Comparative assessment of global horizontal radiation and temperature data for photovoltaic plant applications

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Abstract

Global demand for energy is growing beyond the limits of installed generation capacity. To meet these future demands alternative energy sources need to be investigated. Photovoltaic (PV) power generation is a prominent source of alternative energy and is the focus of this study.

Acquisition of the finance needed to develop a PV plant requires an assurance of the amount energy yield that a plant will generate. The energy yield available at a potential PV site is highly dependent on the amount of solar radiation. Most sites in South Africa that are suitable for PV plant applications do not have sufficient or reliable data available to determine adequate solar radiation estimates. To address this limitation a number of software packages can be used to estimate solar radiation data. This study will investigate the use of one of these software packages, namely Meteonorm.

This study evaluates the accuracy of the database of Meteonorm by comparing the results to actual measured data in South Africa. A profile analysis will be used to test whether the overall trend of global horizontal radiation and temperature estimates of Meteonorm are significantly different from actual measured data.

An additional investigation will be conducted on interval estimates of global horizontal radiation and temperature. Interval estimates for these variables were calculated using 10 year solar radiation data generated from Meteonorm. If the algorithms within Meteonorm are accurate the simulated data should provide interval estimates, which include the actual measured data.

Keywords: solar radiation; profile analysis; confidence interval estimates.

1. Introduction

Global interest in renewable energy has been largely driven by the impacts of fossil fuels on the environment, the volatility of fossil fuel prices and the enhancement of national energy security (Sebitosi & Pillay, 2008). South Africa is a country that is fossil fuel based and emission intensive (Pegels, 2010). ESKOM, the dominant energy supplier in South Africa, is under enormous strain to deal with the energy demand in the country. This has impacted the country in such a way that ESKOM

has implemented national system load shedding. This load shedding has an effect on the economy growth and sustainability of the country. Renewable energy products can potentially assist by alleviating the pressure on Eskom.

South Africa has great potential in the renewable energy sector. However, a number of barriers still need to be overcome with regards to these applications. These barriers include (Msimanga & Sebitosi, 2014):

1. Subsidies for competing fossil fuels and high initial capital costs.
2. Lack of legal framework for Independent Power Produces (IPP's), utility interconnections requirements and liability insurance requirements.
3. Lack of access to credit, perceived technology performance, uncertainty and risk, lack of technical and commercial skills and information.
4. Lack of reliable and sufficient data for energy yield estimates.

Investigating the use of PV power generation as an alternative energy system is the focus of this study. For local investors to aquire finance to develop a PV plant requires assurance of the energy yield amount that a plant will generate. Legal agreements with national utility providers usually stipulate a consistent supply of energy from independent producers. The supply restrictions are within tight intervals and penalties are incurred if supply is outside of these boundaries. Most sites in South Africa that are suitable for PV plant applications do not have sufficient or reliable data available to determine adequate solar radiation estimates. To address this limitation a number of software packages can be used to estimate solar radiation data. The algorithms within these software packages are often confidential and usage of the software is accepted as standard practice. Questions have however surfaced as to the validity of the estimators produced. This study investigates the validity of one of these software packages, namely Meteonorm.

2. Data Collection

Meteonorm is a meteorological database that contains climatological data for solar applications. The data are stochastically generated for a typical year from interpolated data or long-term monthly means stored within Meteonorm, which have been collected previously. Daily averages of global horizontal radiation and temperature values were estimated from Meteonorm for a single year. These estimates were used for a profile analysis. For the interval estimation, Meteonorm was used to generate ten years of global horizontal radiation and temperature values.

The actual measured data (source data) were obtained from the Outdoor Research Facility (ORF) at the Nelson Mandela Metropolitan University (NMMU) in PE for the year 2013 and 2014. The daily and hourly average values for global horizontal radiation and temperature were calculated from 15-second observations. Measured data was also collected from the Cape Town region. This data was retrieved from Sauran (www.sauran.net). Sauran is an online database of solar radiation data from stations located across the Southern African region. These include stations in South Africa, Namibia, Botswana and the Reunion Islands.

3. Methodology

This study is divided into two sections. The first section uses a profile analysis to assess the trend of solar radiation estimates of Meteonorm and compare these estimates to actual measured data. The second section uses statistical techniques to calculate interval estimates from ten year data generated from Meteonorm. If the algorithms within Meteonorm are accurate the simulated data should provide interval estimates which include the actual measured data.

Profile analysis is a multivariate technique used to analyse the shape (profile) of variables across groups. A two-sample profile analysis is used to compare Meteonorm generated data to actual

measured data from the PE region for 2013. The package *profileR* (Bulut & Desjardins, 2013) in R3.1.1 (R Core Team, 2014) was used for the profile analysis plots and tests.

A profile plot was generated to compare the monthly average data generated from Meteonorm to the source data. Daily averages were used to calculate the monthly averages for the profile plots for both the global horizontal radiation and temperature values. A requirement for a profile analysis is that the number of daily values for each month has to be the same. As such the first 28 days of each month were used to bring all the monthly values in line with February which had the fewest days. Two tests were conducted on the profiles to determine whether the Meteonorm generated data were parallel and coincidental to the 2013 source data.

Section two required the collection of ten years of solar radiation data from Meteonorm for the PE and Cape Town region. Interval estimates for global horizontal radiation and temperature were then generated from the ten year data set. If the algorithms within Meteonorm are accurate, the simulated data should provide interval estimates which in most cases cover the source data. The confidence interval estimates for January, March, July and October will be discussed in this study. These months were chosen as they represent different seasons in the year.

4. Results

Figure 1 and 2 show the profile plots for global horizontal radiation and temperature respectively. From Figure 1 it appears that global horizontal radiation data from Meteonorm is parallel and at the same level as the 2013 source data. From Figure 2 it appears that temperature data from Meteonorm is parallel to the source data but under estimates the source data for 2013.

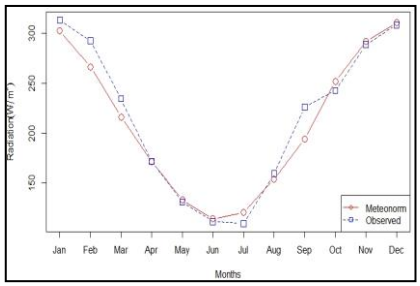


Figure 1: Global horizontal radiation profile plot

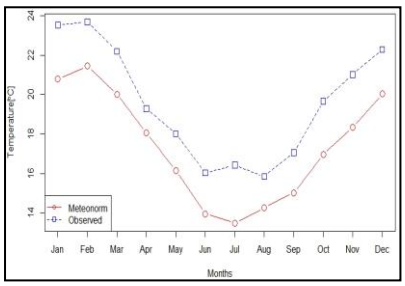


Figure 2: Temperature profile plot

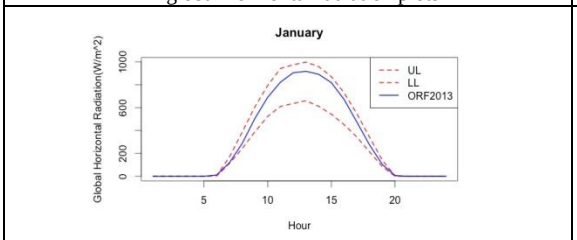
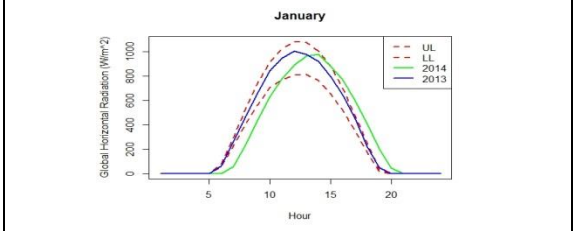
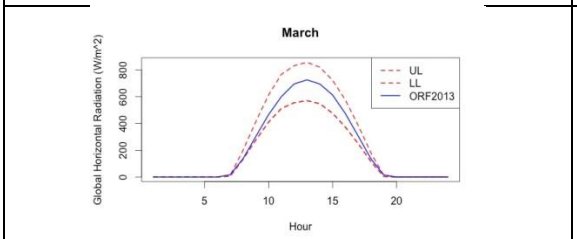
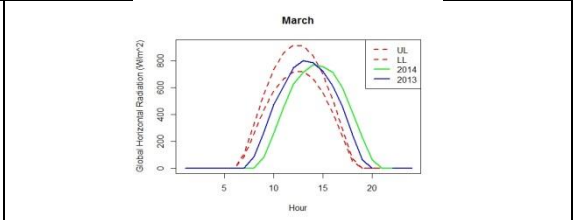
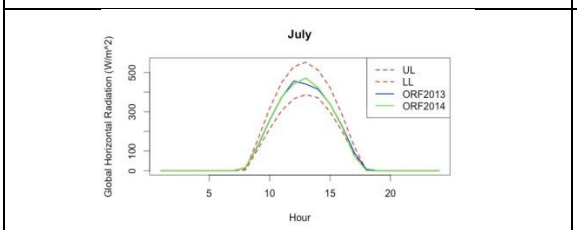
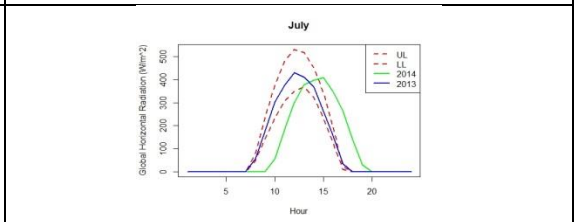
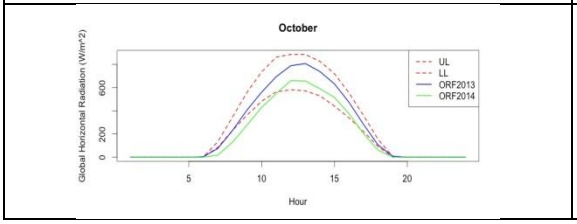
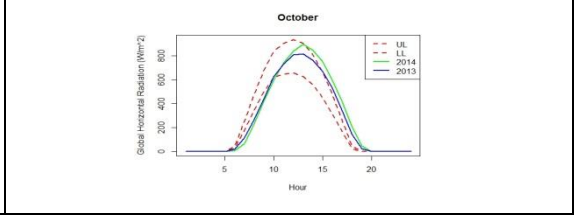
Table 1: Results of the profile analysis

	Test	*F*	*p*-value
Global Horizontal Radiation	H_0: Profiles are parallel	16.17	0.32 (Do not Reject H_0)
	H_0: Profiles are coincidental	1.60	0.21 (Do not Reject H_0)
Temperature	H_0: Profiles are parallel	22.83	0.11 (Do not Reject H_0)
	H_0: Profiles are coincidental	192.11	<0.01 (Reject H_0)

The results from the profile analysis test support the observations made from both profile plots. The null hypothesis was not rejected at a 5% significance level for the global horizontal radiation profile and it was concluded that the Meteonorm and the source data (2013) were parallel and coincidental for PE. The null hypothesis to test whether the profiles were parallel for temperature was not rejected at a 5% significance level. However, the null hypothesis was rejected for the temperature profile being coincidental. From the graphs it was observed that Meteonorm under estimated temperature for the 2013 source data of PE.

Figure 3 shows the interval estimate plots for global horizontal radiation for the PE and Cape Town region.

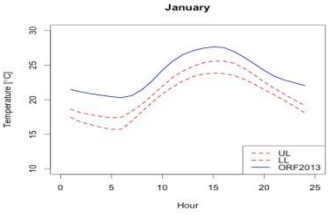
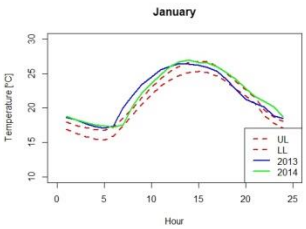
Figure 3: Confidence interval estimates for global horizontal radiation

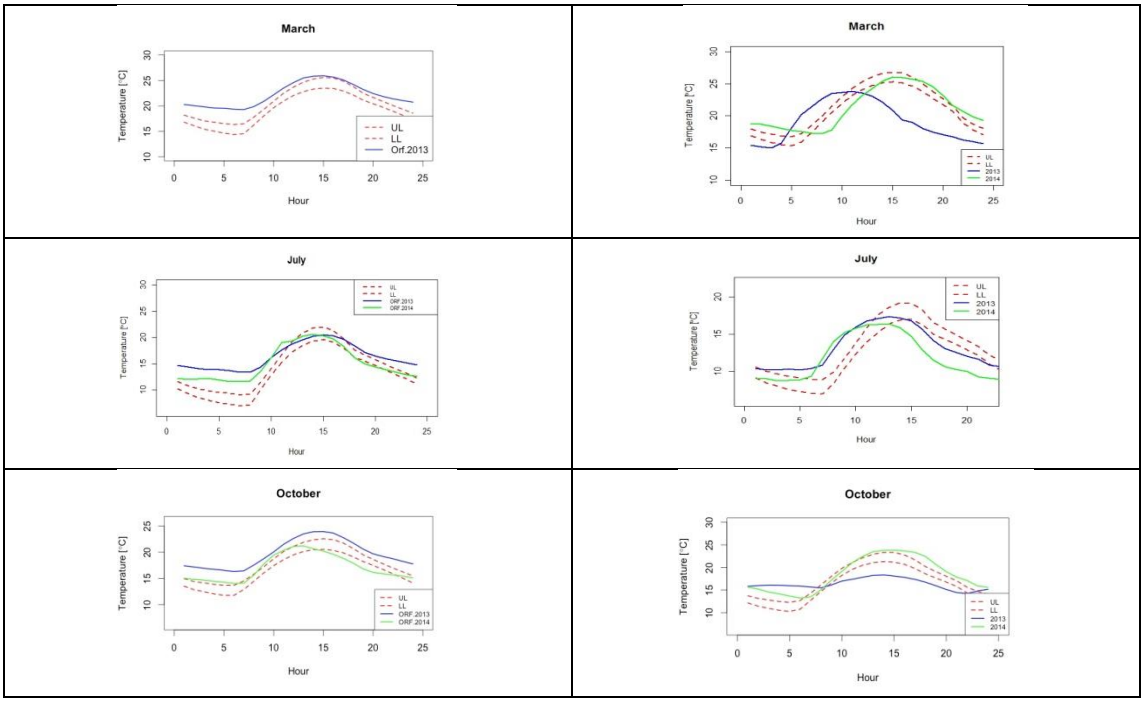
PE global horizontal radiation plots	Cape Town global horizontal radiation plots
	
	
	
	

Source data from PE for the years 2013 and 2014 (July and October) fall within the interval estimates. There was no source data available for PE in January and March of 2014. The source data for the Cape Town in 2014 fell within the interval estimates of the region. 2013 source data for Cape Town appeared to have the same shape as the interval estimates of Meteonorm (and 2014 source data) however the distribution appears to have shifted to the right by one to two hours. The reason for this shift could be that the source data for 2013 in Cape Town was incorrectly time stamped.

Figure 4 shows the interval estimate plots for temperature for the PE and Cape Town region.

Figure 4: Confidence interval estimates for temperature.

Port Elizabeth temperature plots	Cape Town temperature plots
	



Temperature interval estimates for PE did not include the source data for 2013 and 2014. However, for the month of July it appears to have included the source data between the hours of 13 (1pm) and 15 (3pm) for 2013 and 2014 data sets. Temperature interval estimates for Cape Town did not include the source data for 2013 and 2014.

5. Conclusions

The profile analysis showed that the global horizontal radiation data and the source data for 2013 were parallel and coincidental. The profile analysis also showed that the temperature data generated by Meteonorm was parallel to the source data for 2013. However, the profiles were not coincidental. The results from the profile plots and tests implied that Meteonorm under estimated temperature for PE in 2013. The study demonstrates the usefulness of profile analysis as a tool to compare estimated solar radiation data to actual measured data.

Source data was used to determine whether Meteonorm provided accurate interval estimates for global horizontal radiation and temperature for the PE and Cape Town region. The interval estimates of global horizontal radiation included the source data and the under estimated temperature for PE. These results agree with the findings of the profile analysis.

Source data for 2014 was included in the interval estimates for the Cape Town region. However, 2013 source data appeared to have the same shape as the interval estimates of Meteonorm (and 2014 source data) and did not fall in the interval estimate. The reason for this shift could be that the source data for 2013 in Cape Town was incorrectly time stamped. The interval estimates for temperature in Cape Town did not include the source data.

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