SIXTH FRAMEWORK PROGRAMME

MESOR

Management and Exploitation of Solar Resource Knowledge

CA – Contract No. 038665

D 1.3.3 Recommendations on an Improved Earth Observation System to better support solar energy

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1 Introduction

1.1 Methodology

Results from the **user surveys of MESOR** WP 4 (D4.1 and D4.2) on requirements from various stakeholders are taken as the base for the work towards defining needs for future Earth Observation systems. All MESoR partners provided their views on requested services and gaps currently existing. Additionally, the **report on 'New Solar Radiation Services'** (D1.3.2) prioritizes new services needed and the **report on 'Future research objectives and priorities in the field of solar resources'** (D1.3.1) are the basis of this report which **summarizes all findings relevant for GEOSS in a single document**.

A review by external experts further adds to this report. All participants of the International Energy Agency, Task 36 Solar Resource Knowledge Management and the GEOSS Energy Community of Practice Solar Energy Working Group were invited to review the document.

The following criteria are looked for

- New sensors/satellites and requirements/specifications
- Improved usage of existing sensors/satellite capabilities
- Temporal/spatial/spectral resolution of EO sensors
- Easier access to worldwide data
- Easier access to European resources
- Software tools to be provided with data (reading modules, data extraction, averaging routines), online/offline tools
- Standard processing to be provided by satellite data providers

Emphasis is laid on capabilities available for European industries.

Please note that this report does not focus on the technology required to provide an Earth Observation system. Therefore, system requirements and system processing parameters are not provided. Also, a detailed user requirement definition is outside the scope of this document.

A first effort was taken to harmonize terminology on timescales of data availability. Based on different traditions in the energy and the meteorological community the following compromise is used:

- Historic long-term data: > 5 years duration of timeseries
- Near real time data: last 24 hours up to the upcoming 3 hours
- Nowcasting: Now and up to 3 hours from now
- Forcasting: Up to 2 days from now
- Seasonal forecasting: several months from now

Additionally, some definitions on physical radiation quantities are given (Tab.1).

Table 1: Parameter definitions

Parameter name		Unit	Explanation
aerosol optical depth	δ_{ae}	unit less	Aerosol optical depth integrated over the whole solar spectrum
atmospheric absorption	α	unit less or %	Atmospheric absorption, may be specified as below.
atmospheric transmission	τ	unit less or %	Atmospheric transmittance, may be specified by indices for atmospheric constituents, e.g. *ae* for aerosol, *cl* for clouds or *O3* for ozone. If not further indicated this refers to the perpendicular path of radiation through the atmosphere, otherwise *sl* indicates the slant optical depth.
clearness index	k^*	unit less	Ratio of the irradiance (irradiation) at ground level to the extraterrestrial irradiance (irradiation) for a given instant
cloud index	n	unit less	A quantity used in the Heliosat-1 and -2 family of algorithms. Denotes the total attenuation of the radiation by the atmosphere
cloud optical depth	δ_{cl}	unit less	Cloud optical depth integrated over the whole solar spectrum
diffuse irradiance	E_{dif}	W m^{-2}	Irradiance reaching the ground after being scattered by the atmosphere and received on an horizontal surface
diffuse irradiation	H_{dif}	J m^{-2} or kWh m^{-2}	Irradiation reaching the ground after being scattered by the atmosphere and received on an horizontal surface
direct irradiance direct normal irradiance (or beam Irradiance)	E_D E_{DN}	W m^{-2}	Irradiance received directly from the solar disk on an horizontal surface Same as direct irradiance but for a surface normal to the sun beam
direct irradiation direct normal irradiation (or beam irradiation)	H_D H_{DN}	J m^{-2} or kWh m^{-2}	Irradiation received directly from the solar disk on an horizontal surface Same as direct irradiation but for a surface normal to the sun beam
extraterrestrial irradiance	E_0	W m^{-2}	Extraterrestrial Irradiance at top of Earth' atmosphere. Often called solar constant, which actually is relatively constant with an annual average of 1366 W m^{-2} +/-0.1% for the period 1979 to 1997 (Fröhlich and Lean, 1998).
global irradiance	E_g	W m^{-2}	Sum of direct and diffuse irradiances
global irradiation	H_g	J m^{-2} or kWh m^{-2}	Sum of direct and diffuse irradiations
illuminance		Lux	Irradiance integrated over wavelength from approx. 0.3 to 0.7 μm following a spectral gauge describing the human eye sensitivity
irradiance	E	W m^{-2}	Radiant flux of any origin incident onto an area element and integrated over the whole solar spectrum wavelength range from 0.3 to 3 μm (International Lighting Vocabulary, CIE-no 45-05-160, 1970). The irradiance is a power. It is usually calculated from a temporal integration. Dividing by the time gives the average irradiance over this period. Consequently, one should formally say mean irradiance over an hour (hourly mean irradiance) etc. Note that the mean daily irradiance is calculated with days of 24 hours, whatever the daytime length.
irradiation	H	J m^{-2} or kWh m^{-2}	Irradiance integrated over a certain period of time. For example, quarter-hourly irradiation is the integration of the irradiance over 15 minutes. Daily irradiation, also called daily sum of irradiation, is the energy received during a day (24 hours). Monthly irradiation values refer to the actual sum of all days in the indicated month. Due to variable length of months these values are harder to compare against each other than monthly averaged irradiances.
irradiance (irradiation) on slopes	E_{sl} (H_{sl})	W m^{-2} (J m^{-2})	Irradiance (irradiation) received on an inclined surface
radiance	L	W m^{-2} sr^{-1}	Irradiance from a certain solid angle onto an area element and integrated over the whole solar spectrum wavelength range (International Lighting Vocabulary, CIE-no 45-05-150, 1970)
radiation			General term denoting either irradiance or irradiation or any quantity relating to radiation depending upon the context.
reflectance	ρ	unit less or %	Reflectance of surfaces, e.g. indicated by indices *cl* for clouds, *gr* for ground (= albedo when integrated over all viewing angles)
spectral irradiance, spectral irradiation, spectral radiance	E_λ H_λ L_λ		Denotes these quantities but integrated over a spectral window, e.g. a satellite channel or the response function of PV cell. May also denotes the spectral distribution of these quantities. If a wavelength is indicated this refers to the geometric center wavelength of a specific window.

1.2 Background

Deeper knowledge of the solar energy resource has been generated over the past years within several international projects like SWERA, several European and national projects. Large steps forward have been made for the benefit of research, renewable energy industry, policy making and the environment. Nevertheless, 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 common understanding how to exploit the developed knowledge.

The coordination action MESoR aims at removing the uncertainty and improving the management of the solar energy resource knowledge. The results of past and present large-scale initiatives in Europe, will be integrated, standardised and disseminated in a harmonised way to facilitate their effective exploitation by stakeholders. This coordination action will contribute to preparation of the future roadmap for R&D and strengthening the European position in the international field.

The project includes activities in user guidance (benchmarking of models and data sets; handbook; best practices), unification of access to information (use of advanced information technologies; offering one-stop-access to several databases), 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 dissemination (stakeholders involvement, future R&D, communication).

Further, a roadmap to the future objectives and priorities is developed, describing requirements for measuring systems, including Earth observation systems, services for effective management and deployment of solar resource knowledge and better fulfilment of the demands of the stakeholders.

1.3 Connecting to the GEOSS System

The Group on Earth Observations (GEO) promotes the coordination of Earth observations through the Global Earth Observation System of Systems (GEOSS) establishment. Among nine specific Societal Benefit Areas (SBAs) in the fields of agriculture, biodiversity, climate, disasters, ecosystems, health, water, and weather, the **Energy Societal Benefit Area** is within the focus of this report.

The Energy SBA focuses on improving management of energy resources. The GEOSS 10-Year Implementation Plan states that ‘GEOSS outcomes in the energy area will support: environmentally responsible and equitable energy management; better matching of energy supply and demand; reduction of risks to energy infrastructure; more accurate inventories of greenhouse gases and pollutants; and a better understanding of renewable energy potential.’

The Energy SBA includes coal, gas, oil, nuclear, hydropower, solar, ocean, wind, bioenergy and geothermal energy resources, while this report contributes in the field of solar energy.

MESOR is strongly connected to the **GEOSS Energy Community of Practice** (GEOSS-ECP, http://www.geoss-ecp.org/) as several MESOR consortium members are participants in the solar working group of the GEOSS-ECP.

Also, MESOR is connecting to the **International Energy Agency**, Solar Heating and Cooling Programme, Task 36 on Solar Ressource Knowledge Management. This task is also contributing to the GEOSS-ECP.

Therefore, this report can be seen as a **European contribution to GEOSS work plan item EN-07-01**.

1.4 Document Structure

Chapter 1 provides an executive summary providing an overview on all recommendations given. Chapter 2 reviews the needs for ground measurements, while chapter 3 focuses on satellite-based capabilities. Chapter 4 reports on evolution needs in the field of numerical modelling including both numerical weather prediction and chemical transport modelling. Finally, chapter 5 analyses needs in the field of information technologies dealing especially with interoperability issues for processes and data.

2 GEOSS Area 1 - Ground Measurements

The quality of the data derived from satellite images is such now that it can even point out problems with ground measurements. Satellite images have also the advantage to provide a full spatial coverage with a resolution which could never be obtained with a ground measurement network. Therefore, **nowadays, ground measurement stations should be thought as data providers for the development and the validation of methods deriving solar radiation information from satellite images**. This means that they should be of very high quality and that they should measure all the parameters produced by the satellite methods (horizontal and tilted irradiances, sky vault radiance distribution, spectrum…see below) as well as all the ancillary parameters needed by the methods (temperature, humidity, water vapour, aerosol…). The stations should be located in areas where validation data is particularly needed and/or where satellite data is showing significant variations in terms of solar radiation availability.

Irradiance validation stations should have a quality standard comparable to the BSRN (Baseline Surface Radiation Network, http://www.bsrn.awi.de/). These stations are very well maintained ensuring a high quality of the measurements which is necessary for any model development and validation. These data sets also have a very high time resolution of 1 minute which makes them very useful for simulation studies of transient electrical or solar energy system behaviour.

An accuracy of 3% for global and 5% for direct normal radiation measurement values is recommended.

Within Europe and North Africa there are only very few BSRN stations on non-elevated areas suitable for solar energy purposes (fig. 1). Especially in southern Europe and North Africa there are almost no stations (only one in Spain without data so far and one in Algeria).

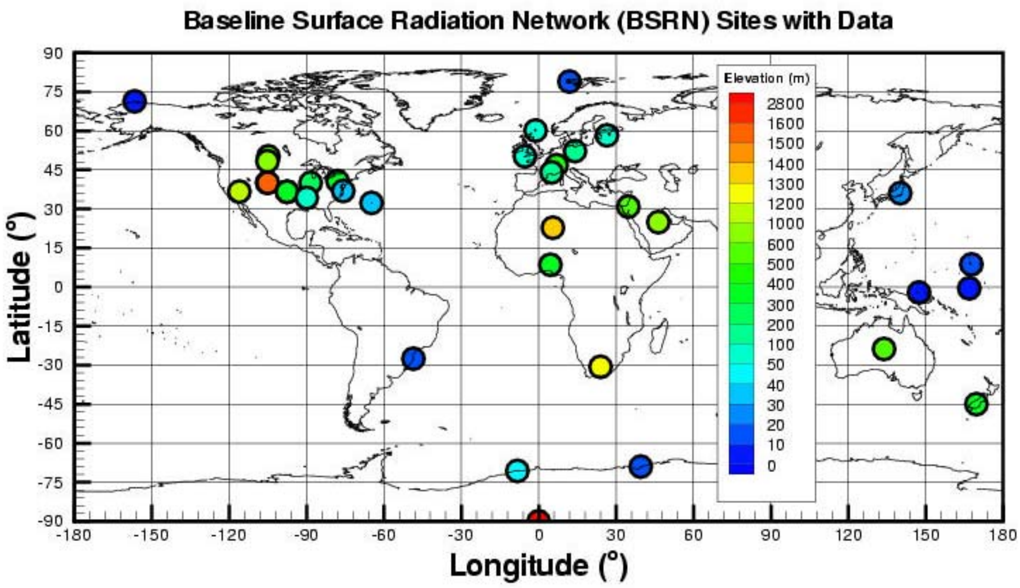

Figure 1: BSRN station network (image source NASA)

A network of **high quality solar radiation measurements (measuring all three components global, direct and diffuse separately)** would improve the quality and lower the uncertainty of solar resource assessments in a significant way. This will have a direct positive impact for the risk assessment in project financing.

A measurement network can be used to **improve resource maps** and to **benchmark project specific measurements**. For **project specific measurements general quality standards have not been defined yet** and their quality is ranging in a wide range.

For irradiance measurements at **remote project sites** meteorological equipment as **pyranometers and pyrheliometers is very expensive** and measurements are **very energy intensive.** Therefore, different approaches have been made to utilise simpler instruments based on **photovoltaic sensors**. These devices need careful calibration and corrections for temperature dependence and spectral sensitivity. There is the need to better characterise these instruments and to develop new sensors with a better known spectral response function. Calibration is currently done by parallel measurements with high quality sensors, which needs time. New lab based calibration procedures could reduce the necessary calibration time and effort.

Soiling of radiation measurements can spoil the quality of solar radiation measurements significantly. Devices which can reduce soiling (by special coating, automatic cleaning devices) can improve the quality of measurements and reduce the necessary maintenance effort.

Besides direct irradiance, high quality data of **measured global irradiance** data are an important component for projects e.g. in the photovoltaics sector. For global irradiance measurements the spatial coverage is much better (fig. 2).

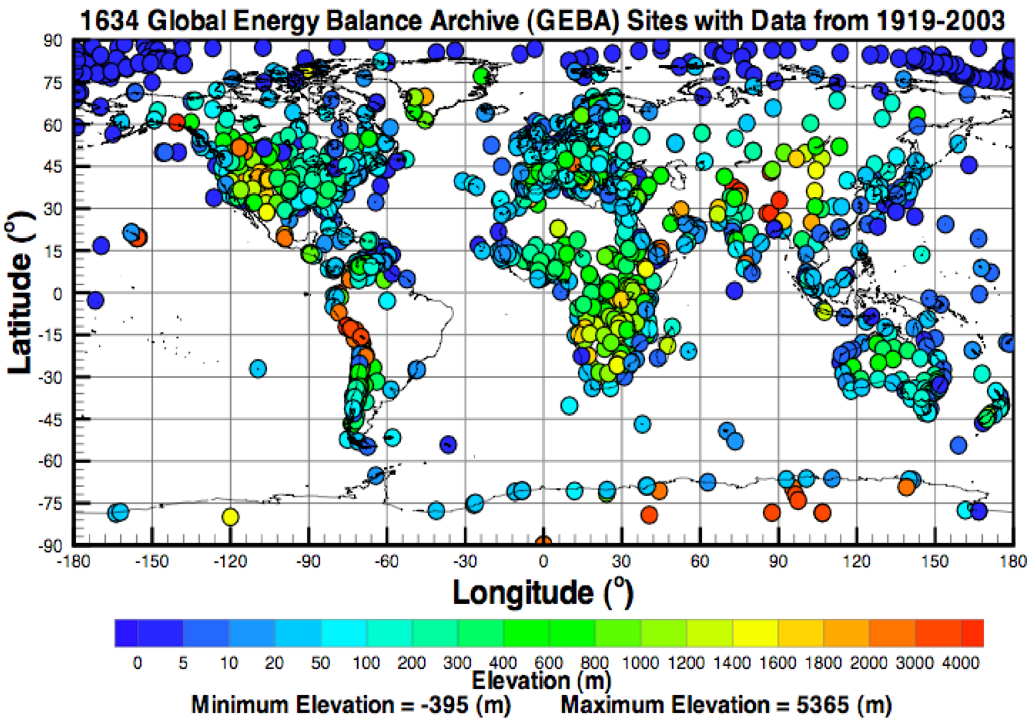

Figure 2: GEBA station network (image source NASA)

The World Radiation Data Center (WRDC) has in its archive solar radiation, radiation balance, and sunshine duration data observed at actinometry stations over 6 regions of the WMO. National weather services and other Institutions have been submitting the data to the WRDC since 1964. They are responsible for quality control of their data sets. For more than 40 years now the WRDC centrally collects, archives and distributes the data in the periodical issues of 'Solar Radiation and Radiation Balance Data - The World Network' among national weather services of those countries participating in the exchange of data under the auspices of the WMO. Recently the WRDC began distributing the issues in pdf formats. Remote users may get access to two different data sets which consist of conventional data and data of the GAW (Global Atmosphere Watch) program. The term "conventional data" means that solar data observed at the global solar radiation network over 6 regions defined by the WMO have been submitted to the WRDC archive from National weather services since 1964. The radiation data from GAW sites consists of mainly hourly values and can be easily copied to the user's computer. Conventional data can be viewed and requests to prepare subsets are to be sent to WRDC via e-mail. Nowadays, a re-engineering of the WRDC server is ongoing and a new more user-friendly interface will be set up soon. Provisional data tables in html format covering the period 1964-2007 are now opened for research and educational purposes at http://wrdc.mgo.rssi.ru.

Global Energy Balance Archive (GEBA)
An update of the GEBA runs since 2001 at the Institute for Atmospheric and Climate Science of ETH Zurich (IACETH). The update is not yet officially finished. The reasons for the increased time are the low financial means and the large effort to include different data sources (mainly national weather services) in all different formats and the slow access to WRDC data.

The version of 1995 (GEBA Report 3) did have about 176'000 monthly means of global radiation, now there are more than 288'000 values. For China, Japan und Australia there are much more data available than in the earlier version.

The time series end during the year 2005, but not all time series have been officially released as some quality checks have not yet been done. GEBA is not yet officially opened. For team members of IEA SHC Task 36 (as other scientific users) data can be used. The person in charge is Dr. Martin Wild (martin.wild@env.ethz.ch), the prototype homepage is: http://proto-geba.ethz.ch/. For commercial applications GEBA data can be accessed via Meteonorm (www.meteonorm.com).

Recommendation:
GEBA contains very valuable data for solar energy use. The new user interface allows to access data quickly. It consists mainly of data of WRDC St. Petersburg (but not only), which is based on measurements of national weather services. GEBA data undergo additional quality checks, so quality is somewhat higher than WRDC data. Nevertheless not all data are without errors. So users have to be aware of the need to check the data.

Also, near-real-time access to irradiance measurements is an urgent need.

2.1 Global Irradiance

With regard to the relatively high density of weather stations in Europe measuring a whole range of meteorological data, the parameter **global irradiance does often not belong to the measured standard parameter**. Thus, there is a lack of ground-based measurements in huge areas all over Europe.

To have an area-wide access to measured data, it is indispensable **to increase the number of weather stations equipped with pyranometers** measuring the global irradiance directly.

2.2 Direct Normal and Diffuse Irradiance

BSRN stations measure typically with a high quality, but they are **mostly not representative for the solar radiation conditions over larger areas**.

Concerning measured data of direct normal and diffuse irradiance the problem of too little density of weather stations all over Europe is very similar to the measured data of global irradiance mentioned above. However, the **availability of measured data of direct normal and diffuse irradiance is often dramatically smaller than data of global irradiance**. Only a few stations exist per country as maximum.

Besides, the **available measured data are often in regions (e.g. mountains) which are barely representative** for large areas. Thus, they **can not be used for all solar energy applications** and have to be excluded.

2.3 Spectral Measurements

The use of radiative transfer models in the satellite image processing chain will allow soon producing spectral irradiances. This will open the use of satellite based products to a much **wider variety of applications** for which each part of the solar spectrum has a specific influence as e.g. **lighting, agriculture, or health**. These methods will need to be **validated using high quality spectral measurements from ground**. A **network of stations** measuring the solar radiation spectrum over Europe can not be setup without help from the European commission or other funding bodies.

2.4 Illuminance Measurements

Until the end of the 1980s, very few ground stations had been measuring daylight (the visible spectrum of solar radiation corrected by the spectral sensitivity of our eye). The lack of knowledge on the outdoor daylight climate was really impeding the evaluation of the energy savings brought by a better use of daylight inside buildings. In 1991, the International Commission on Illumination (CIE) started, the **International Daylight Measurement Programme (IDMP)**. In **2001**, the IDMP was gathering about **50 stations in the world, half of them in Europe.** Most stations measured every minute, global and diffuse horizontal illuminances, global vertical illuminances in four directions (N, E, S and W), global and diffuse horizontal irradiances as well as “classic” parameters such as temperature, humidity and wind speed and direction. The initial and the operational cost of an IDMP station were quite high, so most stations were setup by lighting research laboratories at their location. This means that many areas of the world could only be covered with one station. With the years, the number of stations in operation decreased due to lack of funds or scientists leave. **In 2008, there were less than 10 IDMP stations in operation in Europe.**

The **data from the IDMP has not been gathered in a central place**. The network was set up before the Internet and there was a general agreement that the measurements would first be used by the researcher running the station before being released to other researchers. Since 2000, very few stations have made available their data directly though the Internet. This means that to obtain up to date IDMP measurements, you still have to send a request to each station.

A good knowledge of **sky luminance distributions is essential to daylighting**. Since, they have rarely been measured, even within the IDMP, sky luminances and radiances should be part of high quality ground measurement stations. So far, the **sky scanners** used for these measurements have often been developed by technical universities for local measurements only and eventually sold on a very small scale. As a result, these **instruments are quite diverse in terms of number and type of sensors** (aperture angle, spectral sensitivity), some use one rotating sensor, and others use a given number of fixed sensors. This makes the measurements from these sky scanners hard to compare. Recent studies have shown that properly calibrated imaging devices based on CMOS sensors could provide luminance distributions with a much finer resolution and accuracy not too far from the sky scanners. **There should be a European or International effort to develop a standard procedure based on this technology.**

2.5 User-Specific Irradiance Measurements

One of the most significant fields is the calculation of forecasted data of global irradiance based on actual measured data e.g. in model output statistics. Forecast data are an indispensable input for all operators of the transmission grid and power traders to calculate e.g. **load forecasts**. It is evident that the weather service provider, who sells this kind of forecast data to the mentioned clients, tries to adapt the data format and the time pattern to the demands of the customer. Operators of the transmission grid and power traders are mostly interested in **solar data with high temporal resolution, 15- or 10-minutes interval at the best**. The measurement of global irradiance of many **WMO weather stations all over Europe does still take place every hour or at least one time per day**; hence, the switch from former frequency of measuring to 15- or 10-minutes interval has to be aspired in future for all available weather stations. To fulfil the requirements nowadays, the weather service provider has to interpolate the 15-minutes values based on hourly measured data.

Additionally, such **measurements need to be provided in near-real-time** to be useful for these applications.

For most users acting in business areas like **energy management, building control systems as well as local energy providers** the **high spatial resolution of measured data is a very important thing**. Not only the immediate vicinity between the site of interest and the local measuring point play an important role; also the interplay of all measured meteorological parameters at the same location can not be disregarded, in case of customers applying not only solar data, but additional parameters like temperature or relative humidity.

Besides, the wide variety of users belonging to the solar sector should not be ignored, needing measured data of global and direct irradiances for adjustment and operating control for all solar plants. The main use thereby is to have a **second independent data base** in addition to satellite data for the purpose of comparison.

3 GEOSS Area 2 - Satellite-Based Measurements

3.1 Visible Imagery

The modelling of the performance of an ensemble of solar energy systems that are connected to the same electrical supply grid requires information on the irradiance field beyond the single point characteristics.

Requests from companies are for one or more services supplying **total irradiance as well as direct and diffuse components on a horizontal or inclined surface**.

Temporal and spatial resolution of irradiance databases on visible imagery has been fairly good, though a finer resolution in hourly values on a 1 km² grid is recommended.

Long-term time-series of irradiance data are required to perform sizing of systems, for risk analysis, and for modelling the return of investment over the typical project lifetime of at least 20 years. At least one service must be deployed to offer access to such data. **The depth of the archive shall be at least ten years.** For inter-comparison to on-site measured data the archived data shall be as recent as possible. The requested coverage is mainly for land areas, I.e., most of the emerged lands, though the idea of exploiting solar energy in the ocean areas is emerging.

In the meanwhile the geostationary satellite capabilities provide the 1 km spatial resolution on a global scale (tab. 1) and therefore, satellite-based irradiance databases need to be extended accordingly.
Generally, **data availability in non-European regions is low for European users**. Efforts to make non-European irradiance data available in comparable quality are recommended.

A **faster access to long-term radiation archives with an automatic interface** is required together with an **extended documentation how archived irradiance data** have been processed and which auxiliary data sets have been used. Additionally, a detailed description on any statistical post-processing as e.g. horizontal interpolation through kriging techniques or inclusion of a digital elevation model has to be provided.

A link to the efforts within the **GEOSS Architecture and Data** activities (Task DA-06-04) is seen. SoDa as a web-based set of services dedicated to solar energy (http://www.soda-is.com) is taking part in a GEOSS demonstration project offering solar information worldwide based on interoperation of SoDa and NASA databases. It will serve also as a test-bed for the Energy Community of Practice for testing interoperability, architecture and data standard requirements from ADC and UIC.

Nowcasting of solar irradiances in high temporal and spatial resolution is required, as a sudden decent of irradiances can cause transients in the solar field which are challenging to control. At the moment, the appropriate control depends predominantly on the experience of the plant operator. If nowcasting of these descents was possible, control strategies could make use of that. The problem is, however, that the **time frame is in the range of a few minutes and the spatial resolution in the range of less than one kilometre**. **This resolution is too small for satellite nowcasting (at the moment), but it might be possible to develop models for predicting these "high resolution disturbances", when information of both satellite nowcasting and measurements on and near the site are combined.**

Table 2: Geostationary satellite capabilities for irradiance measurements

Satellite	Meteosat Prime (Europe)	Meteosat East (IODC, provided by Europe)	*Kalpana 1 (India) Encrypted to Indian use only*	*INSAT 3A (India) Encrypted to Indian use only*	FY-2 (China)	MTSAT-1R (Japan)	GOES West (USA)	GOES East (USA)
Channels [µm]	11 channels HRV 0.5-0.9	VIS 0.45 to 1.0 WV 5.7 to 7.1 IR 10.5to 12.5	*VIS 0.55-0.75 WV 5.7-7.1 IR 10.5-12.5*	*VIS 0.55-0.75 WV 5.7-7.1 IR 10.5-12.5*	VIS 0.55-1.05 WV 6.2-7.6 IR 10.5-12.5	VIS 0.55-0.90 +IR 6.5-7.0 3.5-4.0 10.3-11.3 11.5-12.5	VIS 0.55-0.75 +IR 3.80-4.00 6.50-7.00 10.2-11.2 11.5- 12.5	VIS 0.55-0.75 +IR 3.80-4.00 6.50-7.00 10.2-11.2 11.5- 12.5
Central longitude	0° E	57° E	*74°E*	*93.5°E*	105°E	140°E	135° W (225 ° E)	75° W (285 ° E)
Nadir resolution	1 km HRV, 3 km VIS/IR	2.5 km	*2 km VIS 8 km IR + WV 1 km VIS*	*2 km VIS 8 km IR + WV 1 km VIS*	1.25 km VIS 5 km WV/IR	1 km VIS and 4 km IR	1 km (VIS) 4 km (3.9;11;12) 8 km (6.8)	1 km (VIS) 4 km (3.9;11;12) 8 km (6.8)
Temporal resolution	15 minutes 5 minutes rapid scan over Europe/ North Africa	30 minutes	*30 minutes full disk*	*30 minutes Northern hemisphere 60 minutes full disk*	30 minutes	30 minutes Northern hemisphere Full disk hourly	30 minutes North and South hemisphere Pacific/US every 15 min Rapid scan US conus, 7-8 min Super rapid scan 4-5 min in some hurricane regions Full disk only every 3 hours	30 minutes North and South America, continental US every 15 min Rapid scan US conus, 7-8 min Super rapid scan 4-5 min in some hurricane regions Full disk only every 3 hours
Cloud index possible/ Tracking	yes	Yes	*yes*	*yes*	Yes	yes	yes	yes
Cloud physical parameters possible	yes	No	*no*	*no*	No	no	no	no

For all nowcasting approaches a **fast delivery for cloud physical parameters and aerosol retrieval products from geostationary and polar orbiting satellites via e.g. the EUMETCast scheme** is required in **very near real time** (below 30 minutes) and with the **full pixel and temporal resolution**.

It is **recommended to compare existing now-casting based on different principles based on satellite and ground measurements**. These are based on the improvement of models for solar radiation predictions by aerosol forecasting, ensemble forecasting, best member selection in a probabilistic approach, and through the assimilation by satellite data.

A comprehensive forecasting scheme using the best practice for each time frame (now, upcoming hour, next 3 hours, intra-day up to 24h, day-ahead up to 48 h) is needed for plant monitoring and operations, grid integration

and market participation in liberalized electricity markets. For all these forecast horizons the identification of most-promising models is needed.

Daylighting a building is a complex task which requires defining (1) the size and the position of the windows which will provide the best distribution of daylight in the space, (2) the shades and their control which will protect users against glare and overheat and (3) the controls which for energy savings will adjust the power of the artificial lighting system according to the amount of daylight available. Since, the luminance distribution of the sky vault is difficult to measure; models have been developed to produce this information from more widely measured parameters such as the global and diffuse horizontal irradiances and illuminances. Today, satellite images could describe the luminance distribution of the sky vault with only four values (4 zones) which is far from sufficient and not enough to improve the performance of the existing models. **However, it is expected that a better knowledge of the atmospheric state (aerosol content, water vapour, cloud opacity) combined with increased spatial (< 1 km) and temporal (< 5 min) resolutions should allow the processing of satellite images to produce non homogeneous sky luminance distributions much closer to reality than the existing models. Therefore, a rapid scanning mode for satellite imagery as provided e.g. by EUMETSAT is highly recommended.**

For a potential power plant site ground measurements are typically available only for one or two years. On the other hand, both economic assessments and technical design of the plant requires long-term data information. Therefore, satellite time series lasting e.g. 10 years long are used. Ground measurements are assumed to be more accurate than satellite measurements assuming that they are cleaned daily and are well maintained. Therefore, the comparison of a 1 year ground data set versus the overlapping year of satellite measurements can reveal systematic deviations typical for this certain location. **Methods for a systematic assessment of differences in statistical mean and distribution parameters between ground measurements, model results and long term time series have to be developed** or to be transferred from other fields of science to this application. The overall aim is to establish methods for long-term adjustment of local data sets.

For all solar applications, the inter-annual variations are needed to explain by how much the annual production of the solar system could vary from the results presented in the design phase. The **inter-annual variability** with its temporal-spatial characteristics have to be assessed first using long-term satellite data bases over larger spatial areas (e.g. NASA SSE or DLR SOLEMI databases) or meteorological long-term reanalysis data sets. Therefore, systematic deviations between long-term data sets have to be assessed. Dependencies on NAO/ENSO structures or the long-term influence of volcanic eruptions on direct solar irradiance should be assessed. Up to now there are only very few results available on long-term affects due to climate change. It is recommended to seek collaboration with the climate modelling science community to develop, assess, and disseminate model results.

Downscaling approaches for regional-level energy assessment activities responding to climate change impacts have to be developed. This includes e.g. supply and load forecasting, renewable energy resource assessments, urban heat island impacts, and population growth.

Scenarios of global climate models should be analysed for their sensitivity to describe possible changes of the available solar resource due to global change and subsequent changes in regional cloud patterns or atmospheric aerosol load.

3.2 Atmospheric Input Parameters

To derive the surface irradiance, **the cloud index is combined with a clear sky model describing the irradiance for clear sky conditions in dependence on the atmospheric parameters**. Most cloud-index methods consider atmospheric input parameters (Linke turbidity or alternatively aerosol optical depth, water vapour and ozone) in form of **climatological values**. There exist several data sets of atmospheric parameters that considerably differ from each other. The choice of the atmospheric input data has a strong influence on the irradiance calculation, especially when considering direct normal irradiance.

Therefore, larger research effort to provide more accurate and better time-space resolved aerosol optical depth information is recommended. This includes especially improvements in emission databases, modelling of aerosols and data assimilation of satellite or ground based observations into models. **This effort has to be defined by solar energy users to ensure suitable research covering not only the currently dominating climate and air quality communities and their information needs, but also the solar energy community needs.** Distinguishing requirements are mainly found in the temporal and spatial resolution and in the request for deriving spectrally resolved aerosol optical depth. An accurate modelling of dust outbreak situations is of major importance for the solar energy community using concentrating technologies, while the air quality community concentrates their research efforts on smaller particles which cause negative health effects.

Besides the use of cloud index algorithms, several algorithms start to include **radiative transfer modelling**. Oumbe et al. (2008) performed an inventory of the variables (e.g., clouds) and their attributes (e.g., optical depth) available in an operational mode and assessed to which degree the uncertainty on an attribute of a variable –including the absence of value– leads to a variation on the SSI. They found a number of significant inputs:

- solar zenith angle and number of the day in the year,
- cloud optical depth,
- cloud type,
- water vapor amount,
- aerosol optical depth and its spectral variation,
- aerosol type,
- ground albedo and its spectral variation,
- atmospheric profile,
- ground altitude.

Oumbe et al. (2008) underline that these influence parameters are **currently available on different spatial resolutions and temporal frequencies**. For example, water vapour may be estimated every 50 km once a day, while cloud properties may be assessed every 3 km and 15 min using Meteosat data. This heterogeneity in inputs has a strong impact on the design and realisation of an operational system for providing direct and diffuse components and spectral distribution of irradiances.

For further detailed analysis **long-term data bases** like the European Cloud Climatology, derived from NOAA AVHRR data in a 1 km resolution at DLR, the measurements of the NASA MODIS instrument or the MSG-SEVIRI based cloud physical parameter datasets available at DLR or EUMETSAT **should be made easily accessible to solar project developers**.

Besides irradiances, atmospheric parameters like air temperature and wind speed is needed by solar energy users. **Therefore, it is recommended to proceed with the existing efforts (as e.g. in the Meteonorm database) to provide air temperature together with all irradiance databases and to solve data policy issues accordingly.**

In both cloud index and radiative transfer methodologies, the **integration of an advanced model for aerosol content** will increase the accuracy especially in clear sky situations with high irradiance. For this purpose special adaptations to meso-scale or global chemical transport models are available as well as an integration of aerosol forecasts in the ECMWF model.

3.3 Land Surface Input Parameters

3.3.1 Land Cover and Albedo

Ground reflectance impacts the irradiance because of its influence in the multiple reflections between the ground and the atmosphere and the clouds layer. These reflections contribute to the diffuse component of the irradiance. If the surface is not horizontal, it also influences the reflected component of the irradiance that impinges on the surface.

Solar irradiance retrieval and forecasting using radiative transfer models need a monitoring of surface albedo. Recent approaches (e.g. Breitkreuz, 2009) used satellite-based MODIS 10 day composites of surface albedo. **Satellite-based albedo data sets should be made available within the one-stop shop philosophy to the solar energy community.**

The scientific challenge is here due to the **temporal and spatial changes of the ground reflectance**. This reflectance depends upon the land cover which may change dramatically within short distance, e.g., between the sea and the beach, as well within hours, e.g., snow fall on a dark surface. Work should be encouraged for the mapping on a daily basis of the ground reflectance over the world at say, 1-km scale.

3.3.2 Snow Monitoring

Despite the good performance of cloud index methods for deriving irradiances in general, there are certain situations, like the presence of snow cover, where large deviations between grounds measured and satellite derived irradiances may occur, and further research is required. In addition, the use of additional information, e.g. on cloud height or detailed topographic features, can further improve the accuracy of cloud index methods. **It is recommended to implement these satellite-based snow cover data sets in existing PV plant monitoring schemes. Further validation of satellite-based snow products extended to larger spatial areas and temporal periods is needed.**

Snow depth information would be helpful to estimate mechanical loads on photovoltaic systems in the planning phase. Up to now long-term data sets as e.g. monthly climatologies or extreme value statistics are not available in the solar energy community.

3.3.3 Digital Elevation Models

Digital elevation models are required in order to take decreased Rayleigh scattering and aerosol load with increased elevation into account. Also, the separation of direct and diffuse radiation (if only global radiation values are available as e.g. in numerical weather prediction models) depends of the surface elevation. **State-of-the-art digital elevation datasets should be made available with easy access (one-shop philosophy) to the solar energy community.**

4 GEOSS Area 3 – Numerical Modelling Capabilities

One of the largest problems of the fluctuating renewable energy sources solar and wind power, as compared to conventionally generated electricity, is its dependence on the partially non-deterministic weather patterns. This characteristic behaviour is most relevant (a) on a short time scale from seconds to a few hours in which the control of the respective system (e.g., a wind turbine or a large building) is done and (b) on a larger time scale of typically one to three days, in which the integration of power in the electrical grid takes place.

4.1 Meteorological Information

Solar plant yield is influenced significantly not only by hardware components and the available solar radiation, but also by meteorological parameters as snow cover, temperature, wind speed, or rain depending on the solar technology used. While this qualitative relationship is known, a quantitative description is still missing.

Stakeholders feel the need to install e.g. a Data Warehouse containing meteorological parameters in order to build quantitative models. A systematic analysis of several solar systems carried out with the Data Warehouse can give an idea what the main meteorological effects are and which ones a negligible. Also, a yield prediction will be more accurate by knowing the influence of the meteorological variables. Short and long term forecasts of the behaviour of solar plants will be more precise.

Meteorological parameters as **DNI, temperature, relative humidity, wind speed and gust speed have to be provided in a time resolution of at least one hour**, since this is the resolution demanded by the market. A higher resolution of up to 10 minutes is appreciated in order to get higher model output quality of a CSP system, thus less uncertainty in the prediction forecast. For a meaningful yield prediction for a single CSP plant **a spatial resolution of less than 1 km² is needed.**

Some stakeholders express their need for atmospheric relative humidity. Relative humidity is generally provided by meteorological modelling, but it is not clear if up-to-date atmospheric modelling provides a sufficient accuracy. **A further analysis of user requirements vs. state of the art modelling accuracy of relative humidity is recommended.**

Humidity has large impact on the power output of steam turbine plants (with wet cooling tower) since it defines together with the ambient temperature the condensation pressure. Therefore information on this is one of the key input parameters for CSP-plant modelling. It should be analyzed which impact this parameter has and which accuracy is favourable.

Some stakeholders express their need for wind speed and direction. These parameters are generally provided by meteorological, but it is not clear if up-to-date atmospheric modelling provides a sufficient accuracy especially in gusty conditions. **A further analysis of user requirements vs. state of the art modelling accuracy is recommended. A nowcasting approach for wind gusts needs to be developed.**

For system analysis and development also the **data access to historical forecasts** is required.

For the Spanish market, there already is the need for **short term forecasts**. By law, solar plant operators in Spain are forced to provide forecasts of their system's power output for the day ahead. Penalties have to be paid if real power output deviates from these forecasts. However, plant operators have the possibility to provide updates of their forecasts during the day. Certainly, nowcasting has the potential to improve the results compared to forecasts that are based on numerical weather prediction models only.

The electricity market allows adjustments of former forecasts during intraday trading. For example the intraday market in Spain opens six times during the day. So, the meteorological forecasting have to be on hand before the market opens and an operation strategy can be set up by the plant operator. Thus, **the point in time when the forecast is provided has to be synchronized with the needs of the specific electricity market.** Currently, the main wholesale electricity market for CSP is the Spanish OMEL, thus it should serve as first reference market. Nevertheless, it can be seen already nowadays, that the intention of the Spanish legislation is adopted by other countries, thus it is not only a single Spanish aspect.

Despite the need to improve the representation of irradiance in numerical weather prediction models in general, **a major improvement on model forecasts concerning temporal resolution is required**. Output of global models like ECMWF is provided in 3h interval only. For yield predictions, **at least an hourly resolution is required and 10 minutes would be appreciated**. Yield prediction models have to calculate direct and diffuse radiation from the global irradiation provided from the weather model. For this calculation the solar zenith angle is needed, and using a 3 hourly mean value of the zenith angle leads to unnecessary uncertainties.

4.2 Solar Energy-Specific Meteorological Information

Short term (some hour), and day ahead forecast as well as knowledge of reliable historic data of direct normal irradiances are required for solar thermal power plants for project development (historical data) solar field control (short term forecast) and storage management or electricity trading (short-term, day-ahead forecast and two days-ahead forecast). **For solar field control a high spatial (less than 1 km²) and temporal resolution (less than one hour) is required. The forecast horizon for solar field control could be 1-2 hours. For storage management the forecast horizon should be 1-2 days with a time resolution of 1 hour. The spatial resolution should be the size of the solar field (approx. 1km²).**

Solar irradiance is - contrary to wind speed - **not available as a direct prognostic variable in numerical weather prediction** (NWP) schemes. It is diagnostically calculated and most NWP models even do not provide irradiance information as forecasting product. Improvements in its parameterisation within these models have been introduced usually regarding their impact on overall model accuracy and computing efficiency. **This results in an overall poor quality of surface solar irradiance forecasts provided by these models.**

A common way to handle these deficiencies is the introduction of **Model Output Statistics** (MOS). MOS is an entirely statistical method based on simple regressions between NWP model outputs and given meteorological variables not provided by these models. Also, gridded low-resolution NWP output can be adapted to the special local situation (Fig. 17). This method is based on regression analyses using long-term time series of NWP data and observations.

Forecasts of solar irradiance using MOS are widely used because of its simple implementation. **However, maintenance of such a system is expensive due to its need of continuous adaptation to the NWP model and its potential for improvements is limited as it adds no additional (physical) information to the NWP results.**

Deficiencies of state-of-the-art weather prediction models with respect to forecasting solar irradiance mainly arise from the **insufficient representation of smaller scale physical processes** - especially of local effects leading to a change in **cloudiness**. In addition to an inadequate physical modelling necessary information about the small-scale surface characteristics is lacking.

A **strong benefit of a NWP-integrated approach is the potential to directly include further atmospheric influences on surface solar irradiance**. The introduction of **aerosol** information into NWP models has been recently shown and may lead to superior results. Improvements are expected in regions frequently showing strong events of atmospheric contamination by dust, desert sand, and biomass burning. As these are usually regions with high irradiance, the impact on the accuracy of solar power forecasts is evident.

Any information from weather forecasts is inherently uncertain. A proper assessment of this uncertainty provides very valuable information for any forecast user when appropriate methods for the integration of this knowledge in the applications are available. Uncertainty of weather forecasts results to a large extend from errors in the estimate of the current atmospheric state. By performing a number of simulations (an ensemble) made by making small changes to the estimate of the current state used to initialise the simulation this uncertainty can be addressed. It can be expressed by **probabilistic forecasts**, which provide probability distributions of future weather quantities or events instead of deterministic (i.e. fixed) values. Statistical methods for assessing uncertainty in NWP ensembles and statistical post processing via Bayesian Model Averaging have been introduced, but not yet applied for solar irradiance forecasting.

As the day-ahead schedule can be adopted during the day in the intra-day trading, updated direct solar irradiance forecasts according to the intra-day trading timelines promise a further reduction of scheduling and therefore economic uncertainty.

It is finally recommended to provide **hourly irradiance forecast values instead of irradiance sums of several hours** as e.g. provided in the ECMWF.

4.3 Circum-Solar Irradiance Modelling

There is a need to describe the circum solar ratio (CSR) on a site-specific level. Circum solar radiation is mainly caused by thin cirrus clouds and aerosols. **Depending on typical cirrus and aerosol conditions the CSR is location-**

specific. Methods to derive climatologies or long-term time series of CSR have to be developed based on radiative transfer modelling.

4.4 Climate and Long-term Modelling

The electricity wholesale market offers besides the marketplace for day-ahead trading, i.e. the spot market, a market for derivatives, i.e. option and future markets. These markets serve as hedging against price uncertainties. With a high market penetration of solar energy in the future, solar energy will convert from a price-taker to a price-influencing technology. Then, long-term forecasts of solar energy, i.e. global irradiation for PV and direct irradiation for CSP, will become necessary for the derivative market traders. **Typical products in a derivative market have delivery periods of weeks, months, quarters and years. This means that for these periods forecasts of direct and global irradiation, respectively, will be needed.**

Furthermore, **long-term forecasts, i.e. one year forecast**, will be useful for CSP when a restricted amount of yearly fossil backup firing, like in Spain, is allowed. The operator must then set up a policy when he supposes to use the limited backup source. As methodology he will have to plan the fossil backup based on the forecast of the probabilities of the long-term DNI forecasts, since high uncertainties correlates with high probability of the need of backup usage.

5 GEOSS Area 4 - Information technologies

This chapter focuses on information technologies for **interoperability of processes and data exchanges**. In order to establish appropriate instruments and strategies for the introduction of renewable energy (RE) in the market, well-founded information on demand, resources, technologies, and applications, is essential.

The first necessary step in a cascade for the successful development of investments in RE is the analysis of the available resources. These are e.g. maps of annual solar irradiance. These results can be combined with data on available areas for the different technologies –e.g., roofs and land area for PV, land area with suitable irradiance levels for concentrating solar power– to determine the technical feasible potential of the different technologies. The level of the available resources can then be used to calculate where these technologies become economically viable, in order to determine the economic potential.

Let's take an example of a real use case for "sitting solar power plants", encountered by various solar energy stakeholders. It presents itself as the following steps:

- investors and electricity producers willing to invest in solar plants need precise and thorough information to support decision-making;
- on their behalf, consulting companies perform feasibility studies in order to decide where to sit power plants and which technology to use ensuring a profitable return on investment;
- to reach that goal, consultants need an easy and unified access to data sets. Such data sets include meteorological, geographical and environmental parameters.

This example addresses two kinds of resources:

- **the "core" layers made of meteorological data such as map of annual irradiation extracted from a database, and layers including shadows (%), terrain elevation (m) and local max slope (in degree) derived by an appropriate processing of terrain data from the SRTM database;**

- **other layers valuable for the renewable energy planner that include geographical information on hydrological features (rivers, lake, channels), gazetteer and land use, environmental data like protected area, risks and hazards.**

Several works have underlined the benefit of the exploitation of Earth observation data for the development and integration of renewable energy in energy production. Beyond the data directly relating to the SSI, there is a need for exploiting other geographical information in combination with the SSI. Interoperability as defined by the GEOSS or INSPIRE initiatives is a key element in this respect as it ease the access to information provided by multiple sources.

Work should be encouraged in developing tools for facilitating interoperability in order to enable practitioners in RE to take the most of the EO data and geographical information.

The GEOSS initiative reveals its usefulness in bringing solutions. Standards for exchange and supply of data, interoperability are a means to improve access to data as well as extensive use of Internet and geographically-distributed services that can be exploited by a collaborative information system (Gschwind et al., 2006). Images from meteorological satellites together with appropriate processing methods are a means to improve knowledge on space and time structures as they offer every hour a synoptic view of the clouds and more generally of the optical state of the atmosphere (Hammer et al., 2003; Perez et al., 2002; Rigollier et al., 2004). Finally, availability of data of various types from various sources is enabled by the GEOSS, especially interoperability capabilities, which improve the matching of service supply to actual users needs.

Interoperability is the key concept of GEOSS. The GEOSS Architecture & Data Committee (ADC) is in charge of developing and implementing this concept in several phases. The GEOSS Architecture Implementation Pilot task aims at incorporating contributed components consistent with the GEOSS Architecture. Within the current Architecture Implementation Pilot Phase 2 (AIP-2), initiatives, called Process Pilot Projects, have been issued not only to address conceptual design but to demonstrate interoperability through real and persistent use cases. Mines ParisTech and its associates: DLR (Deutsches Zentrum für Luft- und Raumfahrt), Joint Research Center – European Commission, Meteotest, NASA (Langley Research Center), Rutherford Appleton Laboratory, answered the AIP-2 call. Thereby, they express the global concern of a large community of users covering a broad spectrum: researchers, investors, producers, utilities, consulting companies, in the field of renewable energy looking mainly for solar radiation data but having also needs to access other various data sets to fulfil their objectives. The needs for Earth observation data in RE has been addressed by the Community of Practice “Energy” (GEOSS-ECP). A scenario based on the example given above has been proposed (Ménard et al., 2009). It intends to federate the RE community towards GEOSS interoperability concepts in order to provide as much as possible standard access to energy related catalogues and resources, and to demonstrate interoperability concepts and their benefits to users communities.

Within this framework, a series of services has been developed. The study demonstrates the capability of the ADC to develop interoperability arrangements that accommodates various standards. A more easy and open access to Earth observation data and services achieved and user-oriented services specific to RE are proposed that are compliant to GEOSS requirements. **This study is a first step towards the extensive use of web services and collaborative**

information systems that are technical solutions for practitioners to easily access and exploit EO data.

Access to bulk information on SSI is not enough. As mentioned several times by users in the course of the MESoR project, accuracy on information is needed. **Very often, the presentation of the SSI to the users is made by time-series of SSI for a given location, TMY and statistical parameters. A great deal of work has been paid to the assessment of the accuracy of such representations. However, the request for maps – more exactly, values on a grid, or pixel-wise values over a large area – is increasing. There is a lack of strategies and tools for assessing the quality of the representation of the spatial distribution of the SSI.**

6 References

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7 Abbreviations

AOD	*aerosol optical depth*
CI	*cloud index*
COD	*cloud optical depth*
CS	*clear sky*
CSP	*concentrating solar power*
CSR	*circum solar radiation*
CTM	*chemical transport model*
DLR	*Deutsches Zentrum für Luft- und Raumfahrt e.V.*
DNI	*direct normal irradiance*
ECMWF	*European Centre for Medium-Range Weather Forecasts*
ENSO	*El Niño / Southern Oscillation*
ESRA	*European Solar Radiation Atlas*
EUMETSAT	*European Meteorological Satellites Organisation*
IEA	*Internal Energy Agency*
INSPIRE	*Infrastructure for Spatial Information in Europe*
GEO	*Group on Earth Observations*
GEOSS	*Global Earth Observation System of Systems*
GMES	*Global Monitoring of Environment and Security*
GHI	*global horizontal irradiance*
GUI	*Graphical User Interface*
ISO	*International Organization for Standardisation*
MESoR	*Management and Exploitation of Solar Resource Knowledge*
METEONORM	*meteorological database*
METEOSAT	*meteorological satellite series*
MOS	*model output statistics*
MSG	*Meteosat Second Generation*
NAO	*Northern-Atlantic oscillation*
NASA	*National Aeronautics and Space Administration*
NCEP	*National Center for Environmental Predictions*
NOAA	*National Oceanic and Atmospheric Administration*
NWP	*numerical weather prediction*
OGC	*Open Geospatial Consortium*
PV	*photovoltaics*
PVPS	*Photovoltaic Power Systems Programme*
PVSAT	*photovoltaic plant monitoring scheme*
RTM	*radiative transfer modeling*
SEVIRI	*Spinning Enhanced Visible and Infrared Imager*
SHC	*Solar Heating and Cooling Programme of the IEA*
SoDa	*portal for solar energy resources*
SOLEMI	*solar energy mining, long-term solar irradiance database*
SSE	*surface meteorology and solar energy dataset (NASA)*
SSI	*surface solar irradiance*
STP	*solar thermal power*
STPP	*solar thermal power plant*
W3C	*World Wide Web Consortium*