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MESoR – MANAGEMENT AND EXPLOITATION OF SOLAR RESORCE KNOWLEDGE

Carsten Hoyer-Klick[1], Hans-Georg Beyer[2], Dominique Dumortier[3], Marion Schroedter-Homscheidt[4], Lucien Wald[5], Mario Martinoli[6], Christoph Schilings[1], Benoit Gschwind[5], Lionel Menard[5], Elena Gaboardi[6], Jesus Polo[7], Thomas Cebecauer[8],Thomas Huld[9], Marcel Suri[8], Marian de Blas[10], Elke Lorenz[11], Christian Kurz[12], Jan Remund[13], Pierre Ineichen[14], Anatoly Tsvetkov[15], Jaro Hofierka[16]

[1] German Aerospace Center, Institute of Technical Thermodynamics, Pfaffenwaldring 38-40, D-70374 Stuttgart, Tel. +49-711-6862-728, e-mail: carsten.hoyer-klick@dlr.de [2] Hochschule Magdeburg-Standal, Germany. [3] Ecole Nationale des Travaus Publics de l'Etat (ENTPE), France [4] German Aerospace Center, German Remote Sensing Data Center, Germany [5] Ecole des Mines de Paris, France [6] Icons srl., Italy [7] CIEMAT, Spain [8] GeoModel, Slovakia [9] Joint Research Center, Institute for Environment and Sustainability, Italy [10] Universidad Publica de Navarra, Spain [11] Oldenburg University, Energy- and Semiconductor Research Lab, Germany [12] meteocontrol GmbH, Germany [13]Meteotest, Switzerland

[14]University of Geneva, Switzerland [5] Voeikov Main Geophysical Observatory, World Radiation Data Center, Russia

[16]University of Presov, Slovakia

Abstract

Knowledge of the solar resource is essential for the planning and operation of solar energy systems. A number of data bases giving information on solar resources have been developed over the past years. The result is a fragmentation of services each having each own mechanism of access and all are giving different results due to different methods, input data and base years. The project MESoR, co-funded by the European Commission, reduces the associated uncertainty by setting up standard benchmarking rules and measures for comparing the data bases, user guidance to the application of resource data and unifying access to various data bases.

Keywords: Solar radiation, benchmarking, unifying access, user guidance

1 Introduction

Knowledge of the solar energy resource is essential for the planning and operation of solar energy systems. In the past years a number of data bases giving information on solar resources have been developed, such as the European Solar Radiation Atlas (ESRA), the projects SoDa [1], Satel-Light [2], PVGIS [3], PVSAT, PVSAT-2 [4] or Heliosat-3 [5] and the Envisolar [6] project of the European Space Agency (ESA). In addition more services were set up by national funding, such as Meteonorm [7] by Meteotest in Switzerland and SOLEMI [8] by DLR in Germany. This has led to the situation that several different data bases exist in parallel, developed by different approaches, various spatial and temporal coverages and different time and space resolutions, even for those exploiting satellite data. The users comparing information from different data sources for the requested sites may end up with uncertainty that is difficult to deal with.

These multiple efforts have led to a fragmentation and uncoordinated access: different sources of information and solar radiation products are now available, but uncertainty about their quality remains. At the same time, communities of users lack a common understanding on how to exploit the developed knowledge.

The project MESoR is a European funded Coordination Action which started in June 2007 and aimed at reducing the uncertainty and improving the management of the solar energy resource knowledge. Within this project, the results of past and present large-scale initiatives in Europe, were further integrated, standardised and disseminated in a harmonised way to improve their exploitation by stakeholders. The project also prepared roadmaps for future R&D.

The MESoR project includes activities in **(i)** user guidance (benchmarking of models and data sets; handbook of best practices), **(ii)** unification of access to information (use of advanced information technologies;

offering one-stop-access to several databases), **(iii)** connecting to other initiatives (INSPIRE of the EU, POWER of the NASA, SHC and PVPS of the IEA, GMES/GEO) and to related scientific communities (energy, meteorology, geography, medicine, ecology), and **(iv)** information dissemination (stakeholders involvement, future R&D, communication).

MESoR outcomes are direct contribution to the work programme of the IEA Solar Heating and Cooling Task 36 on “Solar Resource Knowledge Management”.

2 Benchmarking

Benchmarking is the largest activity within the MESoR project. The aim is to establish a coherent set of benchmarking rules and reference data sets to enable a transparent and comparable evaluation of the different solar radiation data sources. The rules are developed in conjunction with the IEA Task 36 on “Solar Resource Management” of the Solar Heating and Cooling Implementing Agreement and shall serve as a standard for benchmarking to make results comparable.

2.1 Reference data

The establishment of a good reference is the first step. The MESoR project collected high quality ground measurements which can be used as a reference in the benchmarking exercises. The measurements should be conducted with high accuracy, high frequency and traceable maintenance of the equipment. Data has been collected from the Baseline surface radiation network (BSRN), International Daylight Measurement programme (IDMP), the meteomedia network, the World Radiation Data Center (WRDC) and the Global Atmospheric Watch (GAW) programme. In addition, further measurements were collected from scientific institutions, providing they fulfil the quality criteria above. The collection continues under the IEA SHC Task 36 / SolarPaces Task 5 and high quality ground measurements are always welcome.

A common quality control procedure has been defined for all broadband time series data. The parameters for the quality assessment have been deducted from the Baseline Surface Radiation Network Operation Manual [9] and operational experience of the partners involved.

2.2 Benchmarking measures and rules

Benchmarking of solar radiation products can be done in different ways. If high-quality reference data are available, the modelled data sets can be compared and ranked according to how well they represent the reference data. But there is not always reference data available: e.g. for solar radiation spatial products (maps). Here benchmarking can assess the uncertainty of mapping products by their relative cross-comparison.

For site specific time series there are a number of different measures for benchmarking. A first set is based on first order statistics. These are the well known *bias, root mean square deviation, standard deviation*, their relative values to the average of the data set, and the *correlation coefficient*. These measures show how well data pairs at the same point of time compare with each other. They are important if one needs an exact representation of real data, e.g. for evaluations of real operating systems or forecasts of solar radiation parameters.

This exact match is not always important, e.g. for system design studies. Here the similarity of statistical properties such as *frequency distributions* is more important than the exact match of data pairs. The MESoR project therefore suggests a number of parameters based on second order statistics. The measures are described in detail in [10]. They are based on the Kolmogorov-Smirnov (KS) test [11,12]. Although there are several statistical tests and ways of evaluating the goodness of a model, the KS test has the advantage of making no assumption about the data distribution, and is thus a non-parametric, distribution-free test [13].

The idea is to compare the cumulative distribution functions (CDF) and measure the distance between the curves of the modelled and the reference data set. The CDFs are therefore binned into m intervals and the distance D_n is computed for each interval.

$$D_n = \left| M(x_n) - R(x_n) \right| \tag{1}$$

where $M(x_n)$ is the CDF of the modelled data and $R(x_n)$ is that of the reference data set. Figure 1 shows a sample CDF for a modelled and measured data set on the left and the corresponding D_n on the right. A critical value V_c can be determined from the number of values N in the sample:

$$V_c = \frac{1.63}{\sqrt{N}}, \quad N \geq 35 \tag{2}$$

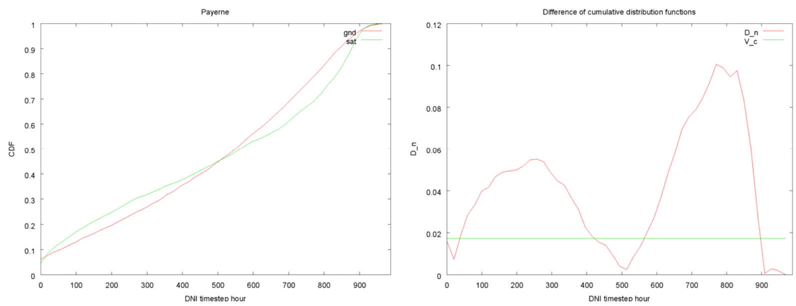

Figure 1: Cumulative distribution functions (CDF) of hourly DNI values from modelled and measured values for the BSRN ground station in Payerne on the left. The distance D_n for each interval on the right.

The original KS test probes for the maximum D_n to be below V_c to evaluate if the two samples have similar distribution functions.

The representation of the values D_n, along with the critical value, gives the complete testing behaviour of the CDF with respect to the reference over the whole range. Thus, the extended KS test is very useful for model response assessments, and has been used for several studies [14,15,16]. However, although application of the KS test contributes valuable information, it only materializes in the acceptance or rejection of the null hypothesis. In the next paragraphs new parameters are proposed, which, based on the estimation of the distance between the two CDFs for the sets compared, define quantitative measures that can be used to rank models.

The KSI parameter (**K**olmogorov-**S**mirnov test **I**ntegral) is defined as the integral of the area between the CDFs for the two sets, the area below D_n. The unit of this index is the same for the corresponding magnitude, the value of which depends on it. As an example, the left graph of figure 1 shows the CDFs for the data set of hourly irradiance sums measured at the station of Payerne over a period of 5 years (1996-2000) and set of daily sums gained by the analysis of satellite data for the same location and period. This set was derived using the SOLEMI data base of DLR. In the right plot the distances between them, D_n are displayed. The green line represents the critical limit, V_c, calculated for the number of available data.

The KSI is defined as the integral:

$$KSI = \int_{x\min}^{x\max} D_n d(x) \tag{3}$$

As D_n is a discrete variable and the number of integration intervals is identical in all cases, trapezoidal integration is possible over the whole range of the independent variable x. A percentage of KSI is obtained by normalizing the critical area, $a_{critical}$:

$$KSI\% = \frac{\int_{x\min}^{x\max} D_n dx}{a_{critical}} * 100 \tag{4}$$

where $a_{critical}$ is calculated as:

$$a_{critical} = V_c * (x_{\max} - x_{\min}) \tag{5}$$

where V_c is the critical value for the level of confidence selected and (x_{max}, x_{min}) are the extreme values of the independent variable. Normalization to the critical area enables the comparison of different KSI values from different tests. The minimum value of the KSI index is zero, in which case, it can be said that the CDFs of the two sets compared are the same. A value of 100 indicates that the area below D_n is equal to the area below the critical value.

An important factor to achieve comparable benchmarking results is the selection of valid data pairs (modelled and measured) values which are taken into account. Therefore, in addition to the measures described above, a set of rules to be applied for benchmarking was defined. Within MESoR we suggest to use only data pairs where

- The ground data has passed the quality-checking (QC) procedure;
- Global irradiance/illuminance is greater zero (exclude night values and missing measurements);
- The modelled value is valid.

Averages are calculated from all valid data pairs. E.g. $\overline{x_m}$ in equations (2.3), (2.4) and (2.6) is only calculated form the validated data.

Averages for multiple stations are created in a way that all data pairs are packed into one analysis, so that each data pair in the analysis gains the same weight. This is of special importance if the stations have different numbers of valid data pairs. If the results would be calculated for each station separately and the average of stations would calculated afterwards, the values in the station with the least number of data pairs would gain the highest weight.

Solar spatial databases (map data) can be benchmarked in two ways, either point based or map based. The point based benchmarking is similar to the time series benchmarking. Data is extracted from the maps and compared to the measurements ("ground truth"). First and second order statistics can be applied. Map based cross comparison of solar radiation provides means for improved understanding of regional distribution of the uncertainty by combining all existing resources (calculating the average of all) and quantifying their mutual agreement by the means of standard deviation (Fig. 2). An evaluation of long-term yearly averages of Direct Normal Irradiation (DNI) has been done with five spatial data bases: ESRA, PVGIS, Meteonorm, Satel-light and NASE SSE [17].

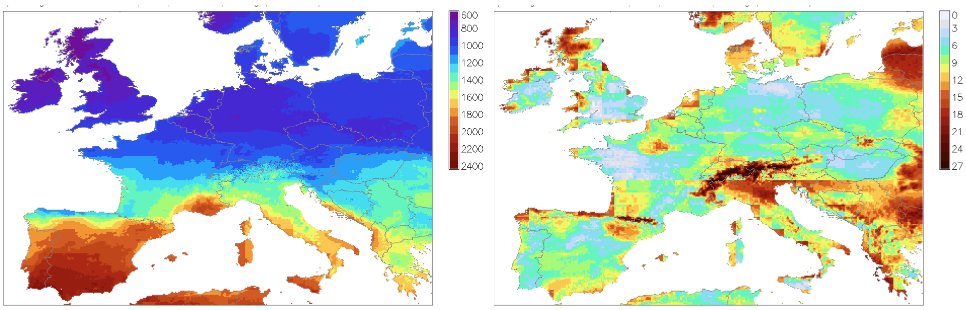

Figure 2: Yearly sum of direct normal irradiation: average of all five data bases (kWh/m²) on the left, and relative standard deviation from the comparison of the five data bases (%) on the (right)

2.3 Sample Benchmarking results

The MESoR project also applied the developed benchmarking. Within MESoR several different benchmarking exercises have been performed. The exercise I which is shown here focuses on DNI for the years 1996 to 2000 in Europe. The stations Nantes and Thessaloniki were excluded in the DNI evaluation as they did not contain a DNI measurement but only global and diffuse.

The results presented here compare three different data sets providing hourly data, SOLEMI from DLR, EnMetSol from Oldenburg University, and Satel-light from ENTPE. Meteonorm is only included for the KSI% test, as the Meteonorm hourly data are synthesised from the monthly averages. Bias and RMSD (root mean square deviation) make no sense in this case. The overall bias was low for all data bases, 1% for SOLEMI, 4% for Satel-light and -1% for EnMetSol. The RMSD is 48% for SOLEMI and 36% for Satel-light and EnMetSol. As stated above, bias is more important in prefeasibility project evaluation, while the match of the frequency distribution is more important for system design and system operation. An overall value for the KSI% cannot be given, as it would need an overall reference distribution, which is very difficult if the distributions for the stations are very different. The KSI values are only compared graphically.

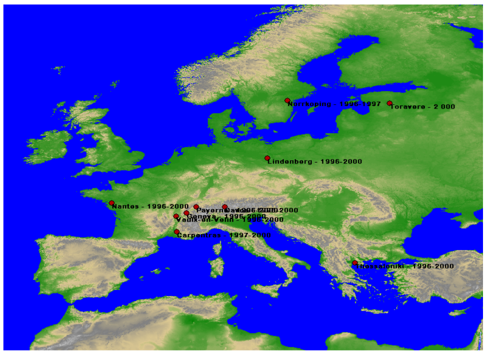

Figure 3: Ground measurement stations in the MESoR benchmarking exercise I

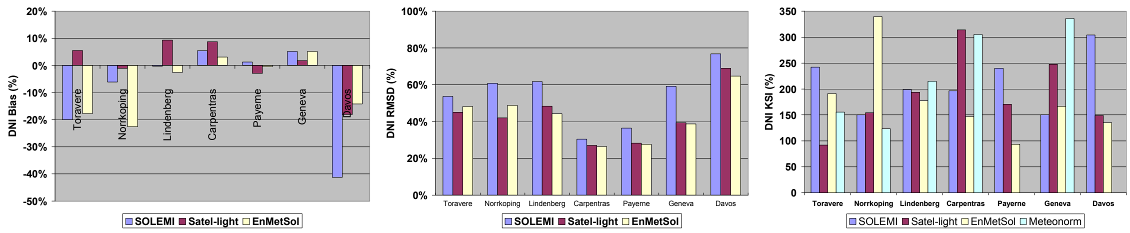

Figure 4: Benchmarking results from MESoR Exercise I for DNI. Bias (left), RMSD (middle), KSI% (right). Station names from left to right are Toravere, Norrkoping, Lindenberg, Carpentras, Payerne, Geneva and Davos.

The analysis of the KSI% shows rather high values mostly above 100. This means that even if bias is well met, the match in the distribution functions needs further improvement. There is no clear difference between the various data bases. The map based cross-comparison of five data sources (Fig. 2) shows that there are regions with higher disagreement between individual databases. The main drivers of such differences are imperfections of cloud detection models (especially in mountains and snow/ice conditions), interannual variability, high differences in the existing aerosol and water vapour databases, lack of high-quality data in some regions, complex terrain and climate conditions in mountains and in coastal zones. The uncertainty in these regions can be decreased by detailed analysis of the above mentioned determining factors, followed by improved modelling procedures.

Benchmarking Conclusions

The developed benchmarking measures and rules do not give clear recommendations on which data set should be used for selection of sites, system design or support of power plant operation. But the project has developed transparent measures and rules, including the new ones for quality assessment of the distribution functions, which are recommended to solar community. Following these standardised benchmarking rules, it should be easier to select a data base meeting the user specific needs.

3 User Guidance

3.1 User guide of best practices

User guidance is one of the main objectives of the MESoR project. This is realized by writing a guide (handbook) that will include also best practices in the application of solar resource data. The benchmarking is one chapter in this guide. The results give the users a better indication of the uncertainty of the available data sources and fitness of data for different applications. Best practices in the application of solar resource information are demonstrated in the use cases. These use cases cover applications such as photovoltaics, solar thermal, solar concentrating and daylighting systems. It also covers solar forecasting applications. As a basis, it covers requirements and examples for the design and operation of various solar technologies.

3.2 Roadmap

Based on the feedback from the stakeholders and the benchmarking results, a number of Road Map documents have been compiled within the MESoR project. They identify future research objectives in the field of solar resources, as well as new solar radiation services for faster deployment of solar energy markets and for optimized grid integration. The Road Map also provides recommendations for an improved Earth Observation system to better support solar energy. The Road Map documents will be continuously updated within the IEA SHC Task 36, SolarPaces Task 5 operations.

4 Unifying Access

The second major objective of the MESoR project is to unify and ease access to solar resource information. This builds upon experiences made within the SoDa portal, adopting interactive mapping and analytical features from PVGIS web system. The original SoDa portal was built with proprietary software and communication protocols. As the World Wide Web evolved over recent years, we decided to build a new web portal within MESoR, using open source software with support from a large development community and standardised web services. This makes the new portal more sustainable (in terms of software development), and the connection to the portal easier and more open (as only widely accepted standards are followed).

The portal serves as a broker to solar resource information and services. It does not itself contain and maintain data; instead it links data bases and services within one single point of entry and a common user interface. Databases and services are hosted by their providers, who keep control over their data and applications.

Metadata are essential to exchange knowledge between applications. They describe objects to be exchanged (e.g. a time series of irradiance, a geographical location, a date…). After a series of consultations with several bodies involved in standards, such as ISO, GEOSS (Global Earth Observation System of Systems), INSPIRE (Infrastructure for Spatial Information in Europe) and national meteorological offices, a thesaurus has been defined which is specific to solar resource. A thesaurus is a set of terms that describe the solar resource.

A prototype of the broker has been set up during the project. A new user interface has been designed, including the API (application programming interface) of Google Maps. Users can therefore use the full capabilities (geographical search, maps and images) of Google to identify their sites and select the right locations or regions. As this interface is easy to use and applied already in many other applications, the user is likely to be familiar with it. The front page of a service gives the site selection window and some descriptive information of the service, as a general description, property rights, credits, inputs and outputs descriptions and benchmark procedure results if relevant. The results can be written to the browser window or saved in a specific format (e.g. spreadsheet-compatible). The available data bases can be selected by the menu on top of the page. The figure below shows two sample screenshots of the current prototype (see http://project.mesor.net).

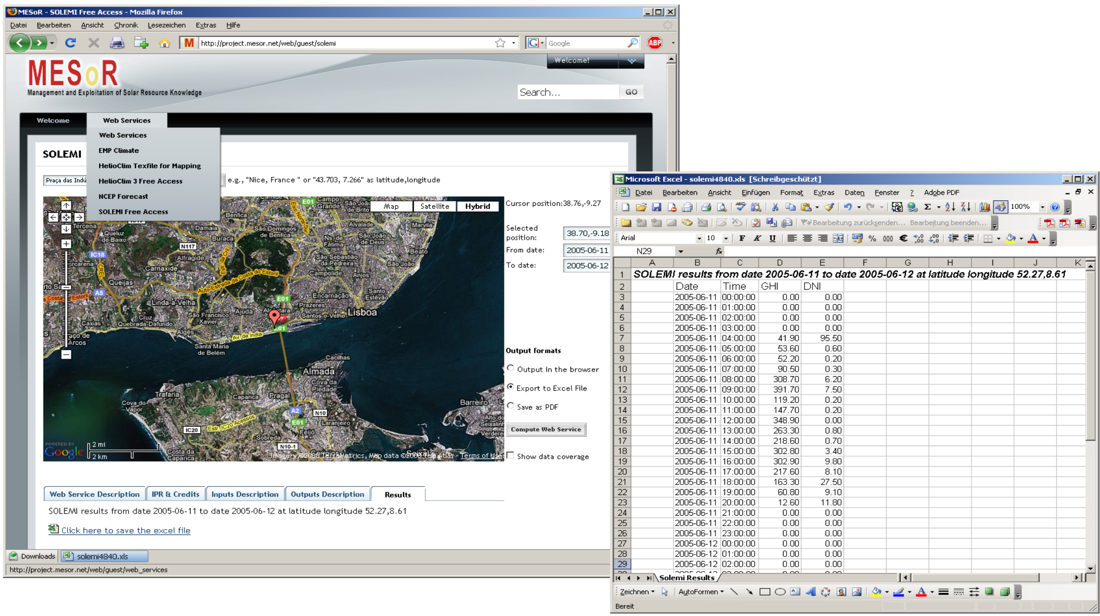

Figure 5: The prototype of the MESoR broker portal. A sample time series has been extracted in an Excel spreadsheet format.

5 Conclusions

The European Union funded project MESoR, in close collaboration with International Energy Agency and their SHC and SolarPACES Implementation Agreements, has brought new benefits for solar energy industry, policy, research, education and broad community:

- Standardised rules are defined for transparent benchmarking of solar radiation products (site observations and spatial databases). The benchmarking exercises provided by the MESoR consortium have improved understanding of the state of the art of solar resource assessment, and the solar products available for Europe.
- A new web portal has been developed, offering technology for harmonised and easy-to-use access to solar radiation and related databases and tools. The portal is based on the use of open source software and implementation of international standards. The MESoR portal already now links several data sources and it is intended to be used as one-stop shop for those who need data for their projects.
- The MESoR consortium has developed and improved links to all international scientific and policy initiatives that are relevant to solar renewable energy. Active participation in these initiatives has facilitated transfer of scientific know-how to "daily life".
- The MESoR consortium has identified further needs for research and development in enhancing the solar resource knowledge, which have been described in the Road Map documents of the project.
- The handbook on solar resources and best practices summarises the existing knowledge in a user friendly interpretation and layout, and offers access to this knowledge to the solar energy community.

On one hand the MESoR project brings standardisation, harmonisation, unification, and coordinated approach, on the other hand it has identified a number of new items in the *"to do"* list in both R&D and application fields. To mention some of them:

- Current solar radiation methods, resource data and products need further improvements in order to reduce risk and improve efficiency and reliability of solar energy technology.
- Further integration of information and communication technology with available satellite, and meteorological data streams, supported by high-resolution global data sets, will substantially streamline access to data and derived products requested by service providers and the solar industry.
- The solar resource community is committed to continue in fast development of data and services to support technology operation and maintenance (prefeasibility, project development, system monitoring, forecasting of power generation). The issues of grid integration and demand/supply management are

discussed more often then ever. However, solar resource community needs targeted support to keep the pace with development and worldwide deployment of solar energy technology.

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