArcGIS were compared against calculated outputs of insolation from SAM, using typical mean year weather files for Sydney and Brisbane respectively as input in conjunction with shading profiles (see Figure 6 for an example) as calculated using ArcGIS' Solar Radiation Graphic tool.

The results of the analysis indicated that a strong linear correlation existed between ArcGIS and SAM's calculations of insolation, which increased as both the diffusivity and transmittivity parameters decreased. The best linear correlation occurred for diffusivity and transmittivity parameters of 0.2 and 0.4 respectively. However, at these settings, the estimates of insolation from ArcGIS were underestimated in comparison to those from SAM. The analysis also revealed that there was no combination of diffusivity and transmittivity settings that resulted in consistently low levels of bias (i.e. no overestimation or underestimation) for all months of the year. However, this analysis indicated that a simple linear adjustment could be applied to ArcGIS's estimates of insolation to correct for differences observed between ArcGIS and SAM, irrespective of which ArcGIS settings were chosen. It was determined that the settings of 0.2 and 0.4 should be selected as these settings achieved the best linear correlation between the two datasets.

The validation of the linear bias-correction methodology was then tested on 400 randomly placed dot points within a 1km^2 tile for the Brisbane data set. The tested dot points covered the range of tilt, orientation and shading that could possibly occur within the Solar Potential Tool. Figure 8 presents the annual and monthly (January, March and June) scatterplots of the linearly adjusted ArcGIS results in comparison to the outputs from SAM with shading files generated via ArcGIS Solar Radiation Graphic tool. The figure demonstrates that the linearly corrected results from ArcGIS show a strong correlation to the results from SAM with Pearson correlation coefficients of 0.991, 0.994, 0.996 and 0.989 respectively at the annual and monthly levels. The levels of normalised uncertainty (NRMSE) of the results were 4.4%, 2.8%, 2.8% and 7.4% respectively at the annual and monthly levels. The significantly higher level of normalised uncertainty observed for the month of June is due to the lower level of average insolation for this month 2.07 kWh/m^2/day in comparison to 5.19 and 3.9 kWh/m^2/day for the months of January and March respectively rather than due to a significantly higher level of absolute uncertainty (0.15 kWh/m^2/day in June) in comparison to 0.14 and 0.11 kWh/m^2/day for January and March respectively.

In addition, two examples of the uncorrected and corrected monthly insolation profiles from ArcGIS are presented in Figure 9 in comparison to SAM's estimates of monthly insolation. The results in both Figure 8 and Figure 9 illustrate that the corrected ArcGIS results are almost identical to those from SAM, and that the output from the ArcGIS tool can be used to estimate insolation for the purposes of the Solar Potential Tool, thus avoiding the need to run a SAM simulation with the ArcGIS shading data as input for every analysis point.

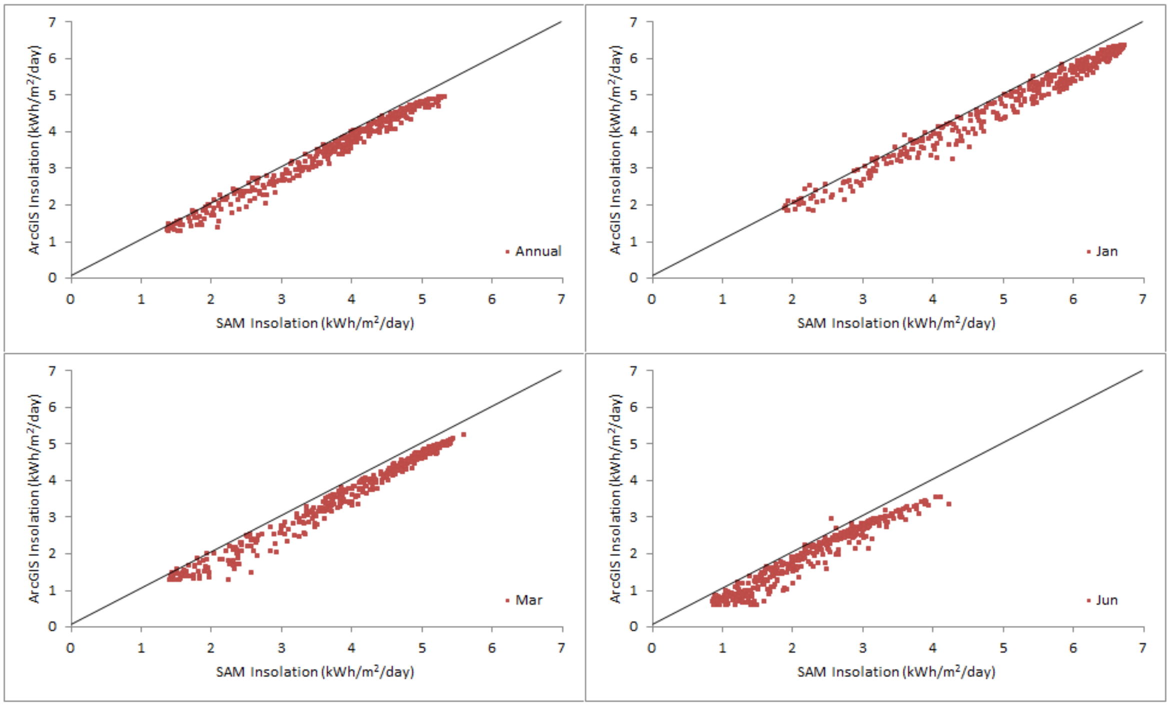

Figure 8: ArcGIS (linearly adjusted) vs. SAM Insolation (kWh/m^2/day) for Brisbane

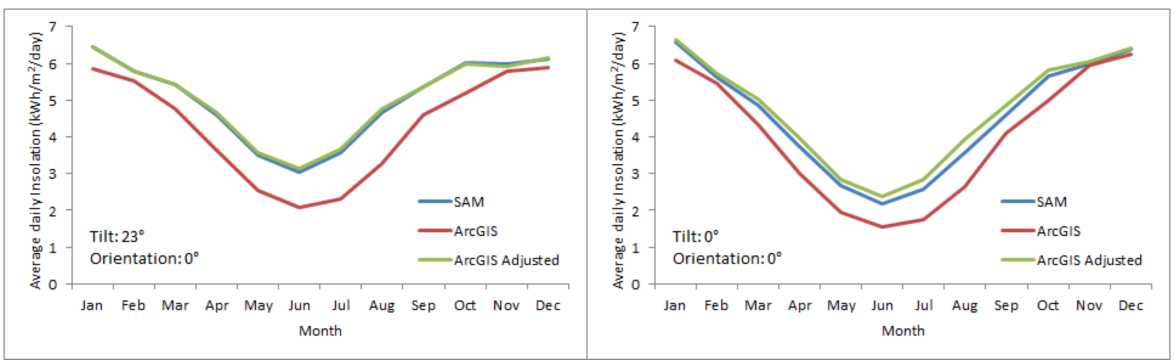

Figure 9: Two examples of SAM vs ArcGIS adjusted and un-adjusted insolation

5. Conclusions

This paper detailed the validation tests undertaken as part of the development of APVI's Solar Potential Tool. The three primary validation tests revealed that (1) the Solar Potential Tool is able to model the AC output of PV systems capturing the effects of shading from surrounding buildings and vegetation, at both the monthly and annual levels; (2) NREL's SAM models the daily output of PV systems with a low level of uncertainty (< 4.5% when onsite measurements of irradiance are available) in addition to modelling the hourly impacts of shading when used in conjunction with ArcGIS's Solar Radiation Graphics tool and (3) a linear correction can be applied to ArcGIS's estimates of insolation, resulting in a Pearson correlation coefficient of 0.991 between the linear corrected ArcGIS results and insolation as reported by SAM. Overall these validation tests indicate that the Solar Potential Tool is able to estimate the AC performance of PV system's in urban environments for a typical mean year.

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