Interoperable Exchange Of Surface Solar Irradiance Observations: A Challenge

Lionel Ménard, Daniel Nüst, Khai-Minh Ngo, Philippe Blanc, Simon Jirka, Joan Masó, Thierry Ranchin, Lucien Wald

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 76 (2015) 113 – 120

Energy Procedia

European Geosciences Union General Assembly 2015, EGU

Division Energy, Resources & Environment, ERE

Interoperable Exchange Of Surface Solar Irradiance Observations: A Challenge

Lionel Ménard[a]*, Daniel Nüst[b], Khai-Minh Ngo[a],Philippe Blanc[a], Simon Jirka[b], Joan Masó[c], Thierry Ranchin[a], Lucien Wald[a]

[a]MINES ParisTech - PSL Research University, O.I.E. – Centre Observation, Impacts, Energie, CS 10207, rue Claude Daunesse, 06904 Sophia Antipolis Cedex, France
[b]52°North Initiative for Geospatial Open Source Software GmbH, Münster, Germany
[c] Center for Ecological Research and Forestry Applications (CREAF), Universitat Autònoma de Barcelona, Barcelona, Spain

Abstract

We present how implementations of the Sensor Web Enablement framework of the Open Geospatial Consortium are integrated into an existing spatial data infrastructure. The result is registered as a community portal for professionals in solar energy in the GEOSS Common Infrastructure, demonstrating the benefits of interoperable exchange of *in-situ* time-series observations of surface solar irradiation. Easy access to, and sharing of data improves the information base for planning and monitoring of solar power resources. Providing users with visualization and download functionality for *in-situ* measurements is a key aspect for engaging the energy community to share, release and integrate *in-situ* measurements.

Peer-review under responsibility of the GFZ German Research Centre for Geosciences

Keywords: GEOSS; web; spatial data infrastructure; open data; sensor web enablement, solar energy; surface solar irradiance; SSI

* Corresponding author. Tel.:(+33) 04 93 95 74 23
E-mail address: lionel.menard@mines-paristech.fr

Peer-review under responsibility of the GFZ German Research Centre for Geosciences
doi:10.1016/j.egypro.2015.07.867

1. Introduction

Solar energy is one of the main ways for producing electricity in many countries worldwide. Energy producers and project developers of solar power plants (photovoltaic, solar concentrating technologies) have identified the surface solar irradiance (SSI) and its components as an essential variable for their business development [1,2]. Policy-makers also need information based on SSI data to set up energy policies at local to national levels. Usages of SSI data in projects address:

- the potential and prospective solar resources with national, regional, and local maps of SSI integrated in decision support systems;
- the long-term solar resource assessment for a specific site with time series of SSI for technical sizing and yield report simulations;
- the monitoring of existing solar power plants for operation and maintenance purposes;
- the multi-horizon forecast for energy storage, planning or participation in an electricity spot market.

In addition to its use by companies and policy-makers, the SSI is identified as an Essential Climate Variable by the Global Climate Observing System [3]. Different operational Earth Observation (EO) components provide estimations of the SSI:

- in situ pyranometric sensors [4,5];
- processing of images taken by meteorological satellites, such as the HelioClim project [6,7], the Copernicus Atmosphere Service [8,9], or the Eumetsat CM-SAF [10];
- numerical weather models (NWM), such as ECMWF-IFS [11] or re-analyses such as ERA-Interim [12].

Currently, all these components are used by companies and policy-makers in the solar energy domain. However, they are used individually and not in conjunction. Emerging needs clearly show that a great benefit would be achieved by efficient means of joint exploitation. For example, *in-situ* pyranometric stations form a sparse network and do not offer an accurate description of the spatial distributions. Hence, the search for suitable locations for building new plants starts with satellite data, based on which *in-situ* observations are carried out at selected sites. Since *in-situ* pyranometric sensors are deemed to provide the best possible assessment of the SSI at a given location, *in-situ* instruments measuring the SSI must be deployed in selected areas for at least one year. Then, time-series of SSI derived from satellite imagery are adjusted onto these measurements to obtain long-term time-series of calibrated SSI data [13].

To form a convincing picture, answers must be sought in the conjunction of these EO systems, and although companies collecting SSI observations are willing to share this information, the means to exchange *in-situ* measurements across companies and between stakeholders in the market are still missing.

A new spatial information infrastructure can close this gap and enable integration and access to SSI observations by stakeholders. This infrastructure allows on the one hand providers to share their SSI observations and on the other hand users to access them. As there are many data providers using many different sensor instruments this infrastructure should tackle sensor integration and dissemination of measurement data through a uniform, platform-independent and interoperable approach. This could be efficiently achieved by benefiting from GEOSS recommendations on interoperability and by making extensive use of recognized international geospatial standards such as the OGC (Open Geospatial Consortium) SWE (Sensor Web Enablement) framework [14]. The present article addresses this issue.

This work takes place in the newly started project ConnectinGEO funded by the European Commission. ConnectinGEO aims at improving the understanding on which environmental observations are currently available in Europe and subsequently providing an informational basis to close gaps in diverse observation networks [15]. The project utilizes different top-down and bottom-up approaches. It complements consulting, and networking activities (top-down) with supporting actions and practical challenges to test and improve the procedures and methods for identifying observation data gaps. As part of the latter approach, we present the challenges and future concepts for building a data sharing portal for the solar energy industry as well as the state of the art in the domain to ensure viability of the ConnectinGEO methodology in real world scenarios.

2. Solar industry challenges for *in-situ* measurements of SSI

NWM or satellite-based assessments of the SSI are currently easily accessible, yet sometimes against payment, as they obey GEOSS or WMO standards for dissemination, i.e. common data formats. Within a given database, all data for all pixels/cells obey the same format. This facilitates their integration into a user's own workflow and partly explains why they are often exploited by professionals in solar energy. In addition, they offer a high geographical and temporal coverage that satisfies the general needs in solar energy. In other words, these two EO components permit to provide SSI for any place in the world any time.

Taking into account the limitations in spatial and temporal resolutions and also in the underlying empirical or physical modeling, satellite-derived data are generally judged very useful by industry stakeholders for regional prospective or technical pre-feasibility studies. This is less the case for NWM that often exhibit drawbacks due to cloud presence [13]. Both satellite-derived data and NWM are nevertheless considered not accurate enough to convince investors in the commissioning of large-scale solar power plants, or to monitor and forecast production of these plants.

In-situ pyranometric sensors are deemed to provide the best possible assessment of the SSI at a given location. They serve as a reference to assess the quality of the two other components: satellite-derived and numerical weather models. However, though the purchase of a pyranometer can be seen as inexpensive, such a system induces high cost of operation and maintenance to be able to provide valuable, i.e. bankable data sets. This prevents the large-scale deployment of pyranometric stations.

All meteorological networks in Europe are equipped with pyranometric stations but many of them are not fully suitable to fulfil the needs of the solar energy community. There are several international networks that could be suitable such as those under the umbrella of the World Meteorological Organization (Global Atmosphere Watch – GAW, Baseline Surface Radiation Network – BSRN, world radiation data center – WRDC). Most data from these networks are available, though through different modes ranging from web-services to direct human-to-human phone-calls, often with limited rights in access and use [16]. The spatial density of these *in-situ* sensors is quite heterogeneous across the world. In many locations the distance between stations is too large to capture the spatial variability of the solar radiation [1, 2]. Moreover only few stations offer data sets spanning several years and many data sets exhibit temporal gaps of missing data.

Due to these limitations, investors or developers of solar power plant projects have installed or rented their own *in-situ* pyranometric stations and have private data sets from past or present time periods. In Europe, there are currently several hundreds of private ground stations associated with power plants. However, these data sets are currently not accessible for Intellectual Property Rights (IPR) reasons, even though recent efforts undertaken by MINES ParisTech in France seem to demonstrate that exchange of data between companies may be possible and that a network of these private stations may be set up for the common good.

In summary, it can be stated that, for different reasons, networks of meteorological pyranometric sensors, satellite observations or numeric weather models taken separately are not able to answer the needs of industrialists and project developers. Solutions can be found in the conjunction of these EO systems, such as those listed in the work plan of subtask B "standardization and Integration Procedures for Data Bankability" of the Task SHC 46 "Solar Resource Assessment and Forecasting" of the International Energy Agency:

- short-term calibration of long term satellite-based time series of SSI with *in-situ* measurements;
- quality check procedures of *in-situ* measurement with satellite-based SSI estimation;
- *in-situ* data completion (gap-filling) with satellite-based SSI estimation.

The merging of *in-situ* measurements with satellite or NWM data to get valuable, bankable datasets ready for the business development corresponds to a very active and mature R&D activity. Several algorithms and methods are already available [13], for example in the FP7-funded ENDORSE project "ENergy DOwnstReam SErvices - Providing energy components for GMES" coordinated by ARMINES [17]. The main bottlenecks to the implementation of these solutions are technological obstacles and IPR. From the practical side, except within a given network, there is a lack of a common, interoperable (i.e. collaboratively discussed and well-defined or specified) framework to collect, store, process (quality-check, gap-filling, temporal aggregation) and disseminate *in-situ* measurements. From the IPR point of view, the use of data from large networks (BSRN, GAW, WRDC) is not allowed for commercial purposes and companies are not sharing their data, even though this would largely contribute to a larger penetration of solar energy in the European electricity mix.

ConnectinGEO will undertake efforts for 1) developing an interoperable framework, and 2) creating a demonstrator and convincing incentives for public or private bodies measuring SSI to share their data based on this framework under a license that explicitly allows commercial use [18].

Providing an easy and open access to SSI measurements is therefore a key feature to be developed in ConnectinGEO. From the end-user point of view, *in-situ* measurements should be easy to find, easy to access (view, download) and consequently easy to use (data format, metadata, documentation). From the data provider point of view *in-situ* measurements should be easy to register and upload, easy to qualify by flagging suspicious or erroneous data following well-established quality check procedures [19,20]. To enable this in a sustainable manner, *in-situ* measurements should be integrated and made available by using existing and recognized open international standards. In that respect, ISO (International Organization for Standardization) and OGC (Open Geospatial Consortium) standards address the full spectrum from the use of standardized metadata to data integration, data search and discovery to the exploitation of SSI parameters. This way a virtuous circle actively involving data users and data providers can be put into place exploiting established Sensor Web standards and implementations.

3. Spatial Data Infrastructure

A spatial data infrastructure (SDI, http://www.gsdi.org/gsdicookbookindex) should be deployed to enable the integration of and access to *in-situ* measurements of SSI. As discussed above, the SDI should tackle sensor integration and dissemination into a uniform, platform-independent and interoperable solution. The OGC SWE (Sensor Web Enablement) architecture is particularly suited to this purpose. It offers support to:

- discover and locate sensor systems and measurements;
- investigate sensor capabilities and information on the quality of the measurements;
- enable access to sensor parameters and data for direct or further processing.

Beside the direct access to *in-situ* sensor information, the SWE specifications allow to couple those assets with any available SSI Earth observation resources (raster or vector data, maps). Being able to combine SSI *in-situ* measurement with additional EO data at the application level will provide value added information maximizing value and enabling decision-making. The Web-based platform developed within the 52°North Sensor Web community is a complete Sensor Web infrastructure particularly designed to provide access to data measured by sensors. It also enables tasking and control of sensors, event detection and triggering of alerts through sensor observations. It implements standardized interfaces developed by the Open Geospatial Consortium (OGC) and its Sensor Web Enablement (SWE) initiative and provides user-friendly interfaces for visualization as well as clients for diverse analysis environments.

In order for data providers to leverage their efforts of releasing *in-situ* measurements of SSI, the SDI should enable a "search and discovery" mechanism of such measurements. This mechanism will be provided by referencing all *in-situ* measurement of SSI available through the Sensor Web infrastructure into an OGC-compliant CSW (Catalog Service for the Web) catalog (http://www.opengeospatial.org/standards/cat). This catalog should allow both humans a user-friendly search experience through a Web based graphical user interface (GUI) (Fig. 1) as well as machine to machine distributed operations for back-office processes.

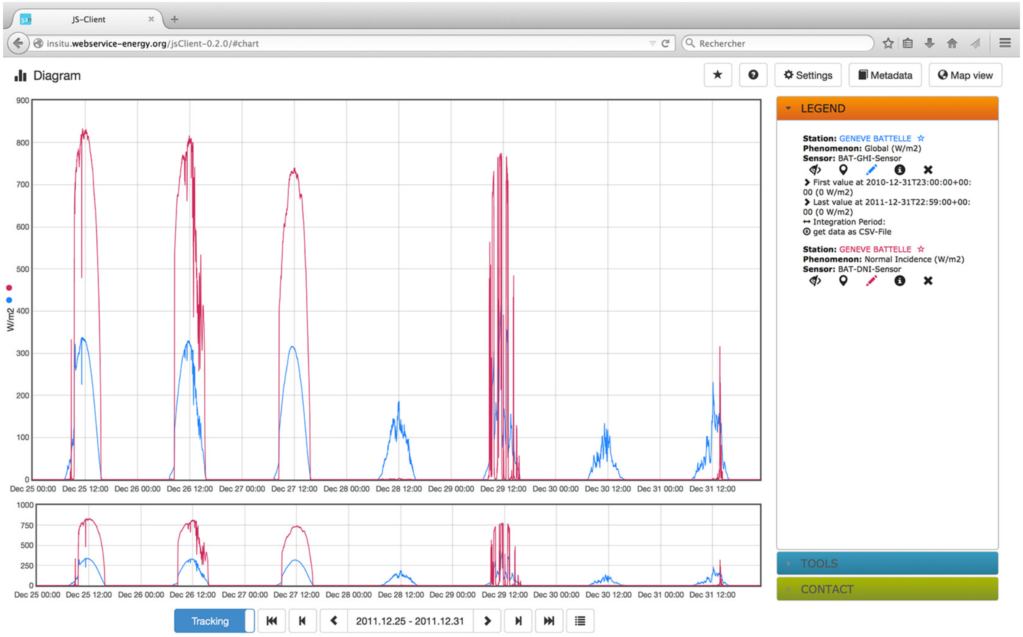

Fig. 1. Screenshot of the web-based GUI

End users should also have the possibility to get an easy access to *in-situ* measurements of SSI. A Web-based GUI, also called a thin client, will allow to:

- geo-locate the site of interest among available surrounding measuring stations;
- select the type and the technical characteristics of sensors and the corresponding data sets of interest provided by the selected stations;
- retrieve metadata; including information about the sensor as well as about the measurement itself regarding for example quality assessment and quality control;
- access time series of *in-situ* measurements; the values should be represented as line chart for a specific period and time integration (sub-hourly, daily, monthly, etc.), and tables and graphs.

End-users should be able then to export/download the measurements of interest for further ingestion into their own processing tools for further analyses and studies. Additional features could be added to the GUI such as averaging over time, or comparison with satellite-based SSI from Copernicus Atmosphere Service (Fig. 2). These extensions to the open source client solution are crucial for the adaptation within the solar energy community.

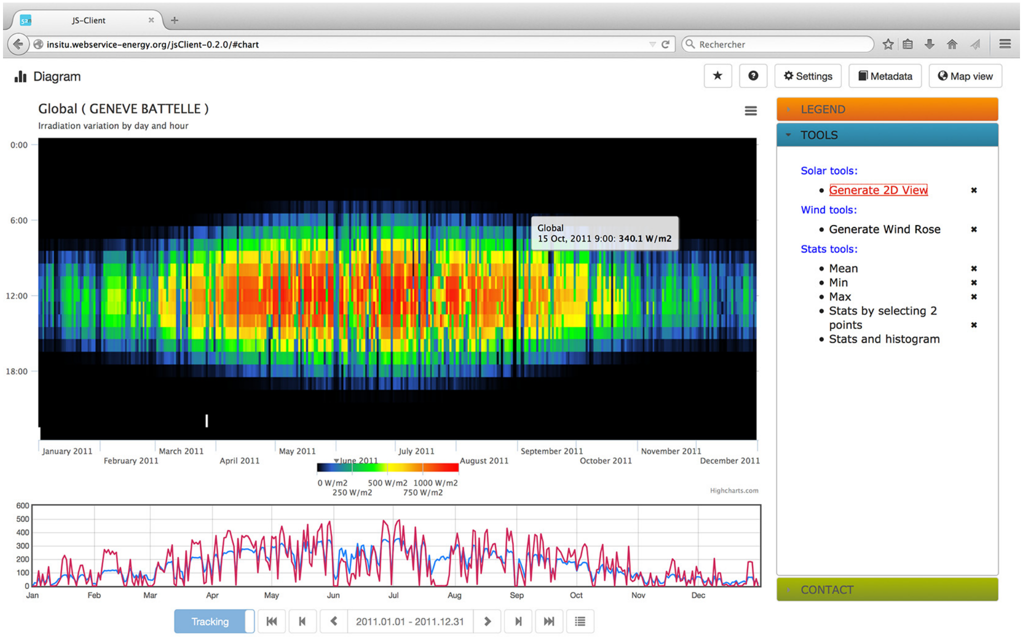

Fig. 2. Screenshot of additional features integrated into the web-based GUI

The newly created Sensor Web infrastructure will be integrated as a new component into the existing SDI known as the “Webservice-Energy.org GEOSS Community Portal dedicated to Energy and Environment”. This SDI developed and managed by MINES ParisTech since 2011 currently comprises a community portal, a catalog, and several client applications, data-models, maps and coverage data. It does not comprise *in-situ* observations yet. The catalog is CSW-compliant and may accommodate for *in-situ* measurements. It is connected to the GEOSS Common Infrastructure (GCI)[†] and is weekly harvested by the GEOSS DAB (Discovery and Access Broker). This allows all existing resources listed in the catalog to be available on the GEO Web Portal (GWP) for search and discovery rewarding efforts of data providers in their outreach and dissemination activities of their legacy data assets.

† *http://www.earthobservations.org/geoss.php*

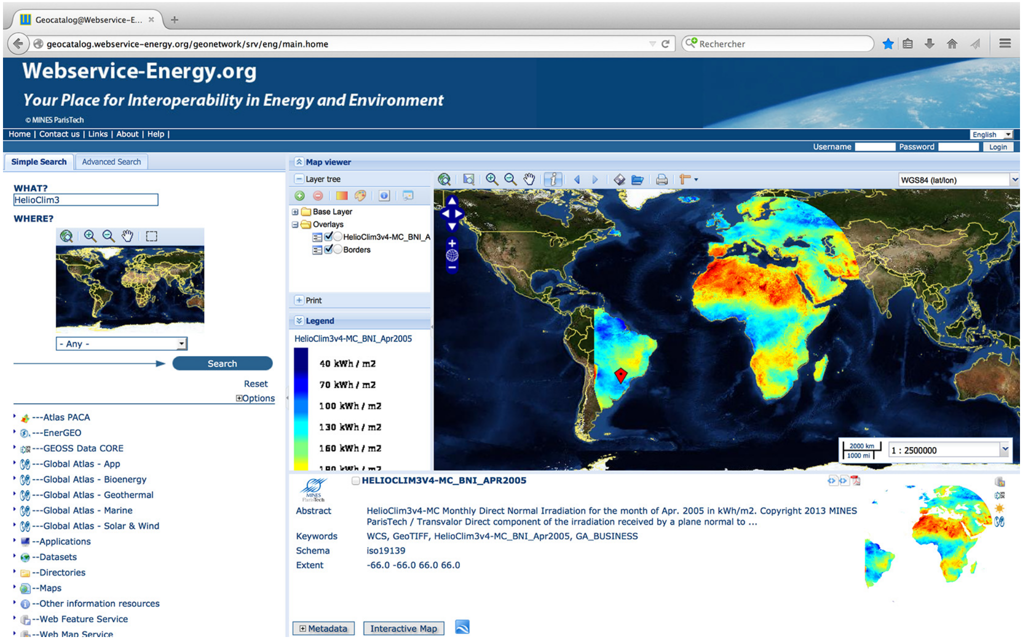

Fig. 3. Screenshot of the webservice-energy catalog

4. Perspectives and assessment by the community of users

A pilot use case will be set up to demonstrate business opportunities in solar energy. Several *in-situ* data sets will be made available through the Sensor Web platform. They will originate from different providers that have agreed to participate to this challenge, namely, MINES ParisTech and Ecole Nationale des Travaux Publics de l'Etat, both from France, as well as the universities of Geneva (Switzerland) and Kishinev (Moldova). Discussions are pending with other providers worldwide, including companies. Once *in-situ* measurements are available, several users, mostly from companies, will be invited to use the platform and to provide their feedbacks on the benefit of this platform and on the networking of resources for improving their daily work and increasing their business. Two specific use cases will be implemented with different scopes: 1) improving the quality of bankable data sets, and 2) improving the design of plants and targeting geographical areas for such plants.

Expected outcomes from the pilot use cases will tackle:

- gaps in data models: Designing standardized data and metadata models to better suit *in-situ* observations of SSI as profiles of OGC Sensor Web Enablement standards;
- gaps in *in-situ* measurements of SSI: Extending the webservice-energy catalog platform with data management functions based on the new (meta)data profiles and the GEOSS recommendations for interoperability based on 52°North Sensor Web platform;
- gaps in collaboration: Presenting the new platform to the community of users at a workshop will help in defining the remaining blockages and next steps to reach our final goal.

The new platform has been selected in GEOSS as a contribution of the energy SBA (Societal Benefit Area) to the AIP-8 (Architecture Implementation Pilot – Phase 8). The AIP-8 results will be presented on November 2015 in Mexico at the GEO-XII Plenary & Mexico City Ministerial Summit. Beside the expected feature on the client side as listed above connections based on GEOSS recommendations on interoperability will be tested between the new platform and more precisely between the metadata description of sensor based resources in this new platform and the GEOSS DAB through a harvesting mechanism. This will extend the existing GEOSS webservice-energy SDI to provide the GEO Energy community with access to *in-situ* measurements of SSI.

Acknowledgements

The research leading to these results has received funding from the European Union's Horizon 2020 Programme (H2020/2014-2020) under grant agreement no. 641538 (ConnectinGEO project).

References

[1] Cros S., Mayer D., Wald L. The availability of Irradiation Data. Report IEA-PVPS T2-04: 2004, International Energy Agency, Vienna, Austria, 2004, 29 p.
[2] Gschwind B., Ménard L., Albuisson M., Wald L. Converting a successful research project into a sustainable service: the case of the SoDa Web service. Environmental Modelling and Software 2006, 21:1555-1561.
[3] GCOS Essential Climate Variables, defined in 2010, available at: www.wmo.int/pages/prog/gcos/index.php?name=EssentialClimateVariables
[4] WMO: Guide to meteorological instruments and methods of observation, World Meteorological Organization, WMO-No 8, 7th Edn., Geneva, Switzerland, 2008.
[5] Vuilleumier L., Hauser M., Félix C., Vignola F., Blanc P., Kazantzidis A., Calpini B. Accuracy of ground surface broadband shortwave radiation monitoring. Journal of Geophysical Research: Atmospheres 2014, 119:13,838–13,860.
[6] Blanc P., Gschwind B., Lefèvre M., Wald L. The HelioClim project: Surface solar irradiance data for climate applications. Remote Sensing 2011, 3:343-361.
[7] Lefevre M., Blanc P., Espinar B., Gschwind B., Ménard L., Ranchin T., Wald L., Saboret L., Thomas C., Wey E. The HelioClim-1 database of daily solar radiation at Earth surface: an example of the benefits of GEOSS Data-CORE. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 2014, 7:1745-1753.
[8] Users' guide to the MACC-RAD Services on solar energy radiation resources, May 2015, available at http://www.gmes-atmosphere.eu/documents/macciii/deliverables/MACCIII_RAD_DEL_D57.5_final.pdf
[9] Qu Z., Oumbe A., Blanc P., Lefevre M., Wald L., Schroedter-Homscheidt M., Gesell G. Assessment of surface solar irradiance by the Heliosat-4 method with cloud product APOLLO derived from SEVIRI images as inputs. In Proceedings of the 2012 EUMETSAT Meteorological Satellite Conference, 3-7 September 2012, Sopot, Poland, EUMETSAT P. 61, s2-03, 2012.
[10] Mueller R.W., Matsoukas C., Gratzki A., Behr H.D., Hollmann, R. The CM SAF operational scheme for the satellite based retrieval of solar surface irradiance - A LUT based eigenvector hybrid approach. Remote Sensing of Environment 2009, 13:1012-1024.
[11] ECMWF, 2015. IFS documentation. https://software.ecmwf.int/wiki/display/IFS/Official+IFS+Documentation (last access: may 2015)
[12] Boilley A., Wald L. Comparison between meteorological re-analyses from ERA-Interim and MERRA and measurements of daily solar irradiation at surface. Renewable Energy 2015, 75:135-143.
[13] Sengupta M., Habte A., Kurtz S., Dobos A., Wilbert S., Lorenz E., Stoffel T., Renné D., Myers D., Wilcox S., Blanc P., Perez R. Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications. Technical Report 2015, NREL/TP-5D00-63112, 251 pages.
[14] Bröring, A., Echterhoff J., Jirka S., Simonis I., Everding T., Stasch C., Liang C., Lemmens R. New generation Sensor Web Enablement. Sensors 2011, 11:2652-2699. doi:10.3390/s110302652.
[15] Maso J., Serral I., Menard L., Wald L., Nativi S., Plag H.-P., Jules-Plag S., Nüst D., Jirka S., Pearlman J., De Maziere M. Towards the creation of a European Network of Earth Observation Networks within GEO. The ConnectinGEO project. European Geosciences Union General Assembly 2015, Vienna, Austria, 12-17 April 2015, EGU2015-13792.
[16] Blanc P., Gschwind B., Lefevre M., Wald L. Validating Meteosat-derived surface solar irradiance in Mozambique. In Proceedings of the 30th Symposium of the European Association of Remote Sensing Laboratories, Ed. Halounova L., held in Prague, Czech Republic, 30 May – 2 June 2011, A. A. Balkema Publisher, 2011.
[17] Wald L., Providing energy components for GMES and GEO. 9th GEO Plenary - European Commission Side Event, 21-23 November 2012, Foz do Iguaçu, Brazil.
[18] Menard L., Nüst D., Jirka S., Maso J., Ranchin T., Wald L. Open surface solar irradiance observations - A challenge. European Geosciences Union General Assembly 2015, Vienna, Austria, 12-17 April 2015, EGU2015-6607.
[19] Roesch A., Wild M., Ohmura A., Dutton E. G., Long C. N., Zhang T. Assessment of BSRN radiation records for the computation of monthly means. Atmospheric Measurement Techniques 2011, 4:339–354. doi:10.5194/amt-4-339-2011.
[20] Espinar B., Blanc P., Wald L., Hoyer-Klick C., Schroedter-Homscheidt M., Wanderer T. On quality control procedures for solar radiation and meteorological measures, from subhourly to monthly average time periods. Geophysical Research Abstracts, Vol. 14, EGU General Assembly 2012, 22-27 April 2012, Vienna, Austria.