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TOWARDS A VERIFIED DNI MAP FOR SOUTH AFRICA

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ABSTRACT

In this project seven high accuracy DNI solar measurement stations, including meteorological equipment, were installed throughout South Africa. After at least one year of operation data from these stations as well as additional DNI data were used to update a satellite derived DNI and GHI map of South Africa. This paper focusses on the learning experience of installing and maintaining a network of DNI measurement stations.

Prior to this project, the operational stations with DNI data available were located at four academic institutions at three different cities as well as nine stations operated by the national utility Eskom. Three solar developers have indicated their willingness to share data from their sites for this project. The paper discusses the methodology that was followed to select the locations of the seven stations. The new stations were to be geographically well distributed and any duplication with existing stations was to be avoided.

On-site staff are required to clean the solar instruments at each station two to three times per week. An electronic log of the cleaning events enable remote monitoring of the cleaning frequency. All stations are visited every two to three months for routine maintenance and to supply the on-site staff with the required consumables e.g. cleaning cloths and desiccant and to perform ad-hoc training of the on-site staff.

A satellite derived DNI and GHI map of South Africa will be provided by GeoModel Solar, the proprietors of the SolarGIS database. This map will be based on 20 years of DNI data and have a spatial resolution of 250m x 250m. The map will be updated by GeoModel based on the DNI and GHI measurements at the various locations. The updated map will be made public in GIS as well as KML (Google Earth) format. DNI and GHI poster maps of SA will also be provided. All data from the seven stations will be made available for free on a public website.

INTRODUCTION

DNI maps and data are used for the development of CSP and CPV plants while GHI data are used for PV plants. Compared to GHI, the availability of DNI data and maps are significantly lower. In addition to this the uncertainties of DNI data and maps are, in general, higher than GHI related products [1]. This, along with the large CSP potential of South Africa, lead to a project in which seven high accuracy DNI measurement stations were deployed throughout South Africa. After one year the data collection from these stations, along with DNI data from some additional stations, will be used to create an updated satellite derived DNI map of South Africa.

NOMENCLATURE

Abbreviations	
ARC	Agricultural Research Council
AWS	Automatic Weather Station
BSRN	Baseline Surface Radiation Network
CSP	Concentrating Solar Power
CPV	Concentrating Photovoltaic
CRSES	Centre for Renewable and Sustainable Energy Studies (University of Stellenbosch)
DIF	Diffuse (Horizontal) Irradiance/Irradiation
DNI	Direct Normal Irradiance/Irradiation
ESKOM	Electricity Supply Commission of South Africa
GIZ	Gesellschaft für Internationale Zusammenarbeit *(German Society for International Cooperation)*
GHI	Global Horizontal Irradiance/Irradiation
NMMU	Nelson Mandela Metropolitan University
RSI	Rotating Shadowband Irradiometer
PV	Photovoltaic
SAWS	South African Weather Services
UKZN	University of Kwazulu-Natal

HISTORY OF SOLAR MEASUREMENTS IN SOUTH AFRICA

A number of organizations in South Africa has been involved with ground measurements and a few solar maps have been derived over the years. Most of the efforts resolved around GHI data and maps.

The South African Weather Services (SAWS) has measured GHI and diffuse irradiation since the 1960s. A dedicated and well maintained network functioned well but gradually decayed in the late 80s and early 90s for various reasons [2]. Although their solar measurement efforts should be commended, the instruments used have a relative high uncertainty compared to modern day pyranometers. The typical SAWS instruments had uncertainties of below 10 % (daily sum) [2], [3] where as a pyranometer today typically has an uncertainty of less than 2 % (daily sum) [3]. The only significant DNI measurements recorded by the SAWS was at the BSRN station in De Aar with data available for the period January 2000 – January 2005 [4]. This station has recently been revamped and is back online and SAWS is in the process on re-establishing its entire solar network with a number of DNI stations [5].

The agricultural research council (ARC) has a large network of agro-meteorological stations (AgroMet) which consists of more than 530 automatic weather stations which include GHI measurements by silicon pyranometers, but no DNI measurements [6].

Solar measurement facilities have been established at various Universities. Durban, a city on the East coast with one of the lowest solar resource potential in the country [6], boasts with DNI measurements dating back to 1996 and three high accuracy solar measurement stations currently in operation at three different tertiary academic campuses [7].

Stellenbosch University has been recording DNI since June 2010 and continues to do so. NMMU in Port Elizabeth has started with DNI measurements in late 2012 [2].

Eskom should be commended for their forward thinking to establishment a network of eight DNI measurement stations, mainly in the high solar resource Northern Cape Province, dating back to 2006 [8].

A number of developers have installed DNI measurement stations for private use. They are mainly CSP and CPV developers, but also a few developers interested in tracking PV [9].

Prior to this project, to the knowledge of the authors, apart from the BSRN station, that of the three Universities mentioned and four of the Eskom stations, no other ground measured DNI data is available in the public domain for South Africa. The result of this is that large areas of South Africa, which stretches 1700 km from West to East and houses various different climatic zones, are without DNI measurements in the public domain.

DNI MEASUREMENT EQUIPMENT SELECTION

There are two main options in terms of DNI field instruments: a pyrheliometer mounted on a tracker (Figure 1a) and a rotating shadowband irradiometer (RSI) (Figure 1b).

Figure 1a Pyrheliometer and tracker type station

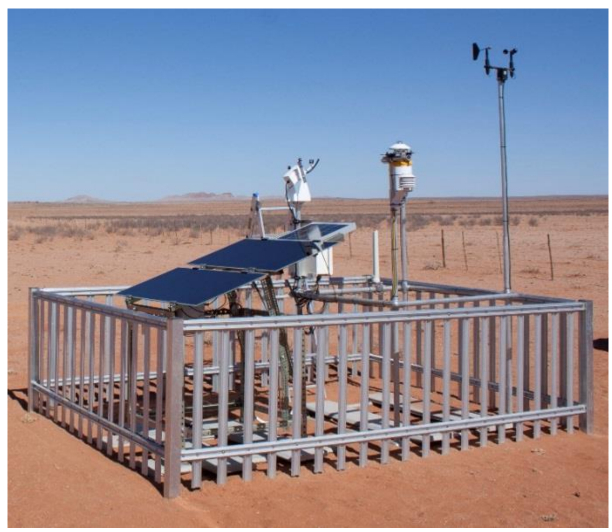

Figure 1b RSI type station

Pyrheliometer and tracker

DNI can be recorded using a pyrheliometer which is a thermopile based broadband radiometer. This device, however, needs to point directly at the sun and therefor requires a solar tracker. The modern day solar trackers are robust and reliable [9] and have a reduced power consumption compared to previous models [11]. It can subsequently be powered by a PV-battery system for field deployment. In addition to the pyrheliometer that records DNI, two pyranometers are typically deployed to record GHI and diffuse irradiance. From the latter two measurement DNI can be calculated and serves as an accurate and robust quality check on the data and also a redundant DNI measurement.

Upon procurement the equipment and sensors are ready for deployment – it is supplied with calibration certificates that are valid for two years. Apart from quality procedures (which could include gap filling, soiling correction and data flagging) the measurements require no post-processing [3], [12]. These instruments are typically used at research facilities and research stations e.g. the BSRN station network [13] as well as at operating CSP and CPV plants for performance guarantees.

Rotating Shadowband Irradiometer (RSI)

The RSI has been developed for remote deployment and requires little attendance apart from regular cleaning of the sensor(s) [14]. The device employs a silicon pyranometer which is also widely used in low cost solar networks such as in the agricultural sector and amateur weather stations. By using a shadow band driven by a small electric motor, a shadow can be cast on the pyranometer so that, apart from recording GHI as a default, it also records diffuse irradiance when the shadow band passes over the sensor, typically every minute. The diffuse measurement is possible due to the fast response time of the silicon pyranometer. From the recorded GHI and diffuse irradiance values DNI can be derived.

Certain suppliers recommend that the RSI be calibrated prior to deployment for two months and ideally the calibration should be done within the country of deployment [15]. This represents the best case in terms of calibration of a RSI. Other methods, e.g. calibration for at least two months at a calibration facility with short term calibration at the site of final deployment, are more used in practice [16]. Calibration is recommended every two years [15]. A thermopile pyranometer is sometimes installed alongside a RSI due to the poor spectral response of the silicon pyranometer, especially by PV developers.

Equipment selection

For this project the pyrheliometer and tracker option was selected based on its comparison to the RSI, Table 1, and the given boundary conditions of the project such as financial resources and available maintenance personnel at each site. For this project the Kipp&Zonen Solys2 tracker, CHP1 pyrheliometer and two CMP11 (or the CMP10 that replaced the CMP11) pyranometers were selected for all stations. Additional factors that were considered on the choice of equipment are:

- There are already 32 known pyrheliometer and tracker based measurement station installed in South Africa (all using Kipp&Zonen equipment mentioned above)
- Kipp&Zonen has representation in South Africa and supplies excellent service and after sales support
- Few RSI devices are installed in South Africa. Eskom used to own three such devices but have shelved them and replaced them with pyrheliometers and trackers. The authors are aware of five RSI stations in South Africa (three used by CSP developers and two (with additional thermopile pyranometers) used by PV developers). The RSI stations mentioned are from different suppliers.

Table 1 Pyrheliometer vs RSI comparison

Pyrheliometer and Tracker
Advantages
Instruments are procured with calibration already done by the supplier [3],[12]
No post processing of the data is required (on data that passes quality check procedures).[3],[12]
Cross checks can be done on data since three different instruments are used measuring three different solar components [15].
Measurements have a very high accuracy (provided they are well maintained) [15].
Disadvantages
Higher cost compared to RSI station [14]
Instruments require a regular (up to daily in locations with an exceptional high soiling load) cleaning frequency [14]
Scheduled site visits are recommended every 2 – 4 months, based on the experience of the authors
Rotating Shadowband Irradiometer (RSI)
Advantages
Lower in cost compared to a pyrheliometer and tracker based station [14]
Less scheduled maintenance site visits are required [14] (typically once every 6 – 12 months based on the experience of the authors)
A lower cleaning frequency is required in most climatic conditions [14], [15]
Disadvantages
Requires calibration of 2 months or longer prior to deployment [15]
Requires post processing of data [15]
Lower accuracy of measurements and poor (non-linear) spectral response when compared to high accuracy and well maintained thermal sensors [14]
No cross checks can be done since only one sensor is used*

*Recently a RSI device with two silicon pyranometers has been introduced with good results being reported. The second instrument will decreases the uncertainty of the measurements but still does not give the ability of an independent cross check of DNI from GHI and diffuse nor address the spectral response issue of these sensors.

In addition to the solar instruments, meteorological equipment consisting of wind speed and direction at 10 m above ground, ambient temperature and relative humidity at 2 m above ground, barometric pressure and precipitation will be deployed.

DEPLOYMENT OF STATIONS

The stations that were deployed in this project is funded by the

GIZ - (six stations in South Africa) and one by Eskom (Sutherland). In an extension of this project the USAid will fund an additional four stations (two stations in South Africa, one each in Namibia and Botswana). On both projects the contract has been placed on the CRSES at Stellenbosch University. The two USAid sponsored stations allocated for South Africa have been earmarked for the University of Fort Hare (UFH) in Alice in the Eastern Cape Province and the University of Venda in Thohoyandou in the Limpopo Province. The two remaining stations will be installed at the University of Botswana in Gaborone and the Polytechnic in Windhoek in Namibia.

Apart from one station near Lephalale in the Limpopo Province, all the Eskom DNI stations are located in the Northern Cape Province with the latest edition a station near Sutherland which is part of this project. The Sutherland station is a joint project between Eskom and Stellenbosch University. Eskom is planning to install a DNI station near Witbank in the Mpumalanga Province near their large fleet of coal power stations.

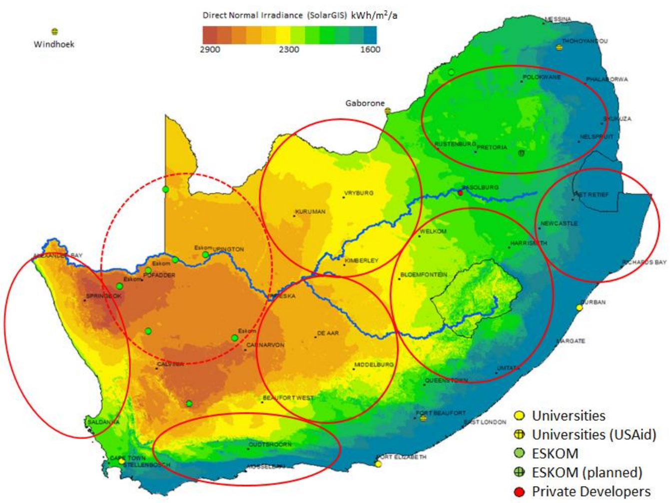

Figure 2 Current and future DNI measurement stations in South Africa on a DNI background, with DNI station gaps identified [10]

The GIZ funded stations were deployed at identified gaps as indicated with red circles in Figure 2.

During a stakeholder meeting where the project was presented, apart from the SAWS and Eskom, no other party indicated that they plan to install a DNI measurement station in the foreseeable future [18]. At this meeting there was no mention made of any DNI station with data in the public domain that has not been mentioned in this paper.

At this meeting the SAWS confirmed that they plan to re-establish their solar network and that within this network a number of DNI stations are planned. These stations will most likely be installed at the manned SAWS weather stations. The exact number of stations and their locations are not yet available. Three CSP developers made their data available for updating the DNI map with data for: Lephalale, Sasolburg and Upington.

Based on the information above the criteria for the placement of the six GIZ DNI stations were:

- In such a way that there are no duplication with current DNI stations (excluding station of which data are not available) or planned (mainly SAWS and Eskom) DNI stations
- In such a way to fill as many as possible of the areas without DNI data
- Preference will be given to areas on the East and South of the country with lower DNI levels. It is foreseen that DNI data in the high DNI areas will be more likely to be available.
- Preference will be given to host that can provide a safe site for the deployment of the equipment, who are willing to perform the regular cleaning of the instruments, is willing to have the equipment donated to after one year and who is in a position to maintain the station beyond hand-over.

OPERATION OF STATIONS

Data of all the stations are downloaded to a server on an hourly basis and displayed on computer monitors for regular visual inspection. Apart from the visual inspections, additional quality checks includes the comparison of measured DNI with DNI calculated from GHI and diffuse, DNI obtained from satellite derived data and a DNI clear sky model.

CONCLUSIONS AND NEXT STEPS

The six GIZ funded station were installed at:

- University of the Free State in Bloemfontein,
- University of Pretoria in Pretoria,
- a private farm near the town of Vryheid in the KwaZulu-Natal Province
- a private farm near the town of Graaff-Reinet in the Eastern Cape Province
- a private farm near the town of Vanrhynsdorp in the Western Cape
- in the Richtersveld area adjacent to the Namibian border

The data from the six GIZ stations as well as eight other DNI stations were made available to GeoModel Solar who used the data to provide updated DNI and GHI maps of South Africa. These maps are available in the public domain.

The data from all the stations are available on the website www.sauran.net. In 2015 the USAid stations will be installed and the monitoring of the GIZ stations will continue.

The CRSES is in the process of starting a calibration facility in collaboration with UKZN as well as other related organizations.

ACKNOWLEDGEMENTS

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