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Ground-measurement GHI map for Qatar

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Abstract

This paper presents several maps of the annual Global Horizontal Irradiation, GHI, over Qatar, based on ground measurements of daily GHI for the period 2007-2012, from as many as 12 monitoring stations. Considering the longest coincident operation period of these stations, a map of 4-year averages from 2009 to 2012 was produced and yearly GHI variations with respect to this map are also presented, showing a maximum inter-annual variability of 6.5%. Moreover, a map produced with yearly values from the HelioClim1 database for the period 1985 to 2005 is shown and compared to the ground based map using the same locations. The ground-measured yearly average for Qatar is 2113 kWh/m^2/year, calculated considering the 4-year period of coincident data.

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1. Introduction

Qatar's geographic location, approximately centered around 25 degrees North and 51 degrees East, places the country within the so-called Sun Belt of the world, a region which receives abundant radiation from the Sun, an ideal place for harvesting solar power.

One of the pillars of the Qatar National Vision 2030 is the preservation and protection of the environment by reducing the dependency on hydrocarbon resources and promoting the use and development of renewable energy sources [1]. With these goals in mind, Qatar has set the target of producing, by 2018, about 10% of its electricity from solar resources [2]. One crucial step towards this objective, or any solar-based energy project, is the assessment of the irradiation available at ground level throughout the country in order to select the best locations for each type

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of solar technology. Given the highly complex atmospheric conditions in Qatar, mainly because of high aerosol loads from oil production and from desert dust, satellite-derived irradiation data must be first validated against ground measurements.

The neighboring Arab countries in the Gulf Region (GCC), Saudi Arabia, UAE and Oman have already started analysis of their own solar energy resource [3, 4, 5] and the UAE have already processed their first solar atlas [6].

The Qatar Meteorological Department (QMD) currently operates a network of 12 automated weather stations distributed in coastal and inland locations throughout the State of Qatar, and most of these stations have been collecting Global Horizontal Irradiation data from as early as 2007, along with meteorological parameters. The Qatar Environment and Energy Research Institute has joined QMD in the plans of upgrading these AWS in order to collect also the Direct and Diffuse components of solar radiation in the future.

In this study, the GHI data collected between 2007 and 2012 by the QMD stations was analyzed in order to produce the first, to the authors' knowledge, GHI map of Qatar entirely from ground measurements. A comparison with a long-term satellite-derived GHI map obtained with values from the HelioClim1 database for the years 1985 to 2005 is also presented.

Nomenclature

AWS	Automated Weather Stations
GHI	Global Horizontal Irradiation
DNI	Direct Normal Irradiation
DHI	Diffuse Horizontal Irradiation

2. Methodology

QMD started installing AWS throughout Qatar from 2007 onwards, with the newest stations installed in 2011, completing a network of 12 stations (see figure 1 for stations locations). These stations measure meteorological parameters along with global solar radiation. GHI is measured using Kipp & Zonen CM6B pyranometers which comply with all ISO-9060 specification criteria for that of an ISO First Class pyranometers. The routine maintenance conducted by QMD consists of weekly cleaning of the domes of the sensors with additional cleaning after dust storms. Daily total irradiation values in J/cm^2 were provided by QMD for the study presented here.

In the next sections different maps showing the spatial variation of annual GHI in $kWh/m^2/year$ in Qatar are presented. The Inverse Distance Squared Weighting [7] interpolation technique was used to produce the maps from point measurements at each station location. The annual GHI is calculated using only non-missing daily values and normalizing to 365 days per year. All stations have 93% or higher data availability, except for Al Karanaah which has about 30% of days with no daily values reported, see table 1.

Firstly, to provide an overview of all available data, a map produced taking the complete dataset of the 12 stations for their full periods of operation is shown. These values represent averages of varying periods from 1.5 to 6 years depending on the station, see table 1; to avoid these inconsistencies in data and in order to have a more uniform representativeness of the data points, a second map was produced using only coincident periods of coverage for all stations; this selection, covering as much statistics as possible, results in a 4-year period from 2009 to 2012 and excludes only 2 stations. This map is compared with a map produced using long term data (1985 – 2005) from the HelioClim1 database, SoDa service [8], for the same 10 locations. In addition, maps of the year by year difference of GHI with respect to these 4-year averages are also presented to illustrate the yearly variability of GHI.

3. Results and discussion

Figure 1a shows the GHI map of Qatar in $kWh/m^2/year$ obtained by including all stations for their full periods of operation. As can be seen, the highest values are found in the South and the North areas except the northern most tip, while the lowest values are found predominantly in the central latitudes of the country and close to the industrial areas. The average for the whole country, using the values of the 12 stations has low significance since the two stations with highest values have been collecting data only from May 2011, so their values have a particularly lower representativeness than the others. Therefore and in order to improve the consistency of the data set, the longest covered period of coincidence among the maximum number of stations was selected to produce another map. Thus only the stations which have data available from January 2009 to December 2012 were used to produce the map shown in figure 1b. The average for Qatar using these 10 stations for the period 2009-2012, is 2113 *kWh/m²/year*.

Table 1. AWS installed by QMD across Qatar, along with their respective start dates, percentage of days with non-missing values, and yearly totals of GHI from QMD ground-measurements and from HelioClim1 database.

Station name	Start date	Percentage of non-missing days	4-year total average ground-based GHI	20-year satellite-derived GHI, HelioClim1 database
Abu Samra	March 2007	95	2132	1758
Al Ghuwayriyah	January 2009	98	2173	1972
Al Karanaah	January 2009	70	2179	1784
Al Khor	March 2007	97	2155	1986
Al Ruwais	March 2007	94	2098	2039
Al Shehaymiyah	May 2011	100	-	-
Al Wakrah	January 2009	99	2118	1999
Doha	January 2008	93	2043	1993
Dukhan	March 2007	96	2035	1748
Qatar University	March 2007	99	2109	1946
Turayna	May 2011	99	-	-
Ummsaid	March 2007	99	2083	1977

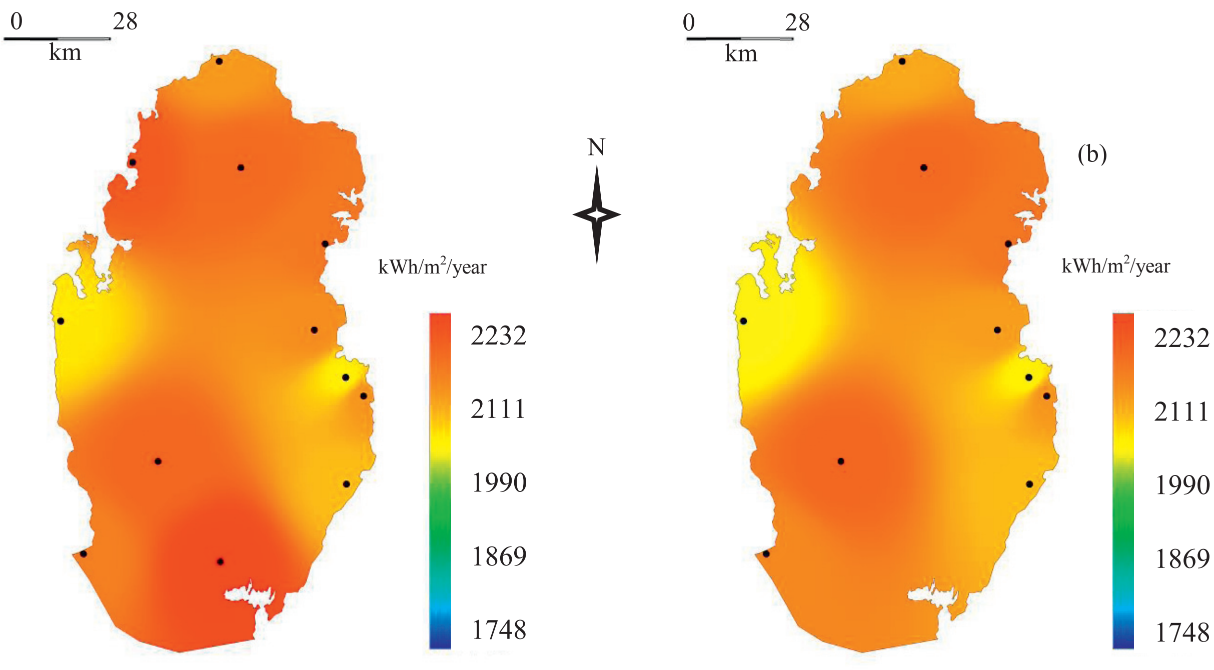

Fig. 1. GHI map of Qatar in kWh/m²/year using ground measurements (a) in 12 locations for varying averaging periods between 2007 and 2012, and (b) in 10 locations from 2009 to 2012; see text for details.

In figure 2, the year by year variations with respect to the 4-year averages per location (map 1b) are shown. In 2009, most of the areas have values below the average. The largest variation was 6% below average. In 2010, most of the areas have values above the average except the area around Al Karanaah station which presents the biggest variation, 6.5% below average. In 2011, the highest variation was found again in Al Karanaah with 6.4% below average. These large variations in Al Karanaah station can be understood because of its high percentage of missing values during these years, which makes the annual total average less representative of the real values. In 2012 the highest variations were 1% of the average.

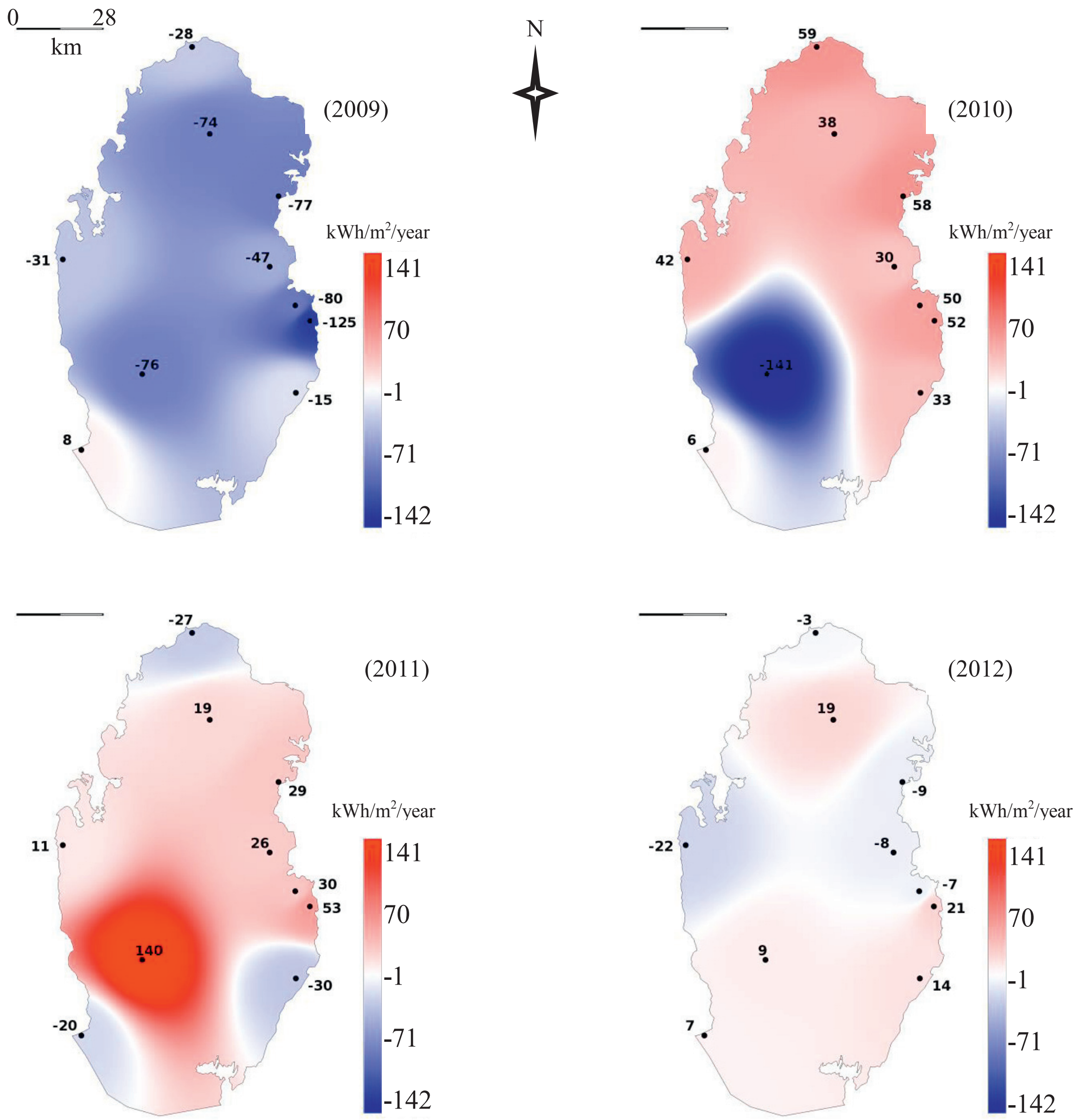

Fig. 2. Year to year variations to the 4-year averages of GHI in kWh/m^2/year.

To have a comparison with long-term satellite-derived data, the map in figure 3 was produced with yearly values from the HelioClim1 database for the period 1985 to 2005 for the same 10 locations as in figure 1b; the same interpolation method used in the previous maps was also used here. The spatial resolution of HelioClim1 is approximately 20x20 km^2, yet it is noted that the 3 stations around Doha, along the central eastern coast, have different values. The Irena Global Atlas For Solar and Wind [9] uses also the HelioClim1 database to display a map of the region and according to this map, these 3 locations belong to the same pixel and have the same GHI value; therefore, it is apparent that the HelioClim1 values provided by the SoDa online service are interpolated.

In figure 3, a similar map as the one in figure 1b covering the 4-year period 2009-2012 and using 10 locations is shown. By comparing the spatial distribution of GHI between maps in figures 3 and 1b, it can be seen that both maps show a different distribution of GHI most notably in the southern and northern ends of the country. The irradiation values are also different, with HelioClim1 values lower than the ground-measured values; these differences range between -2 and -18%. Apart from the fact that both maps cover different temporal periods, these differences can also be attributed to the model used to derive the values of HelioClim1 and its validity in the region. The low values found in the south of Qatar on the HelioClim1 map are most likely influenced by the model's consideration of dust coming from the desert of Saudi Arabia; on the other hand, ground measurements provide the actual conditions around each location reflecting higher resolution spatial variations. The yearly GHI for Qatar is 1920 *kWh/m²/year* using the 10 locations from HelioClim1 values.

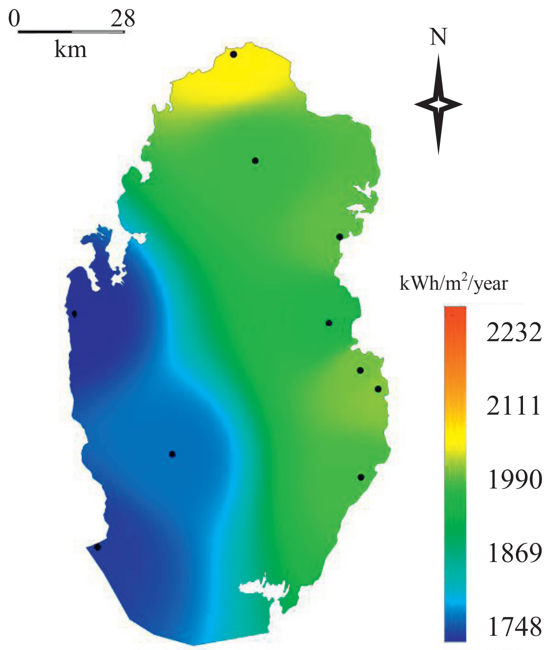

Fig. 3. GHI map of Qatar in kWh/m^2/year using (a) satellite-derived HelioClim1 values in 10 locations from 1985 to 2005, and (b) ground-derived values in 9 locations from 2009 to 2012; see text for details.

4. Conclusion and outlook

In this paper, several maps of annual total GHI in Qatar are presented, derived from daily GHI values collected by a network of 12 AWS deployed throughout the country. The longest coincident operation period of these stations covers a period of 4 years from 2009 to 2012 and 10 of the stations. The ground-based map produced with this selection is considered the representative GHI map for Qatar based on the available daily GHI values. The yearly total GHI average value for Qatar is 2113 $kWh/m^2/year$ and the maximum year to year deviation per location is 6.5%. The yearly total GHI value for Qatar, calculated using the same 10 locations with HelioClim1 values for the period from 1985 to 2005 is 1920 $kWh/m^2/year$, lower than the ground-based value. The annual average for Qatar derived from another satellite-based solar radiation database, SolarGIS, covering a long term period of 18 years from 1994 to 2010 is 2134 $kWh/m^2/year$ [10]. Although the satellite-derived value from SolarGIS could reflect a reliable value of the yearly average for Qatar because of the long term period of coverage of 18 years, individual values in each location may show more discrepancies with respect to ground measurements. A combination of satellite-derived and ground-measured solar data can provide more reliable values with lower uncertainties, see e.g., [11, 12].

The Qatar Environment and Energy Research Institute has the plan to join efforts with QMD to conduct a comprehensive solar resource assessment of the country; apart from upgrading the AWS for measuring the Direct and Diffuse components of solar radiation and providing good quality data, the plan may also include increasing the number of ground stations by deploying one or two additional stations in the center of Qatar to achieve less than 35 km distance between stations in order to spatially cover the whole country in a consistent manner and obtain data with low uncertainty level [12, 13].

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