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Assessment of the Australian Bureau of Meteorology hourly gridded solar data

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Abstract

This paper analyses the accuracy of the satellite-derived gridded global horizontal and direct normal irradiance data available from the Australian Bureau of Meteorology (BoM). For the study, an assessment of the variance, bias and distribution of the gridded data was undertaken in comparison to the one-minute measured solar data from the BoM. The analysis revealed (1) a strong correlation between the normalised levels of the root mean squared difference (RMSD) of the satellite derived data and the clearness index (Pearson correlation coefficients of -0.91 and -0.89 for GHI and DNI respectively); and (2) significant differences between the frequency distributions of the satellite derived and ground measured DNI data. The findings presented in this paper can be used to help quantify the uncertainty of solar resource and PV performance assessments undertaken utilising the BoM gridded solar data.

1. Introduction

Besides the magnitude of the solar resource, knowledge of the uncertainty of the solar resource at any given location is essential for accurate analysis of system performance, financial viability and optimal system design and deployment of solar energy systems (M. Sengupta, A. Habte et al. 2015). The uncertainty of the solar resource, with respect to solar energy system performance and project viability, is typically described by the following two components:

1. The interannual variability of the solar resource; and
2. The inherent uncertainty of the data used to quantify the solar resource.

The focus of this paper is on the second component, the inherent uncertainty of the data used to quantify the solar resource, which is the result of the accuracy of the method used to generate the solar resource data, whether that data is measured by ground based sensors or modelled by satellite based solar models.

The BoM metadata (Bureau of Meteorology 2013) quantifies the accuracy of their satellite derived data by comparing the data to the 1-minute averaged measurements of GHI and DNI from the BoM surface-based instruments, where available. The reported mean bias difference (MBD) and the root mean squared difference (RMSD), calculated on an annual basis across all surfaces sites are reproduced in Table 1. These statistics indicate that the satellite derived DNI data has on average twice the level of variance of the GHI data when referenced to the ground-based measurement data.

The accuracy of what is now a legacy version of the hourly satellite derived gridded data (pre-2012) was independently tested by Blanksby et al. (Blanksby, Bennett et al. 2013). The study compared the gridded data to measured irradiance data from eight of the BoM ground-based stations in addition to four independent stations (3 located in Queensland and one in Victoria). Although the primary results from Blanksby et al. (2013) are now out of date, as the August 2012 release of the gridded BoM dataset introduced a bias correction (Bureau of Meteorology 2013), the results of the comparison presented between different temporal averaging are still relevant. The hourly satellite derived gridded data was compared with the ground based measurements at (i) the satellite observation time; (ii) averaged 15 minutes on either side of the satellite observation time; and (iii) averaged 30 minutes either side of the satellite observation time. The results revealed that temporal averaging of the measured ground data over longer time periods (up to 1 hour), mitigated to some degree the geographic spatial averaging of the gridded satellite data (Blanksby, Bennett et al. 2013). These results indicate that the hourly gridded satellite derived data better reflects hourly averages of the solar resource, rather than the instantaneous values of the solar resource.

Table 1: Statistical metrics of the bias and uncertainty of the BoM hourly gridded satellite derived irradiance data products (Bureau of Meteorology 2013).

	GHI (mean = 480 W/m^2)	**DNI (mean = 500 W/m^2)**
MBE (W/m^2)	-4 to +2; typically around -2	-20 to +18
NMBE (% of mean irradiance)	-0.5%	-4% to +4%
RMSE (W/m^2)	110	210
NRMSE (% of mean irradiance)	23%	42%

Dehghan et al. (Dehghan, Prasad et al. 2014) also undertook an assessment of the GHI satellite derived data in comparison to 5 of the BoM ground based observation locations across Eastern Australia (Rockhampton, Wagga Wagga, Melbourne, Mildura and Adelaide). Their analysis utilised the ground based measurements recorded at the same minute that the satellite image was captured. The results from (Dehghan, Prasad et al. 2014) indicate that the average RMSE and MBE across the 5 stations was 129 W/m^2 and -3.5 W/m^2 respectively. These results are marginally higher than the results reported in Table 1 from the BoM. Although the results from (Dehghan, Prasad et al. 2014) provide an independent assessment of the gridded satellite data, the study had a number of limitations. Primarily, the study only assessed 5 of the ground-based irradiance locations, due to the specific focus of their study over Eastern Australia and the limited release of data at the time the study was undertaken. Secondly the study only considered the time period between 2000 and 2005, which was further confounded as the satellite derived data is sparse during the period from July 2001 to June 2003 (Bureau of Meteorology 2013). Finally, the study only investigated the accuracy of the GHI component of the solar resource and did not assess the DNI component.

Internationally, Ineichen (Ineichen 2011) assessed the performance of five satellite derived data products against measured data from 23 ground sites located within the Northern Hemisphere. The study indicated that the satellite derived GHI and DNI data had negligible levels of bias with the best algorithms achieving standard deviations (uncertainties) around 16% for GHI and around 35% for DNI. In particular, the results in Ineichen (Ineichen 2011) illustrated significant discrepancies between the frequency distributions of the satellite derived and ground measured beam component of the solar resource. Although the BoM satellite derived data products were not tested, the methodology utilised in Ineichen (Ineichen

2011) to test the performance of the satellite data products can be applied to the BoM satellite derived products.

This paper aims to complement the existing literature by assessing the accuracy of both the satellite derived GHI and DNI data products for 20 of the BOM ground-based irradiance measurement locations, including all available data between 1990 and 2014, as at July 2015.

2. Data Sources and Methodology

The BoM solar resource data can be characterised into two primary products: (1) gridded satellite derived data and (2) ground based surface measurements. The gridded satellite derived data is processed by the Australian BoM from satellite imagery sourced from the Geostationary Meteorological Satellite and MTSAT series operated by the Japan Meteorological Agency and from GOES-9 operated by the National Oceanographic & Atmospheric Administration (NOAA) for the Japan Meteorological Agency. The data is available over a number of temporal time frames, including: instantaneous hourly GHI and DNI in W/m^2, average hourly GHI and DNI in W/m^2 averaged over the period 1995 to 2011, and daily and monthly averages of solar exposure in MJ/m^2/day. Each of the gridded satellite derived data products span the entire region of Australia (latitudes: -10.05° to -43.95°, Longitudes: 112.05° to 153.95°) with spatial resolutions of 0.05° (≈5km) (Bureau of Meteorology 2013). The accuracy of the hourly gridded satellite derived irradiance data products as reported by the BoM were presented in Table 1.

The ground based irradiance measurements from the BoM were accessed via the One Minute Solar Data portal (Bureau of Meteorology 2015). Data is currently available for 20 locations across Australia covering a range of time periods from 1 up to 20 years, with various levels of completeness. This study utilised the available data as of July 2015, for the time period between 1990 and 2014, excluding only the location of Cocos Island from the study. The list of stations currently available on the BoM One Minute Solar Data Portal is reproduced in Table 2. The product notes for the one-minute solar radiation data (Bureau of Meteorology 2014) indicates that the uncertainty associated with each solar statistic reported has been calculated using ISO guidelines and are traceable to the World Radiometric Reference for solar components. Similarly, it is reported that the data quality control and assurance is such that the 95% uncertainty for any quantity measured is well within the original network targets of 3% or 15 W/m^2 (whichever is greater) after the post measurement verification is complete (Bureau of Meteorology 2014).

Table 2: BoM One Minute Solar Data station details (Bureau of Meteorology 2015)

Name	State	Latitude	Longitude	End date	Years
Adelaide	SA	-34.9524	138.5204	1/07/2015	15
Alice Springs	NT	-23.7951	133.889	1/07/2015	21
Broome	WA	-17.9475	122.2353	1/07/2015	18
Cairns	QLD	-16.8736	145.7458	18/03/2004	6
Cape Grim	TAS	-40.6817	144.6892	1/07/2015	17
Cobar	NSW	-31.484	145.8294	1/03/2014	1
Cocos Island	WA	-12.1892	96.8344	27/06/2015	9
Darwin	NT	-12.4239	130.8925	1/07/2015	20
Geraldton Airport	WA	-28.8047	114.6989	9/09/2014	1
Geraldton Airport Comparison	WA	-28.7953	114.6975	20/06/2006	9
Kalgoorlie-Boulder	WA	-30.7847	121.4533	1/09/2013	9
Learmonth	WA	-22.2406	114.0967	1/12/2013	10
Longreach Aero	QLD	-23.4397	144.2828	1/01/2014	1
Melbourne Airport	VIC	-37.6655	144.8321	1/07/2015	16
Mildura	VIC	-34.2358	142.0867	1/07/2013	10
Mount Gambier	SA	-37.7473	140.7739	4/03/2006	11
Rockhampton Aero	QLD	-23.3753	150.4775	1/07/2015	19
Tennant Creek Airport	NT	-19.6423	134.1833	25/06/2006	10
Townsville Aero	QLD	-19.2483	146.7661	1/04/2014	1
Wagga Wagga	NSW	-35.1583	147.4575	1/07/2015	18
Woomera	SA	-31.1558	136.8054	1/07/2013	1

The values of GHI and DNI in the BoM satellite derived hourly gridded data are instantaneous intensities of the solar resource (W/m^2), averaged over a 0.5° spatial resolution, at the time of the satellite observation. The number of minutes of the observation time after the start of the hour varies smoothly with latitude in a manner that is fixed for each satellite and hour of the day, but which differs between satellites, and for some satellites, between hours of the day (Bureau of Meteorology 2013). The values reported in the metadata (Bureau of Meteorology 2013) indicate that the observation time can range between 28 to 53 minutes after the start of the hour. Due to this difference, the satellite data cannot be directly compared to the ground-based measured data using the timestamp of the hourly gridded satellite derived data products. The methodology implemented in (Dehghan, Prasad et al. 2014) handled this issue by comparing the ground-based data taken at the same minute as the satellite observation time. This paper will implement a slightly different methodology, as we argue that the hourly satellite derived values are not a true reflection of the instantaneous value of the solar resource at a specific location but rather is the average response over the 0.5° (~5km) spatial resolution of the data. Hence, it is proposed that the hourly satellite derived values better reflect the average response of the solar resource across an hour as observed in (Blanksby, Bennett et al. 2013), rather than at the observation time. The methodology utilised in this paper compares the hourly satellite derived data to averaged hourly values of the ground-based measurements centred on the satellite observation time. For comparative purposes, the results of the analysis using the instantaneous ground-based measurement at the same minute as the satellite data are also reported in the appendix.

Data quality assessment was applied to the one minute solar data via the closure and physical limits approaches. Upper and lower physical limits were defined using the k-space methodology as presented in NREL's SERI QC manual for assessing the quality of solar radiation data (NREL 1993). The analysis considered only hours for which both ground based and satellite measurement data existed and the standard statistical parameters of mean, mean bias difference (MBD), root mean squared difference (RMSD) and the Pearson correlation coefficient (p) were assessed. In addition comparisons between the frequency distributions of the ground based and satellite derived data products were undertaken. Where available, the frequency distribution of the irradiance components within typical/reference mean year (TMY or RMY) weather files were also assessed.

3. Results

Table 3 and Table 4 present the statistical results of the comparison between the satellite derived and hourly averages of the ground based measurements of GHI and DNI respectively. For reference, comparative tables for the analysis undertaken using the instantaneous values of the ground based measurements are presented within the appendices.

For GHI the average level of bias (MBD) across all locations is negligible, varying between -4% at Learmonth to +4.9% at Darwin. Similarly for RMSD, the average across all stations is comparatively low at 15.6%, varying from as low as 10-13% for relatively clear sky locations (i.e. Longreach, Learmonth and Alice Springs) to as high as 22-23% for more diffuse sky locations (i.e. Cairns, Cape Grim, Darwin, Mount Gambier and Melbourne). For DNI the average level of the bias was also negligible, however the overall magnitude of the bias increased significantly varying between -11.5% at Learmonth to +21.3% at Cape Grim. As expected, the RMSD of the DNI data was significantly higher than the case for GHI, with an average across all stations of 31.9%, varying between 20.2% for Longreach to 60.3% for Cape Grim.

Table 3: Hourly statistics – comparison between satellite and ground based GHI

Site	Mean Irradiance for ground station (W/m^2)	Mean Irradiance for Satellite (W/m^2)	MBD	RMSD	NMBD	NRMSD	Pearson	Mean k_t from ground station	Mean k_t from Satellite	KSI
Adelaide	460.80	467.78	6.98	77.04	1.52%	16.72%	0.984	0.57	0.58	0.20
Alice Springs	553.42	547.17	-6.25	69.20	-1.13%	12.50%	0.973	0.64	0.63	0.19
Broome	557.47	555.50	-1.97	69.72	-0.35%	12.51%	0.986	0.62	0.62	0.09
Cairns	479.13	494.96	15.82	109.75	3.30%	22.91%	0.979	0.53	0.55	0.44
Cape Grim	377.42	391.40	13.98	84.10	3.70%	22.28%	0.973	0.49	0.51	0.26
Cobar	538.51	525.92	-12.59	62.74	-2.34%	11.65%	0.995	0.64	0.62	0.26
Darwin	504.57	529.02	24.46	106.82	4.85%	21.17%	0.930	0.56	0.58	0.44
Geraldton Airport Comparison	529.10	515.40	-13.70	75.84	-2.59%	14.33%	0.991	0.62	0.60	0.28
Geraldton Airport	493.25	482.50	-10.75	61.65	-2.18%	12.50%	0.994	0.62	0.60	0.18
Kalgoorlie	499.69	491.47	-8.22	67.12	-1.65%	13.43%	0.992	0.61	0.59	0.16
Learmonth	588.66	565.17	-23.50	67.35	-3.99%	11.44%	0.994	0.66	0.63	0.45
Longreach	580.71	572.39	-8.32	58.17	-1.43%	10.02%	0.996	0.65	0.65	0.22
Melbourne	394.05	404.71	10.66	82.85	2.70%	21.03%	0.978	0.50	0.51	0.24
Mildura	480.80	475.68	-5.12	66.16	-1.06%	13.76%	0.991	0.60	0.59	0.14
Mount Gambier	394.89	404.01	9.12	84.65	2.31%	21.44%	0.981	0.50	0.51	0.16
Rockhampton	494.51	502.17	7.66	84.41	1.55%	17.07%	0.974	0.57	0.58	0.22
Tennant Creek	557.90	558.09	0.20	80.23	0.04%	14.38%	0.990	0.63	0.63	0.08
Townsville	555.25	552.87	-2.39	88.86	-0.43%	16.00%	0.990	0.59	0.60	0.40
Wagga	468.75	467.11	-1.63	70.01	-0.35%	14.94%	0.986	0.58	0.58	0.14
Woomera	505.55	494.77	-10.78	62.25	-2.13%	12.31%	0.994	0.63	0.61	0.27

Table 4: Hourly statistics – comparison between satellite and ground based DNI

Site	Mean Irradiance for ground station (W/m^2)	Mean Irradiance for Satellite (W/m^2)	MBD	RMSD	NMBD	NRMSD	Pearson	Mean k_t from ground station	Mean k_t from Satellite	KSI
Adelaide	511.91	551.68	39.77	175.76	7.77%	34.33%	0.945	0.58	0.59	0.52
Alice Springs	675.09	647.48	-27.61	151.56	-4.09%	22.45%	0.900	0.64	0.63	1.15
Broome	620.48	598.37	-22.11	156.14	-3.56%	25.16%	0.942	0.62	0.62	0.76
Cairns	452.24	468.95	16.70	205.53	3.69%	45.45%	0.930	0.54	0.57	0.79
Cape Grim	334.87	406.11	71.24	201.77	21.27%	60.25%	0.893	0.49	0.51	0.84
Cobar	665.30	625.70	-39.60	151.81	-5.95%	22.82%	0.980	0.64	0.62	1.07
Darwin	486.51	510.12	23.61	174.71	4.85%	35.91%	0.832	0.56	0.59	0.56
Geraldton Airport Comparison	611.88	577.45	-34.42	180.49	-5.63%	29.50%	0.961	0.63	0.60	1.10
Geraldton Airport	584.74	554.87	-29.87	161.41	-5.11%	27.60%	0.971	0.62	0.60	0.89
Kalgoorlie	602.55	571.36	-31.19	151.15	-5.18%	25.08%	0.973	0.61	0.60	1.33
Learmonth	710.73	628.99	-81.74	188.98	-11.50%	26.59%	0.966	0.66	0.63	1.88
Longreach	703.63	664.43	-39.20	142.40	-5.57%	20.24%	0.983	0.66	0.65	1.12
Melbourne	383.02	417.26	34.24	165.61	8.94%	43.24%	0.936	0.50	0.52	0.26
Mildura	574.98	572.05	-2.93	154.07	-0.51%	26.80%	0.968	0.60	0.60	0.72
Mount Gambier	363.65	399.39	35.74	169.41	9.83%	46.59%	0.945	0.49	0.51	0.66
Rockhampton	505.47	516.04	10.57	161.97	2.09%	32.04%	0.927	0.57	0.58	0.48
Tennant Creek	648.96	629.65	-19.31	165.68	-2.98%	25.53%	0.968	0.64	0.63	0.84
Townsville	543.66	551.30	7.64	184.08	1.41%	33.86%	0.957	0.60	0.60	0.56
Wagga	550.39	549.69	-0.70	154.90	-0.13%	28.14%	0.954	0.58	0.58	0.67
Woomera	628.86	597.13	-31.74	167.13	-5.05%	26.58%	0.973	0.63	0.62	1.19

A deeper analysis of the results indicates that an exponential trend in the NRMSD, for both GHI and DNI, exists with respect to the average level of the satellite derived clearness index, Figure 1, with Pearson correlation coefficients of -0.91 and -0.89 for GHI and DNI respectively. To a lesser extent, Figure 1 indicates that a negative linear relationship may exist between the level of bias and the satellite derived clearness index (Pearson coefficients of -0.54 and -0.58 for GHI and DNI respectively). Figure 1 also reveals that clearer sky locations generally result in a negative level of bias whilst more diffuse sky locations result in positive levels of bias, with a cross over point at k_t equal to 0.6. Figure 1 plots the average monthly and individual yearly NRMSD and NMBD statistics calculated for each of the 20 BoM ground based irradiance measurement locations.

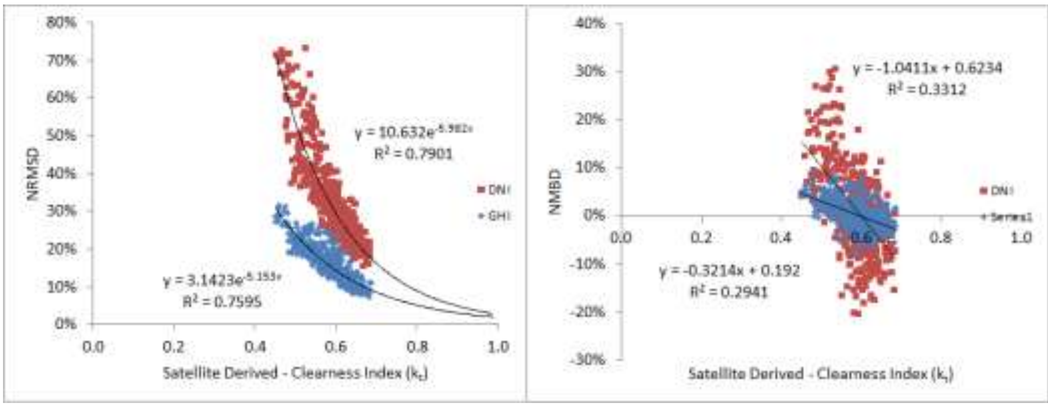

Figure 1: Yearly and monthly NRMSD and NMBD vs. satellite derived clearness index (k_t) across all sites.

Using the relationships defined in Figure 1, with the annual average grid of satellite derived solar exposure from the BoM and the top of the atmosphere insolation grid from NASA (NASA 2015), a spatial map of the predicted levels of NRMSD and NMBD in the satellite derived irradiance data was created, as depicted in Figure 2. This figure reveals that the satellite derived irradiance data is predicted to have lower levels of uncertainty and negative bias (blue regions of the maps) for the vast majority of the Australian mainland, whilst higher levels of uncertainty and positive levels of bias are predicted to exist within the satellite derived irradiance data for the regions of Tasmania and the southern and eastern coastal regions of Australia's mainland.

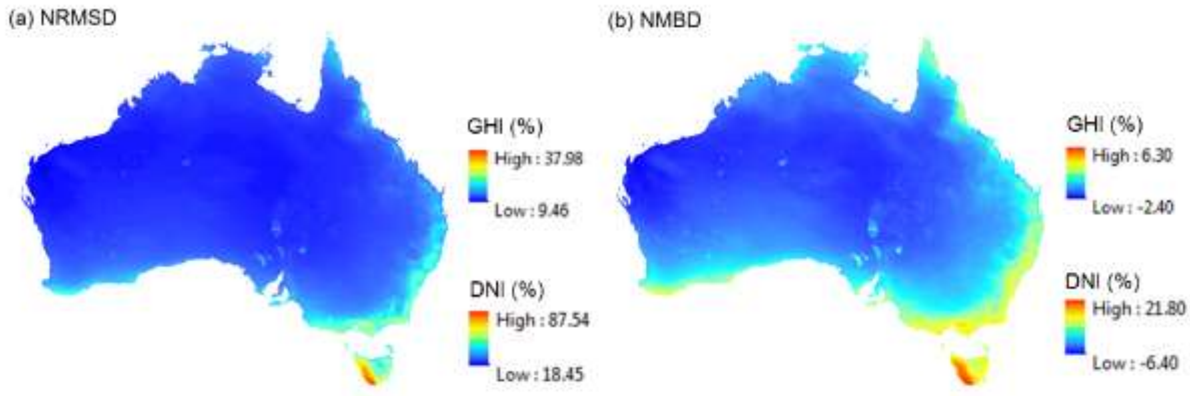

Figure 2: Spatial plots of NRMSD and NMBD – relations presented in Figure 1

When assessing the quality of satellite derived irradiance data, another issue of relevance is the distribution of the data. The Kolmogorov-Smirnov test Integral (KSI) is defined as the integrated difference between the cumulative distribution functions (CDFs) of two data sets (Espinar, Ramírez et al. 2009). This statistic is one metric which can be used to assess the relative difference between the distributions of the ground based and satellite derived irradiance data. The minimum possible value, KSI equal to zero, indicates that the two CDFs are considered equal. Values greater than zero indicate differences in the distributions, where larger values of KSI equate to greater differences in the CDFs.

Table 3 and Table 4 include the calculated KSI statistics for each of the 20 BoM locations investigated, whilst Figure 3 and Figure 4 present examples of the distributions for the GHI and DNI solar components, for a relatively clear sky (Alice Springs) and partially diffuse sky (Melbourne) location. The KSI statistics in Table 4 for the DNI component, indicate a general correlation ($p = 0.55$) with respect to the clear sky index, with clearer sky locations exhibiting larger differences in the distributions of the satellite and ground measured irradiance data. This correlation does not appear to exist for the GHI component ($p = -0.1$) of the satellite derived solar data. This phenomenon is clearly evident in the GHI distributions presented in Figure 3 and Figure 4, for Alice Springs and Melbourne which illustrate only minor differences between the GHI frequency distributions; whereas for DNI, Figure 3 illustrates a significant difference in the frequency distributions for Alice Springs, whilst Figure 4 indicates that the satellite data exhibits a similar distribution to the ground measured data set. These results confirm the trend observed earlier, where the satellite derived DNI was underestimated (negative NMBD) for clear sky locations. The observed differences in the satellite derived DNI distributions for clearer sky locations will also likely lead to underestimations of system performance and financial viability for concentrating and tracking based PV systems. These types of solar energy systems are highly dependent on the intensity and frequency distribution of the DNI component of the solar resource; hence the importance of assessing the frequency distributions of the satellite derived data. It should also be noted that similar observed discrepancies between the frequency distributions for the DNI component of the solar resource was also observed by Ineichen (Ineichen 2011) for the five satellite derived DNI irradiance products tested across Northern Hemisphere locations.

For completeness, Figure 3 and Figure 4 also present the frequency distributions for the Reference Mean Year (RMY) weather files available for the locations of Alice Springs Airport and Melbourne Airport. These weather files are freely available to download from the U.S. DOE EnergyPlus website (US-DOE 2013). The results for these two particular locations indicate that the distributions of the solar components within the RMY weather files sometimes match reasonably well to the distributions of the ground based measurements, where significant improvements for the DNI distribution is observable in the RMY file for the location of Alice Springs. It should however be noted that this was not the case for all locations investigated as evidenced by the mismatch in distributions for the location of Melbourne.

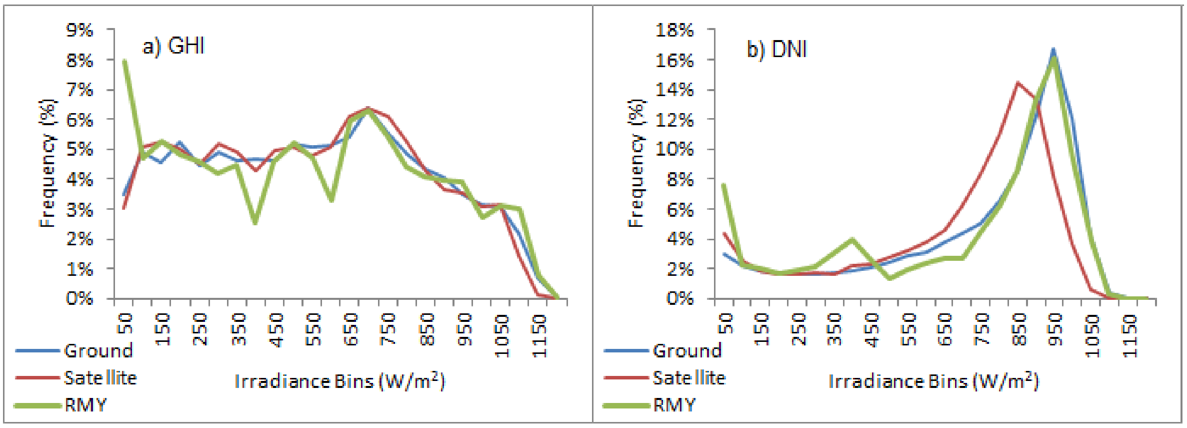

Figure 3: Frequency distributions of (a) GHI and (b) DNI for Alice Springs

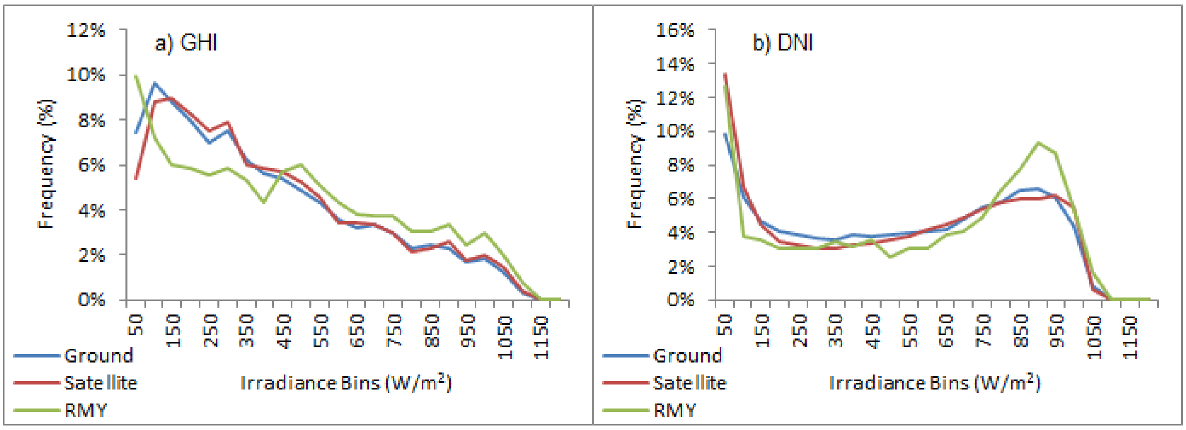

Figure 4: Frequency distribution of (a) GHI and (b) DNI for Melbourne

The results presented within this section highlight that the quality (uncertainty, bias and distribution) of the hourly satellite derived irradiance data varies significantly with location across Australia. For example, the use of the satellite derived irradiance data at a clear sky location like Alice Springs will result in a comparatively low level of uncertainty and negative bias for both components of the solar resource, whilst the difference between the frequency distributions of the DNI component will be relatively high. Whilst for a more diffuse sky location like Melbourne, the analysis revealed that the satellite data would result in comparatively higher levels of uncertainty and positive levels of bias, with smaller differences between the frequency distributions of the DNI component.

4. Conclusions

This paper analysed the satellite-derived gridded global horizontal and direct normal irradiance data available from the Australian Bureau of Meteorology (BoM). The results highlighted (1) a strong correlation between the NRMSD of the gridded data and the clearness index (Pearson correlation coefficients of -0.91 and -0.89 for GHI and DNI respectively); and (2) significant differences between the frequency distributions of the satellite derived and ground measured DNI data products. The findings presented in this paper can be used to help quantify the uncertainty of solar resource assessments and PV performance assessments undertaken utilising BoM gridded solar data products.

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Appendix

Table 5: Hourly statistics – comparison between satellite and instantaneous ground based GHI

Site	Mean Irradiance for ground station (W/m^2)	Mean Irradiance for Satellite (W/m^2)	MBD	RMSD	NMBD	NRMSD	Pearson	Mean k_t from ground station	Mean k_t from Satellite	KSI
Adelaide	451.68	465.25	13.57	105.78	3.00%	23.42%	0.972	0.55	0.57	0.44
Alice Springs	547.91	545.52	-2.39	100.60	-0.44%	18.36%	0.953	0.63	0.63	0.41
Broome	554.94	555.55	0.61	93.23	0.11%	16.80%	0.977	0.62	0.62	0.27
Cairns	469.85	492.09	22.24	151.94	4.73%	32.34%	0.960	0.52	0.55	0.86
Cape Grim	359.23	384.24	25.01	111.97	6.96%	31.17%	0.955	0.47	0.51	0.52
Cobar	533.07	525.67	-7.40	94.56	-1.39%	17.74%	0.988	0.63	0.62	0.48
Darwin	492.93	526.60	33.66	156.64	6.83%	31.78%	0.896	0.54	0.58	0.81
Geraldton Airport Comparison	520.55	513.74	-6.81	107.98	-1.31%	20.74%	0.981	0.61	0.60	0.30
Geraldton Airport	483.87	481.05	-2.81	89.03	-0.58%	18.40%	0.987	0.60	0.60	0.39
Kalgoorlie	489.13	489.20	0.08	100.94	0.02%	20.64%	0.946	0.59	0.59	0.32
Learmonth	583.37	563.46	-19.91	86.43	-3.41%	14.82%	0.990	0.66	0.63	0.44
Longreach	571.43	570.77	-0.66	97.88	-0.12%	17.13%	0.988	0.65	0.65	0.46
Melbourne	371.91	397.18	25.27	117.38	6.79%	31.56%	0.955	0.47	0.51	0.55
Mildura	471.37	473.45	2.08	96.98	0.44%	20.57%	0.981	0.58	0.59	0.36
Mount Gambier	378.45	398.19	19.74	130.70	5.22%	34.54%	0.954	0.48	0.51	0.49
Rockhampton	479.10	496.42	17.32	139.02	3.62%	29.02%	0.935	0.56	0.58	0.75
Tennant Creek	550.63	556.22	5.59	119.07	1.01%	21.62%	0.978	0.63	0.63	0.38
Townsville	542.73	549.85	7.12	120.58	1.31%	22.22%	0.981	0.58	0.60	0.70
Wagga	456.62	463.38	6.77	103.06	1.48%	22.57%	0.970	0.57	0.58	0.40
Woomera	498.23	493.78	-4.45	88.29	-0.89%	17.72%	0.988	0.62	0.61	0.46

Table 6: Hourly statistics – comparison between satellite and instantaneous ground based DNI

Site	Mean Irradiance for ground station (W/m^2)	Mean Irradiance for Satellite (W/m^2)	MBD	RMSD	NMBD	NRMSD	Pearson	Mean k_t from ground station	Mean k_t from Satellite	KSI
Adelaide	529.12	575.25	46.13	221.00	8.72%	41.77%	0.924	0.58	0.60	1.45
Alice Springs	682.76	658.43	-24.32	187.81	-3.56%	27.51%	0.882	0.64	0.64	2.11
Broome	626.95	604.40	-22.54	184.46	-3.60%	29.42%	0.930	0.62	0.62	1.35
Cairns	459.56	482.71	23.15	255.00	5.04%	55.49%	0.900	0.55	0.58	2.24
Cape Grim	335.82	415.45	79.63	249.55	23.71%	74.31%	0.852	0.49	0.52	1.40
Cobar	671.19	635.17	-36.02	191.91	-5.37%	28.59%	0.969	0.63	0.63	2.18
Darwin	495.85	525.75	29.90	219.07	6.03%	44.18%	0.828	0.56	0.60	0.92
Geraldton Airport Comparison	620.98	591.14	-29.84	224.28	-4.81%	36.12%	0.943	0.63	0.61	2.11
Geraldton Airport	588.83	559.15	-29.68	195.91	-5.04%	33.27%	0.960	0.61	0.60	2.34
Kalgoorlie	609.05	584.21	-24.84	199.68	-4.08%	32.78%	0.862	0.61	0.60	2.35
Learmonth	713.30	634.65	-78.66	208.65	-11.03%	29.25%	0.958	0.66	0.64	2.38
Longreach	708.07	673.50	-34.57	182.65	-4.88%	25.80%	0.972	0.66	0.65	1.74
Melbourne	383.19	431.82	48.64	218.06	12.69%	56.91%	0.898	0.50	0.53	2.08
Mildura	579.57	583.39	3.82	197.85	0.66%	34.14%	0.951	0.60	0.60	1.83
Mount Gambier	385.82	433.17	47.36	235.12	12.28%	60.94%	0.903	0.51	0.53	2.02
Rockhampton	502.94	524.50	21.55	220.71	4.29%	43.88%	0.886	0.56	0.59	1.95
Tennant Creek	650.50	637.39	-13.11	202.58	-2.02%	31.14%	0.954	0.63	0.64	1.78
Townsville	554.55	567.52	12.97	226.68	2.34%	40.88%	0.939	0.60	0.61	1.73
Wagga	562.12	567.33	5.20	201.78	0.93%	35.90%	0.928	0.59	0.59	1.85
Woomera	635.48	606.57	-28.90	207.06	-4.55%	32.58%	0.960	0.63	0.62	2.30