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Satellite or ground-based measurements for production of site specific hourly irradiance data: Which is most accurate and where?

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ABSTRACT

Site-specific satellite-derived hourly global horizontal irradiance is compared with that obtained from extrapolation and interpolation of values measured by ground-based weather stations. A national assessment of three satellite models and two ground-based techniques is described. A number of physiographic factors are examined to allow identification of the optimal resource. The chief influences are determined as: factors associated with latitude; terrain ruggedness; and weather station clustering/density. Whilst these factors act in combination, weather station density was found to be fundamental for a country like the UK, with its ever-changing weather. The decision between satellite and ground-based irradiance data based on accuracy is not straightforward. It depends on the exactitude of the selected satellite model and the concentration of pyranometric stations.

1. Introduction

Solar radiation data has many applications, such as solar energy system performance and bankability assessment, building design of passive heating, cooling and daylighting elements, and resource assessment for agriculture and forestry. The most reliable i.e. lowest uncertainty source of solar radiation data is ground-based measurements by weather station networks and dedicated pyranometric stations (Sengupta et al., 2015). They measure the solar irradiance actually received at ground level, where solar systems are located. However, their reliability/uncertainty is conditional upon maintenance and calibration of the instruments. Pyranometer uncertainty must also be considered in the use of data.

This research investigates three methods to obtain solar radiation estimates for locations where it is not directly measured. The first is simply to allocate values from the single nearest measurement point. Here this method is termed "nearest neighbour extrapolation" (NNE) as in (Perez et al., 1997). Alternative names are "nearest neighbour interpolation", "proximal interpolation" and "nearby station method". The second method is to use an interpolation method based on the spatially weighted average of several neighbouring measurement locations. The third alternative approach is to model solar irradiance from cloud images captured by satellite. Like ground-based measurements, satellite data also has disadvantages. One shortcoming is lower accuracy at the specific weather location because the satellite data represents an area of the given pixel size, rather than an exact point.

There are no overall guidelines to direct the choice between ground-based or satellite irradiance data (Meteonorm, n.d.). This research sets out a data-informed methodology to aid the decision-making process and applies it to the UK as an example. It provides an extensive nationwide validation of these two solar irradiance data sources on an hourly basis. The case study area is the entire UK. This is a non-homogeneous region in terms of climate and topography and irradiance values vary significantly across the country.

Previous work has focused on distance from weather station as a deciding factor in the preferred choice of data source. As the distance between the point of measurement and location where data is required increases, the likelihood of divergence of weather conditions at the two sites also increases. In general, a distance decay effect may be observed, due to weather fronts and terrain. A theoretical distance is reached at which the decreasing accuracy of the ground-based data equals and then falls below the otherwise less accurate satellite-modelled data. This cross-over or break-even distance was determined as 34 km for hourly averaged global horizontal irradiance (GHI) data in 1997 (Perez et al., 1997). This research is discussed in Appendix A.

This original work (Perez et al., 1997) referred to *nearest neighbour extrapolation* of ground data, whereas a number of well-known ground data sources (Meteonorm (Meteonorm, n.d.), PVGIS-classic (JRC, 2012a,b)) use *geostatistical interpolation*. Interpolation techniques have been in existence for some time, but more powerful computers have enabled their widespread use and enhanced understanding. The last 20 years have seen considerable advances in satellite modelling also.

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Advances in networking and communication technology have led to increased availability of data of all types. In this context, this paper examines whether the historic break-even distance is still the best criterion on which to base a data source decision.

Other factors in the ground-based or satellite GHI data selection are: proximity to mountains and oceans; urbanisation (associated with high and changeable concentrations of aerosols and water vapour); high latitude; cloud cover (Hall and Hall, 2010; Perez et al., 2013; Suri and Cebecauer, 2014); and weather station density (Paulescu et al., 2013). The differences in accuracy of data derived from extrapolation/interpolation of ground-based sources and satellite-modelled data in these distinct regions have never (to the authors' knowledge) been quantified.

Both ground-based and satellite models are affected by orographic forcing when changes in elevation occur. When air is blown over mountains or hills, it is forced to rise. As it rises, it cools, becoming saturated with condensing water and forming a cloud, a phenomenon that is highly localised. Satellite models produce higher errors in coastal locations and are adversely affected by scattered cloud, especially at high latitudes (Perez et al., 2013). Broken cloud may mask the sun. Conversely, thin cloud close to the sun may enhance solar irradiance due to forward scattering (Yordanov et al., 2013). Current satellite instruments cannot distinguish small broken clouds from large thin cloud (Cebecauer et al., 2010a,b).

Satellite values may also fail to distinguish clouds in the presence of bright surfaces e.g. snow or ice cover, and some types of vegetation. Interpolation of ground data is subject to edge effects. In the case of the UK, the coast is also the edge boundary of the weather station network and correlation might be expected. The temporal granularity of hourly weather station data is too coarse to reflect cloud movements. Thus, it is not at all clear which GHI data source provides the best accuracy in which geographic circumstance. This research will investigate this issue.

The accuracy of both ground-based and satellite-modelled GHI will be assessed in terms of root mean square error (RMSE) and mean bias error (MBE). The following comparisons will be made: (1) pair-wise comparison of weather station reading to nearest weather station value; (2) interpolated ground-measurement to nearest weather station record at various distances; and (3) interpolated ground versus satellite-derived values under differing geographic scenarios.

In the following, an assessment of solar irradiance models is carried out to direct the decision between the use of extrapolated/interpolated ground-measured or satellite-modelled irradiance data. First, the impact of distance to weather station is investigated, followed by the influence of other atmospheric and topographical factors as detailed above.

This paper is structured as follows. Section 2 describes the data employed and quality control procedures performed upon it. Calculation of distance decay errors is detailed. Section 3.1 replicates former research with modern data. An investigation of the influence of distance on whether ground or satellite irradiance data is most accurate, is described. The previous research is then expanded upon and the results clearly visualised. Section 3.2 investigates the influence of atmospheric and topographic factors on whether ground or satellite irradiance data delivers the greater accuracy. These include locational and weather-related features. Finally, Section 4 summarises findings, interprets the results and offers conclusions.

2. Data and methods

All data used is hourly global horizontal solar irradiance data for the complete year of 2014, unless otherwise stated. The case study area is the United Kingdom.

2.1. Ground data description

Ground-based solar irradiance measurements available as hourly averages are used from the UK Meteorological Office Integrated Data Archive System - MIDAS (UK Met Office, 2006). The UK Met Office currently has a network of over 80 automatic weather stations throughout the UK which observe irradiance as well as other meteorological conditions. Figs. 1 and 2 provide details of UK weather stations distribution. It may be seen that the distribution is somewhat uneven. 30% of the stations are clustered in the South East and Midlands i.e. approximately one-third of the weather stations are positioned in one-fifth of the nation. In other words, although stations are typically about 40 km apart, this can more than double, particularly in Wales and Scotland. The weather stations distance distribution has a small positive skew, with slightly more inter-station distances of less than 20 km and slightly fewer greater than 80 km.

The instruments at these stations are CM11/CMP11 (Kipp&Zonen) pyranometers, calibrated by reference to absolute cavity radiometers, traceable to the world radiation standard. Weather station sensors predominantly rely on rainfall for cleaning.

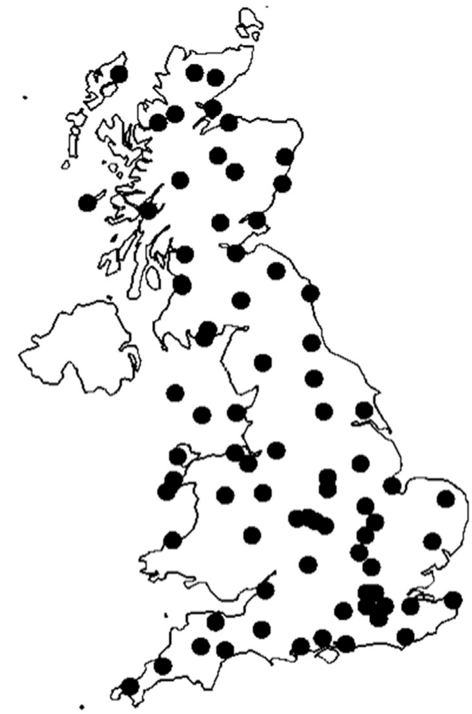

Fig. 1. Map of weather stations distribution.

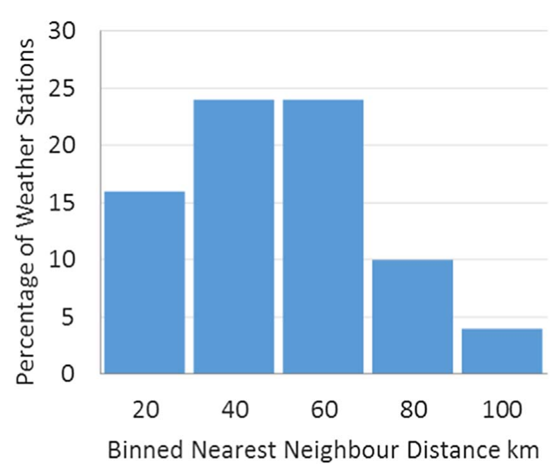

Fig. 2. Histogram of weather stations nearest neighbour distances.

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