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Validation of CM-SAF GHI and DNI against ground-based measurements over South Africa

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11 August 2016

Outline

- Introduction
- Research Question, Aim and Objectives
- Datasets
- Methodology
- Results and Discussions
- Solar Energy Applications
- References
- Acknowledgements

Introduction

- Meteorological satellite images as data sources to evaluate the ground irradiance components have become the state of the art in the field of solar energy systems
- Because of their high spatial coverage, and high temporal resolution (15min)
- Another advantage is that they provide “real time” data used for example to assess the proper operation of solar plants
- On the other hand, long term ground data are very scarce concerning the beam irradiance
- Zelenka argue that the interpolation distance to the nearest ground measurement site is limited to 10 to 30 km, depending on the irradiance parameter
- This strengthens the argument for satellite derived data.

Research Question, Aim & Objectives

Research Question:

- Can satellite-derived surface incoming global solar radiation improve the spatial and temporal distribution of the surface global solar radiation data in South Africa, a country with limited ground-based solar measurement stations and complex terrain?

Research Aim (Purpose Statement):

- To evaluate if the meteorological satellite derived surface incoming global solar radiation could valuably complement the ground-based solar measurements network of the South African Weather Service and thereby improving the spatio-temporal distribution of the surface global solar radiation over the country.

Research Question, Aim & Objectives

Research Objectives:

- Analysis and Comparison of satellite-derived solar radiation against ground-based measurements for Direct Normal Irradiation (DNI)
- Analysis and Comparison of satellite-derived solar radiation against ground-based measurements for Global Horizontal Irradiation (GHI)
- Creation of a solar radiation database for South Africa
- Analyse the potential of solar energy in South Africa
- Develop solar maps for DNI and GHI of monthly, seasonal and yearly mean values.

Datasets: Satellite-derived solar radiation data

- Two different satellite based methodologies have been considered: 'SARAH' and 'Operational'

- Both were developed by the CM-SAF (www.cmsaf.eu), a collaboration between a number of European meteorological services led by Deutscher Wetterdienst (DWD)

- Both datasets contain one value per hour of global horizontal and beam normal irradiance, corresponding to the single image analyzed every hour.

Datasets: Satellite-derived solar radiation data

Operational dataset:

- Derived from measurements of the SEVIRI instruments onboard the Second Generation of Meteosat satellites (MSG) using a look-up table (LUT) retrieval algorithm
- Contains estimates of global horizontal (GHI) and direct normal (DNI) irradiance
- The spatial resolution of the dataset is the original satellite resolution 15 x 15m

SARAH dataset:

- Obtained by applying the SPECMAGIC algorithm, which in addition to the broadband irradiance, also provides the global and beam irradiance distributed in 30 spectral bands in the range from 330 nm to 4600 nm
- The spatial resolution is 3', lower than the Operational data record

Datasets: Satellite-derived solar radiation data

- Both datasets, SARAH and Operational, come from the Prime satellite so the image corresponds to ***three minutes*** after the timestamp in the datasets.

- SARAH: data are every HH:00, but the image corresponds to HH:03.

- Operational: timestamp is HH45, so the image is at HH48.

- This is important for calculating the average measured data afterwards.

- Sarah dataset contains -999 values when the data is wrong or missing. Whilst, the operational dataset has -999 also at night hours.

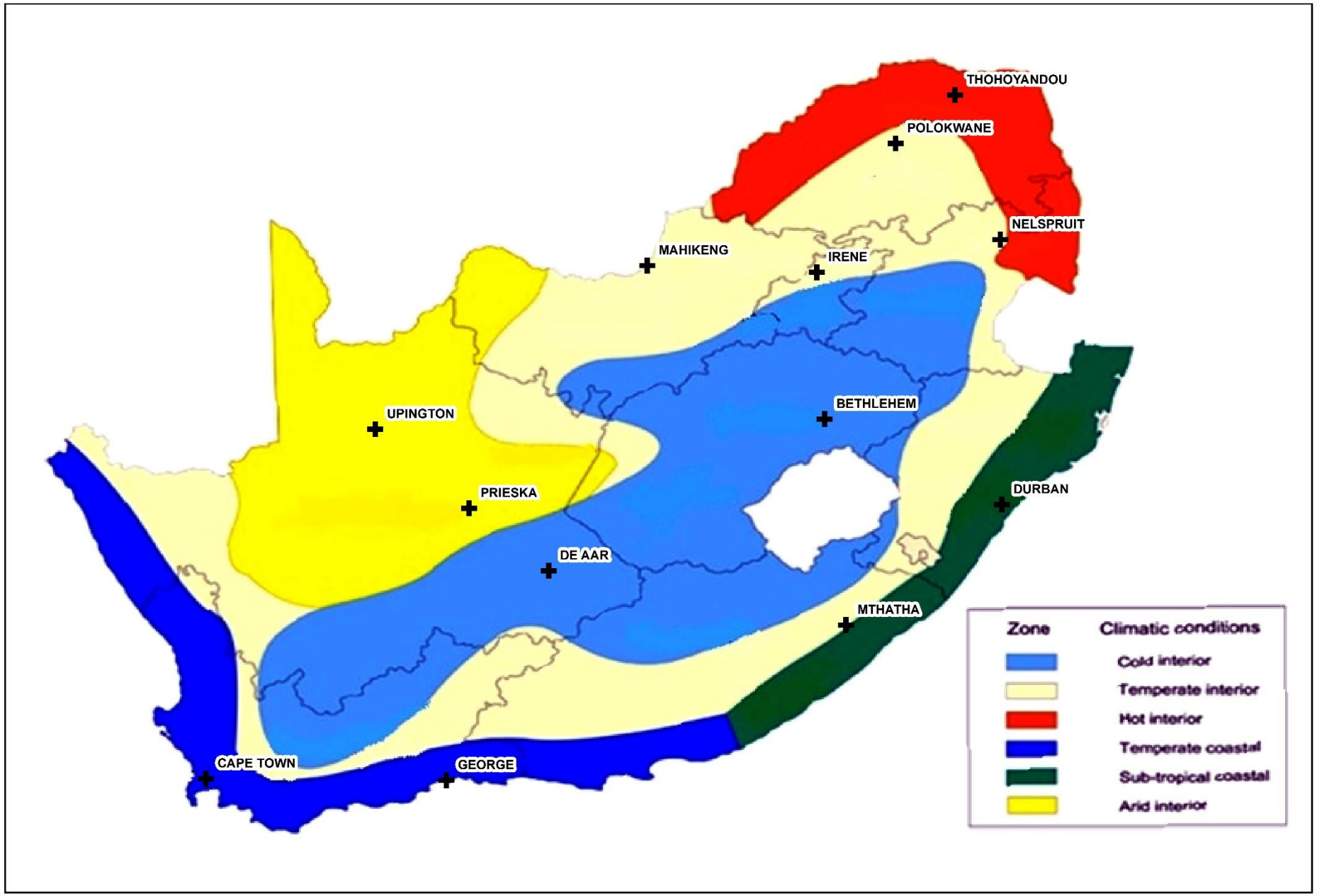
Datasets: Ground-based solar radiation data

- Measured data is sampled at 1 second, averaged at 1minute, hourly and daily
- The stations are cleaned twice a week in accordance to the maintenance guidelines of solar radiation stations.
- Real time monitoring of stations (Campbell Scientific RTMC)
- BSRN quality procedures applied

Datasets: Ground-based solar radiation data

SAWS SOLAR RADIATION NETWORK					
Station Name	**Latitude (Decimal)**	**Longitude (Decimal)**	**Altitude (m)**	**Installation Date**	**Climate**
1. Prieska	-29.6832	22.7099	996	2013-08-15	Arid interior
2. Upington	-28.4794	21.1163	848	2014-01-23	Arid interior
3. Irene	-25.9105	28.2106	1524	2014-02-21	Temperate interior
4. De Aar	-30.6651	23.9927	1286	2014-04-10	Cold interior
5. Nelspruit	-25.3877	31.0995	865	2014-04-25	Hot interior
6. Mthatha	-31.5497	28.6739	745	2014-06-20	Sub-tropical coastal
7. Mahikeng	-25.8037	25.5428	1281	2014-07-03	Temperate interior
8. Cape Point	-34.3531	18.49	228	2014-11-27	Temperate coastal
9. George	-34.0043	22.3843	197	2014-12-05	Temperate coastal
10. Bethlehem	-28.2496	28.3343	1689	2014-12-05	Cold interior
11. Thohoyandou	-23.0872	30.3844	614	2015-02-06	Hot interior
12. Polokwane	-23.8576	29.4517	1226	2015-02-13	Hot interior

The Geographical location of the SAWS Stations within six Climatic Zones



Instrumentation Specifications

Sensor	Parameter	Stations
Kipp & Zonen Solys 2 Sun Tracker	Track the sun	All stations
Kipp & Zonen CHP1 Pyrheliometer	Direct Normal Irradiance	All stations
Kipp & Zonen CHP11 (no 1 :Sun) Pyranometer	Global Horizontal Irradiance	All stations except for De Aar
Kipp & Zonen CHP11 (no 2: Shadow) Pyranometer	Diffuse Horizontal Irradiance	All stations except for De Aar
Kipp & Zonen CHP21 (no 1 :Sun)Pyranometer	Global Horizontal Irradiance	Only at De Aar
Kipp & Zonen CHP21 (no 1 :Shadow) Pyranometer	Diffuse Horizontal Irradiance	Only at De Aar
Kipp & Zonen CGR4 Pyrgeometer	Long-wave Irradiance	Only at De Aar
Kipp & Zonen CUV-5	UV radiation (290-385nm)	Only at Prieska
Kipp & Zonen UVS-AB-T	UVA & UVB	All stations except for Prieska
Barometer PTB110 Vaisala	Pressure	All stations
RM Young Wind Sensor	Wind	All stations
Rotronic Temp and Humidity probe HC2-S3	Humidity and Temperature	All stations

Methodology

- In order to compare the hourly satellite values to the closest in time measured data, for every satellite derived data, a ten minute window centered at the time of the image has been defined
- The measured values inside this interval will be averaged to obtain the final "measured" value to be used in the validation process
- Since Operational and SARAH datasets derive from different images, the measured data used in the validation of each of the satellite data records is different
- As a result, the number of data points considered in the validation may be different
- Also, the number of data points used for the validation of the global horizontal and beam normal irradiance may be different

Methodology

- In addition to the quality control process applied to the data at the measuring stations, before doing the present analysis, an additional simple filtering procedure has been applied as described below.
  - ✓Negative values at night time are replaced by 0 and kept for the validation. However, negative values during day time are removed.
  - ✓Irradiance values higher than 1300 Wm-2 are removed.
  - ✓The coherence between the three irradiance values is checked in order to remove measurement suspicious of coming from moments when the sun tracking system was not working properly.
- If less than 5 valid minute data points remain after applying these filters, the ten minute window is removed entirely and the corresponding satellite data for that hour is dismissed
- If there are enough valid minute data, the average value is calculated and kept as the "measured" value to be used to validate the satellite derived values

Validation Results: Table 1: Results from the validation of the GHI and DNI values retrieved from the Operational dataset - 2014

Operational 2014		Global Horizontal Irradiance (GHI)					Direct Normal Irradiance (DNI)				
Station	**Months**	**MBD (Wm^{-2})**	**rMBD (%)**	**Av meas (Wm^{-2})**	**Av sat (Wm^{-2})**	**N data**	**MBD (Wm^{-2})**	**rMBD (%)**	**Av meas (Wm^{-2})**	**Av sat (Wm^{-2})**	**N data**
Prieska	[1-12]	6.50	2.67	243.64	250.14	7738	19.12	6.01	318.23	337.36	7693
Upington	[2-12]	-0.03	-0.01	246.0	245.97	7343	0.12	0.04	334.42	334.54	7729
Irene	[3-12]	6.17	2.83	218.04	224.21	7112	21.07	8.43	249.93	271.01	7084
De Aar	[5-12]	2.14	0.91	233.93	236.07	5681	4.76	1.47	324.41	329.18	5679
Nelspruit	[5-12	11.62	5.98	194.19	205.81	5640	32.63	16.34	199.70	232.33	5586
Umtata	[7-12]	14.91	7.87	189.60	204.51	4315	38.58	19.88	194.07	232.65	4270
Mahikeng	[8-12]	7.77	3.02	257.51	265.28	3967	49.77	23.59	211.01	260.78	3541

Validation Results: Table 2: Results from the validation of the GHI and DNI values retrieved from the Operational dataset - 2015

Operational 2015		Global Horizontal Irradiance (GHI)					Direct Normal Irradiance (DNI)				
Station	**Months**	**MBD (Wm^{-2})**	**rMBD (%)**	**Av meas (Wm^{-2})**	**Av sat (Wm^{-2})**	**N data**	**MBD (Wm^{-2})**	**rMBD (%)**	**Av meas (Wm^{-2})**	**Av sat (Wm^{-2})**	**N data**
Prieska	[1-09]	5.54	2.52	219.66	225.90	6279	25.47	8.71	292.34	317.81	6273
Upington	[1-12]	1.66	0.72	231.57	233.23	7091	9.35	3.01	310.91	320.26	7081
Irene	[1-12]	8.36	3.73	224.28	232.64	7237	25.30	9.97	253.74	279.04	7215
De Aar	[1-12]	2.91	1.27	228.85	231.76	7078	7.94	2.63	301.31	309.24	7072
Nelspruit	[1-12]	12.73	6.42	198.12	210.83	7239	34.11	17.69	192.82	226.93	7175
Umtata	[1-12]	13.24	7.34	180.41	193.65	7248	35.43	18.22	194.52	229.95	7205
Mahikeng	[1-12]	7.14	3.02	236.36	243.49	7241	26.96	9.51	283.59	310.55	7227
CapePoint	[1-12]	11.22	5.90	190.26	201.48	7052	54.94	28.07	195.71	250.65	6981
George	[1-12]	16.85	9.77	172.47	189.32	7254	57.47	32.44	177.12	234.58	7224
Bethlehe	[1-12]	8.41	3.80	221.02	229.43	7253	23.98	10.02	239.37	263.36	6805
Thohoyan	[3-12]	11.62	5.90	196.90	208.52	6238	30.52	14.45	211.21	241.74	6208
Polokwan	[3-12]	4.44	2.05	216.59	221.03	5919	20.76	8.36	248.19	268.95	5901

Validation Results: Table 3: Results from the validation of the GHI and DNI values retrieved from the SARAH dataset - 2014

SARAH 2014		Global Horizontal Irradiance (GHI)					Direct Normal Irradiance (DNI)				
Station	Months	MBD (Wm^{-2})	rMBD (%)	Av meas (Wm^{-2})	Av sat (Wm^{-2})	N data	MBD (Wm^{-2})	rMBD (%)	Av meas (Wm^{-2})	Av sat (Wm^{-2})	N data
Prieska	[1-12]	-0.72	-0.29	249.13	248.40	7857	-21.64	-6.69	323.71	302.06	7811
Upington	[2-12]	-5.43	-2.18	249.07	243.64	7696	-36.39	-10.78	337.50	301.11	7685
Irene	[3-12]	-0.31	-0.14	218.92	218.60	7078	1.25	0.50	251.28	252.53	7050
De Aar	[5-12]	-2.15	0.92	234.22	232.08	5670	-23.78	-7.36	-323.34	299.56	5667
Nelspruit	[5-12	5.42	2.77	195.33	200.75	5603	19.49	9.78	199.32	218.81	5560
Umtata	[7-12]	1.16	0.60	192.84	194.01	4275	1.35	0.69	196.96	198.31	4223
Mahikeng	[8-12]	0.41	0.16	260.13	260.54	3956	25.21	11.94	211.11	236.32	3539

Validation Results: Table 4: Results from the validation of the GHI and DNI values retrieved from the SARAH dataset - 2015

SARAH 2015		Global Horizontal Irradiance (GHI)					Direct Normal Irradiance (DNI)				
Station	Months	MBD (Wm^{-2})	rMBD (%)	Av meas (Wm^{-2})	Av sat (Wm^{-2})	N data	MBD (Wm^{-2})	rMBD (%)	Av meas (Wm^{-2})	Av sat (Wm^{-2})	N data
Prieska	[1-09]	0.76	0.34	22.07	222.84	6205	-9.34	-3.16	296.09	286.75	6200
Upington	[1-12]	-4.60	-1.79	256.46	251.86	8298	-29.27	-8.68	337.37	308.10	8289
Irene	[1-12]	1.48	0.62	241.22	242.70	8464	2.66	1.01	264.51	267.17	8440
De Aar	[1-12]	0.12	0.05	251.81	251.93	8283	-16.83	-5.21	322.83	306.00	8274
Nelspruit	[1-12]	9.98	4.77	209.43	219.41	8442	24.98	12.80	195.11	220.09	8380
Umtata	[1-12]	4.87	2.52	193.57	198.44	8360	7.46	3.76	198.56	206.02	8296
Mahikeng	[1-12]	1.18	0.46	255.38	256.55	8434	0.92	0.31	296.43	297.35	8413
CapePoint	[1-12]	2.47	1.16	213.13	215.61	8247	24.39	11.39	214.07	238.46	8157
George	[1-12]	7.44	3.91	190.34	197.78	8484	16.78	8.85	189.67	206.46	8435
Bethlehe	[1-12]	1.37	0.57	239.98	241.35	8428	6.74	2.89	232.74	239.49	7500
Thohoyan	[3-12]	10.34	4.98	207.88	218.22	7484	18.37	8.55	214.90	233.27	7455
Polokwan	[3-12]	1.17	0.50	233.98	235.15	7189	10.24	4.02	254.63	264.88	7151

Validation Results

- Show an overall relative mean bias deviation (grMBD) of 4.68% for all stations for the global horizontal irradiance (GHI) and 13.97% for the direct normal irradiance (DNI) with the 'Operational' method.

- As for the 'SARAH' method, the grMBD values for all stations for GHI and DNI estimates are 1.39% and 2.64% respectively.

- When considering all stations, the SARAH data record performs better for both the GHI and the DNI estimation.

- In addition, both satellite datasets present higher relative deviations in the estimation of the beam/direct component even though the average measured DNI values are higher than the GHI values.

Validation Results

- In addition, the validation results for the global horizontal irradiance are very encouraging, while the DNI validation indicates the need for further improvements, in particular in 'SARAH'.

- The underestimation suggest an overestimation of the aerosol loading; which could be due to the use of different aerosol climatologies in the 'Operational' and the 'SARAH' data set.

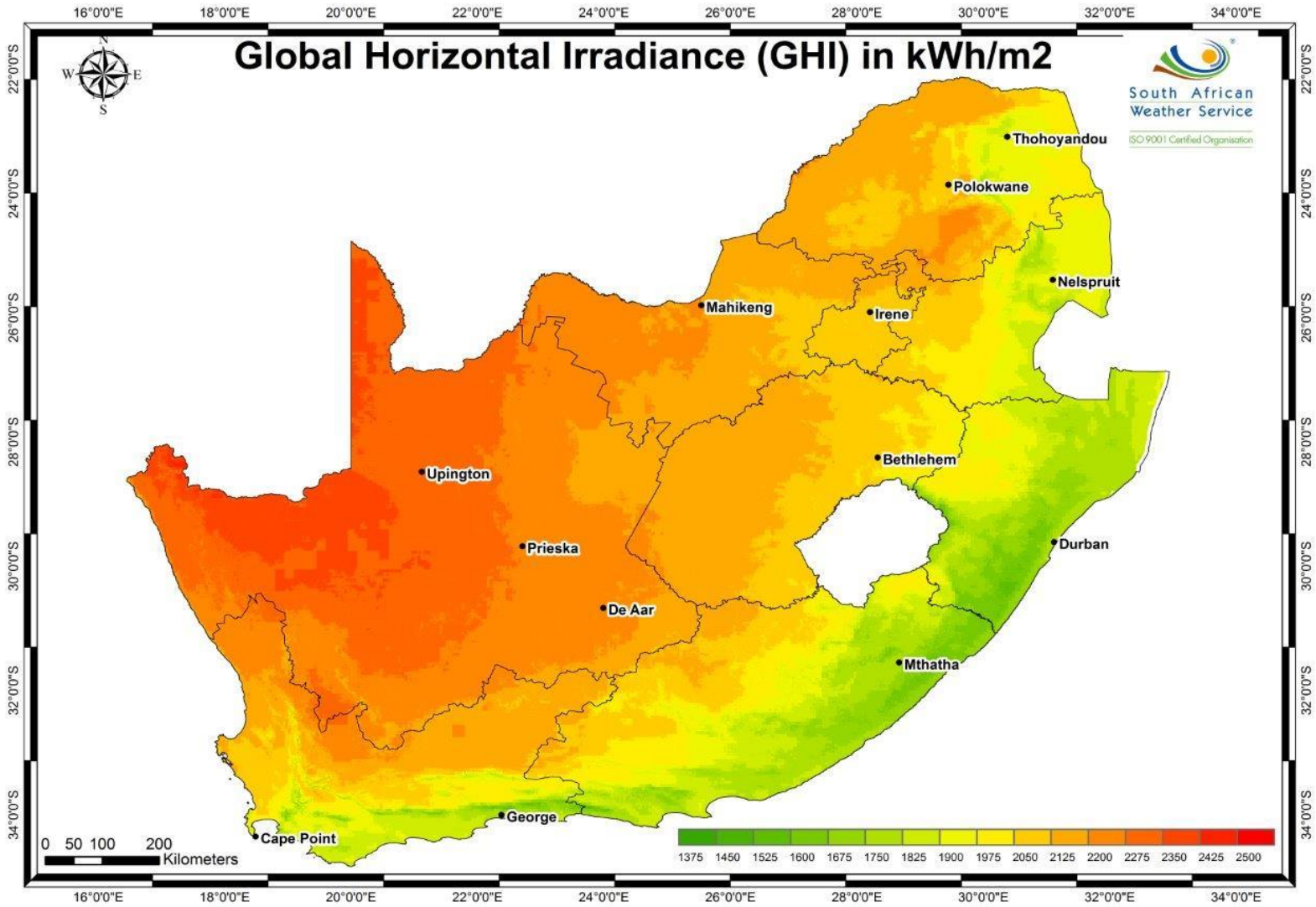
Validation Results

- In addition, the validation results for the global horizontal irradiance are very encouraging, while the DNI validation indicates the need for further improvements, in particular in 'SARAH'.

- The underestimation suggest an overestimation of the aerosol loading; which could be due to the use of different aerosol climatologies in the 'Operational' and the 'SARAH' data set.

- For both satellite datasets, the MBD tends to be higher in the stations with lower elevation such as Durban (105m), George (197m) and Cape Point (228m).

Solar Energy Applications



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Acknowledgements

- Professor Sivakumar Venkataraman - for his contribution and support towards the culmination of this work
- South African Weather Service – My Colleagues for all their support and contributions
- Department of Science and Technology for the funding
- Renewable Energy team of the European Commission Joint Research Centre for hosting and guided me through the validation and mapping processes