Comparison of Different Sources of Meteorological Data for Central Asia and Russia

Christian Budig*, Janybek Orozaliev and Klaus Vajen

Kassel University, Institute of Thermal Engineering, 34109 Kassel, Germany

* Corresponding Author, solar@uni-kassel

Abstract

Plausible meteorological data are essential for simulations of solar energy technologies and buildings. Several meteorological databases are available with data derived from ground measurements, satellite data, or a combination of both. These cover different time periods and have different time intervals and spatial resolutions. Consequently, different values for meteorological data arise from different data sources for the same site. A cross-comparison of data sources for Europe [1] and South Africa [2] has already been carried out, however not for Central Asia and Russia. In this paper, the yearly sum of global irradiation in Central Asia and Russia are compared, derived from available databases (Meteonorm 6.1, NASA SSE rel. 6 and EMP Climate). Two maps are computed to present the yearly average of horizontal irradiation as well as the standard deviation, which visualizes the regional differences between the databases. The differences at a local level have been determined for eight cities. The yearly sum of horizontal irradiation has been calculated for each of these locations. For horizontal irradiation, a large disagreement between the databases has been found: the difference between the databases is up to 30 % and the standard deviation of the average value is up to 11 %. Furthermore, this paper gives an overview about available meteorological databases including specifications on e.g. covered area, time and spatial resolution.

1. Introduction

Yield predictions provide essential information for the design and output of solar thermal and photovoltaic systems. It can have severe economic consequences for the investor if the predictions of energy yields deviate substantially from the prognosis. The yield predictions are based on solar irradiation data that are derived from meteorological databases. Several meteorological databases are currently available as a result of different (inter)national projects over the last years. These are derived from different time periods and have different time intervals and spatial resolutions. Consequently, different values for meteorological data arise for the same site from different data sources. It is difficult for a system designer to decide which database to use.

With the aim to provide the solar energy industry with the most suitable and accurate information on solar irradiation resources, the IEA Task 36 "Solar Resource Knowledge Management" was formed in 2005 [3]. Furthermore, the MESoR project started in 2007 with the aim to reduce the uncertainty and to improve the management of the solar energy resource knowledge [4]. The MESoR findings contributed directly to the work program of the IEA Task 36. A major part of the MESoR project consists of benchmarking meteorological databases. As a result, a cross-comparison of meteorological databases for Europe [1] has been carried out. A cross-comparison has also been made for South Africa [2], however not for Central Asia and Russia. In this paper, the yearly sum of global irradiation in Central Asia and Russia derived from available databases (Meteonorm 6.1, NASA SSE rel. 6 and EMP Climate) are compared.

In the next section an updated and extended overview of meteorological databases is presented.

2. Available meteorological databases

Several meteorological databases are available with different quality of data. However, they differ in input data, covered area, methodology, time intervals and spatial resolution. This section provides an update and extension of the previous analyses [5], [6], [7] on an overview of available meteorological databases. Table 1 gives an overview of available databases for irradiation.

Tab.1: Overview of available meteorological databases

Database based on ground station	Database based on satellite images	Derived database and system integrating data
World Radiation Data Center (WRDC) *http://wrdc.mgo.rssi.ru/ and http://wrdc-mgo.nrel.gov/*	SSE rel. 6 (NASA) *http://eosweb.larc.nasa.gov/sse/*	EMP Climate (Mines-ParisTech) *http://project.mesor.net*
Global Energy Balance Archive (GEBA) *http://www.geba.ethz.ch/*	Satel-light (ENTPE) *http://www.satel-light.com/index2.htm*	NCEP/NCAR reanalysis (ESRL) *http://www.esrl.noaa.gov/psd/data/reanalysis/*
Baseline Surface Radiation Network (BSRN) *www.bsrn.awi.de*	HelioClim (Mines-ParisTech) *http://www.helioclim.org/*	ERA (ECWMF) http://data.ecmwf.int/data/
International Daylight Measurement Programme (IDMP) *http://idmp.entpe.fr/*	SolarAnywhere *http://www.solaranywhere.com*	Meteonorm (Meteotest) *http://www.meteonorm.com*
National Solar Radiation Database (NSRDB) *http://rredc.nrel.gov/solar/old_data/nsrdb/*	3TIER http://3tier.com	ESRA (Mines-ParisTech) *http://www.helioclim.com/esra/*
Deutscher Wetterdienst (DWD) *www.dwd.de*	SOLEMI (DLR) *http://www.solemi.de/home.html*	PVGIS (Joint Research Center) *http://re.jrc.ec.europa.eu/pvgis/*
	EnMetSol (Univ. of Oldenburg)	
	focus solar *http://www.focussolar.de*	
	Solargis http://www.solargis.info	

Solar radiation is measured at ground meteorological stations since mid of the 20th century. Numerous institutions collected data from national databases (e.g. NSRDB and DWD) and summarise them into global databases (e.g. WRDC, GEBA, BSRN, IDMP). Ground stations are highly non-uniformly distributed within the world. For example, there are much less meteorological ground stations in Central Asia and Russia than in e.g. Germany. In an area 65 times larger than Germany are less than one-third of the number of stations. Table 2 describes several specifications for the different ground station databases.

Satellite images of more than 15 geostationary weather satellites are another source for developing meteorological databases (e.g. NASA SSE). The key benefits are spatial-continuous and time-continuous data with invariant uncertainty. However, it is generally accepted that quality ground-measured data are more accurate than satellite-derived data. For daily data, satellite-estimates should be preferred compared to ground measurements if the distance from a measurement station exceeds about 70 km [8]. Table 3 describes several specifications for the different satellite-based databases.

Tab. 2: Specifications of the ground-based meteorological databases

Database based on ground station	Area	Number of stations	Period	Time resolution	Price
World Radiation Data Center (WRDC)	world	1195 [6]	1964-2004 unevenly distributed [7]	daily / hourly sums or instantaneous values unevenly distributed [7]	free
Global Energy Balance Archive (GEBA)	world	1600 [9]	unevenly distributed [10]	monthly averages [6], [10]	free for scientific use
Baseline Surface Radiation Network (BSRN)	world	46	1994 - onwards unevenly distributed	1 to 5 min [11]	free for scientific use
International Daylight Measurement Programme (IDMP)	world	48	1990 - onwards unevenly distributed	1 to 5 min	depends on meteo station [7]
National Solar Radiation Database (NSRDB)	USA	1454 [12]	1991 - 2005 [12]	hourly averages [12]	free
Deutscher Wetterdienst (DWD)	Germany	112	unevenly distributed	hourly averages	free for 46 stations

Tab. 3: Specifications of satellite-based meteorological databases

Database based on satellite images	Data inputs	area	period	Time resolution	Spatial resolution	Simulation of time series	Parameters	Price
SSE rel. 6 (NASA)	GEWEX / SRB 3 [13]	global	1983-2005 [13]	3-hourly [13]	100 km x 100 km [14]	daily average	G, D, DNI, clouds	free
Satel-light (ENTPE)	Meteosat 5..7	Europe	1996 - 2000	30-minute	5 km x 7 km [14]	real 30-minute data	G,B,D, illuminances	free
HelioClim - 1 (Mines-ParisTech)	Meteosat 2..5	Europe and Africa	1985-2005	daily	20 km x 20 km	daily average	G, DNI	free / on request
HelioClim - 3 (Mines-ParisTech)	Meteosat 8, 9	Europe and Africa	2004-onwards	15-min	5 km x 5 km	real 15-minute data	G, DNI	free / on request
SolarAnywhere	GOES-EAST GOES-WEST	USA	1998-onwards	1-hourly	10 km x 10 km	hourly, daily or monthly average	G, DNI	free / on request
3TIER	Meteosat 5, 7, 9 GOES, GMS	Europe, Africa, Asia	1999-2009	1-hourly	3 km x 3 km	hourly, daily or monthly average	G, D, DNI	on request
SOLEMI (DLR)	Meteosat 5, 7 [15]	Europe, Africa and Asia	1991-2005 1999-2006 [16]	1-hourly [16]	2,5 km x 2,5 km	monthly, yearly or multi-annual averages	G, DNI	on request
EnMetSol (Univ. of Oldenburg)	Meteosat [14]	Europe and Africa [14]	1995-onwards [14]	15-min / 1-hourly [14]	(3 x 7) km (1 x 3) km [14]	real 15 minute, 1-hourly data [14]	G, D, DNI, spectra [14]	on request
focus solar	Meteosat 9, GOES, MTSAT	Europe, Africa, USA, Mexico Asia, Australia	2005-2009 1998-2008 2007-2008	15-min	2 km x 2 km	real 15 minute, daily or monthly average	G, DNI	on request
Solargis	Meteosat 9		2004-onwards	15-min	5 km x 5 km	hourly, daily or monthly average	G, D, DNI	on request

Furthermore, several meteorological databases are a result of so called reanalysis projects (e.g. ERA-Interim). The basic idea of a reanalysis is to use a frozen state-of-the-art analysis system and perform data assimilation using historical data. A summary of the current and planned reanalysis projects is given in [17].

Beside the fundamental meteorological databases, integrated information systems are available, where databases are added by software and support services. The Meteonorm database is mainly based on the GEBA ground stations and interpolates between the ground stations. If no ground station is closer than

300 km, the information of five geostationary satellites (period 2003-2005) is used. A combination of satellite and ground information is used if the closest station is more than 50 km away. [18]. Table 4 describes several specifications for the derived and system integrated databases. Furthermore, there are collaborative information systems like SoDa (http://www.soda-is.com), MESOR (http://project.mesor.net) or SWERA (http://swera.unep.net). They offer a unified access to different meteorological databases.

Tab. 4: Specifications of derived and system integrating databases

Derived database and system integrating data	Data inputs	area	period	Time resolution	Spatial resolution	Simulation of time series	Parameters	Price
EMP Climate (Mines-ParisTech)	satellite data and reanalysis	global	1990-2004	monthly average	10 km x 10 km	monthly average	G	free
NCEP/NCAR (ESRL)	reanalysis	global	1948-onwards [17]	4 analyses per day	250 km x 250 km [17]	daily and monthly average	G	free
ERA - Interim (ECWMF)	reanalysis	global	1989-onwards [19]	4 analyses per day	80 km x 80 km [19]	daily and monthly average	G	free
Meteonorm 6.1 (Meteotest)	1422 meteo stations + satellite data	World	1981-2000 unevenly distributed	monthly average	Interpolation	Simulation of daily profile from monthy average	G, D, B, terrain shadowing	ca. 450 €
ESRA (Mines-ParisTech) [20]	586 meteo stations + satellite data	Europe	1981-1990	monthly average	10 km x 10 km	Simulation of daily profile	G,D,B,	commercial
PVGIS (Joint Research Center)	566 meteo stations	Europe and Africa	1981-1990	monthly average	1 km x 1 km 2 km x 2 km	Simulation of daily profile from monthy average	G, D, terrain shadowing	free

3. Method

Two methods, map and point analysis, are applied to compare several databases (Meteonorm 6.1, NASA SSE rel. 6 and EMP Climate) for Central Asia and Russia.

Map analysis: First the colour scales of the maps from the data provider are normalized to facilitate comparison. Two maps are calculated to present the yearly average of the horizontal irradiation as well as the standard deviation that visualizes the differences between the databases at regional level. Due to growing uncertainty with latitude, the map section represents only locations with latitudes beneath 60°.

Point analysis: A set of eight cities has been chosen to compare the databases on a local level. The yearly sum of horizontal irradiation has been calculated for each location. The eight cities, sorted by latitude, are presented in table 5.

Tab. 5: General information on sites chosen for point analysis

	location	northern latitude	eastern longitude	altitude	distance to next ground station
1	Tashkent (Uzbekistan)	41,3	69,2	428	4 km
2	Bishkek (Kyrgyzstan)	42,8	74,6	740	> 300 km
3	Almaty (Kazakhstan)	43,3	76,9	977	> 300 km
4	Astana (Kazakhstan)	51,2	71,5	312	> 300 km
5	Samara (Russia)	53,2	50,2	92	21 km
6	Omsk (Russia)	55,0	73,4	92	8 km
7	Yaroslavl (Russia)	57,6	39,9	123	> 300 km
8	St. Petersburg (Russia)	59,9	30,4	16	8 km

3. Results

The first three figures show the normalized irradiation maps derived from Meteonorm, EMP Climate and NASA respectively. Figure 4 shows the average irradiation map and figure 5 the standard deviations with respect to the average irradiation.

Good agreement between the databases can be found in Afghanistan, Uzbekistan, North-Kazakhstan, Mongolia and North-East-Russia. In comparison to the average irradiation values, EMP Climate delivers in general values above the average for southern China and below it for northern Russia. Hence, high standard deviations occur in these regions.

Figure 6 shows the cumulative distribution of the relative standard deviation. The standard deviation is below 8 % for 67 % of the investigated area and the deviation exceeds 15 % only in a few cases.

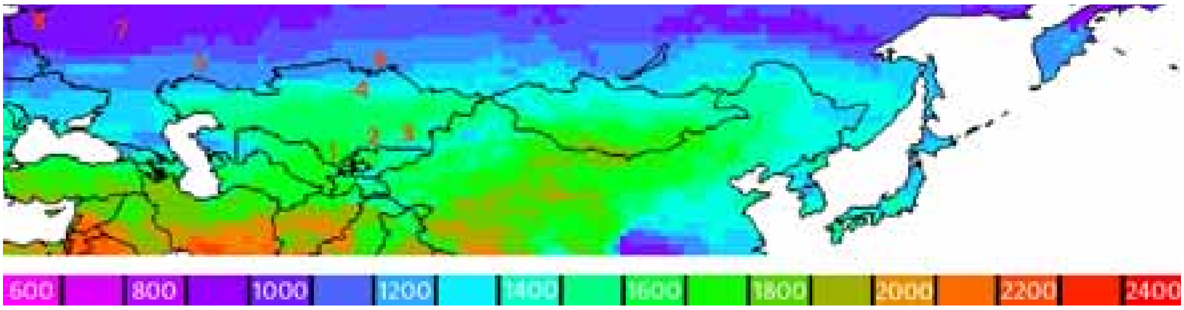

Fig. 1. Global irradiation in kWh/m^2a – Meteonorm 6.1 (1981-2000)

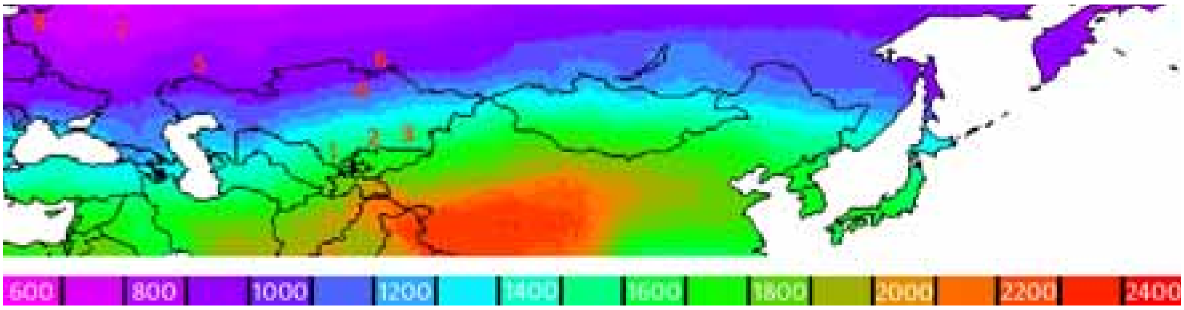

Fig. 2. Global irradiation in kWh/m^2a – EMP Climate (1990-2004)

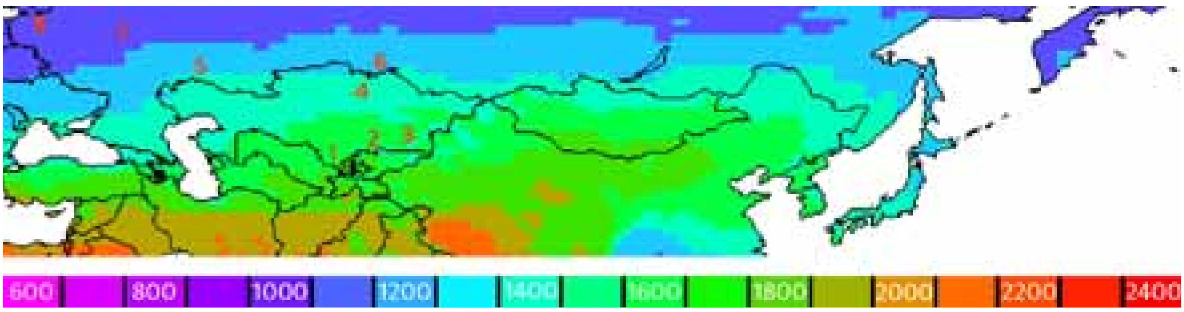

Fig. 3. Global irradiation in kWh/m^2a – NASA SSE rel. 6 (1983-2005)

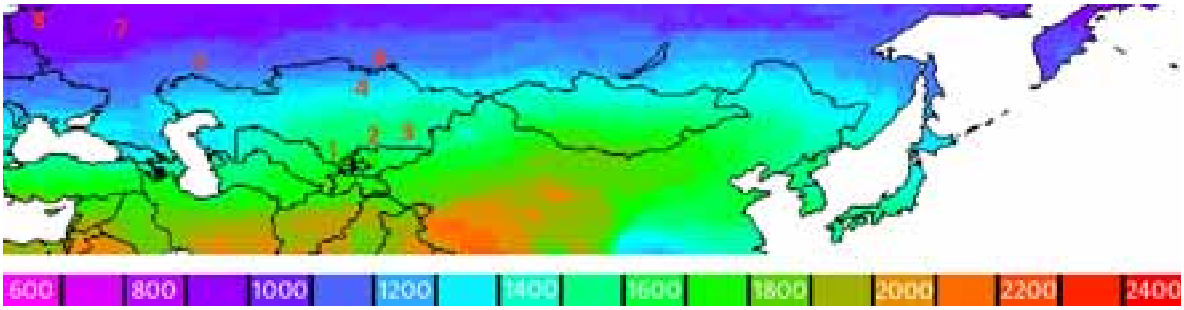

Fig. 4. Global irradiation in kWh/m^{2}a – average of three databases (Meteonorm 6.1, EMPClimate and NASA SSE rel. 6)

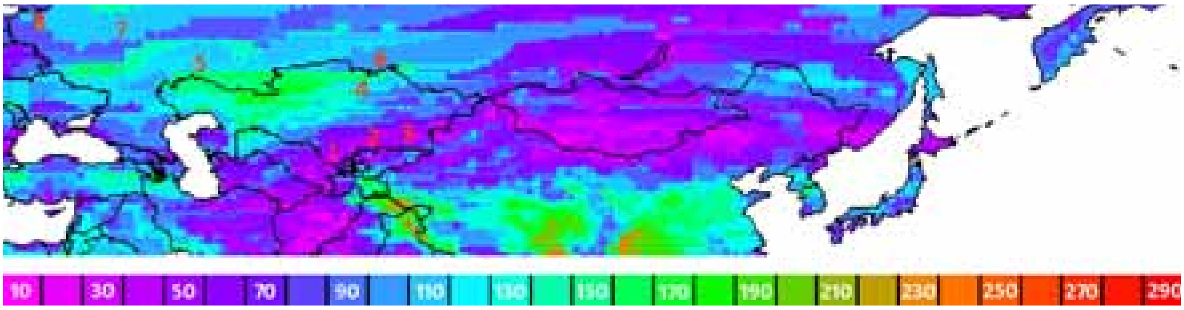

Fig. 5. Global irradiation in kWh/m^{2}a – standard deviation of the values from three databases relative to the overall average in Fig. 4

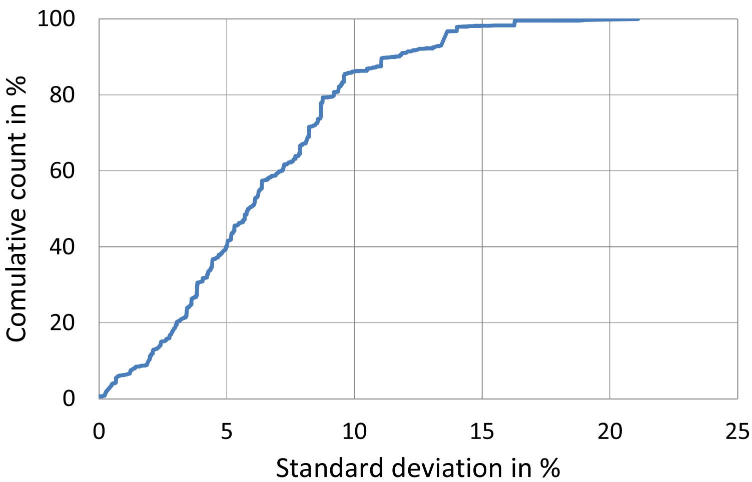

Fig.6: Cumulative distribution of relative standard deviation, summarised from the map in Fig. 5. Thus, the standard deviation between the different databases is below 10% for 85% of the investigated region.

Furthermore, differences between the databases have been determined for eight cities (Table 5). The disagreement between the databases is up to 30 % and the standard deviation from the average value is up to 11 % (Figure 7, Figure 8). Four of these locations have a meteorological ground station (GEBA) nearby. EMP Climate surprisingly differs from the other databases in Samara, Omsk and St. Petersburg. Only in Tashkent all databases are more or less equal.

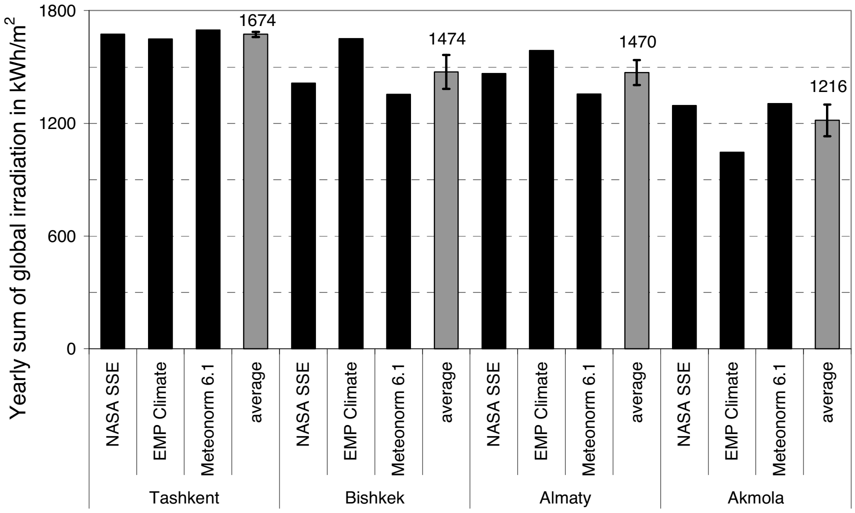

Fig.7: Comparison of the yearly sums of global irradiation of Tashkent, Bishkek, Almaty and Astana.

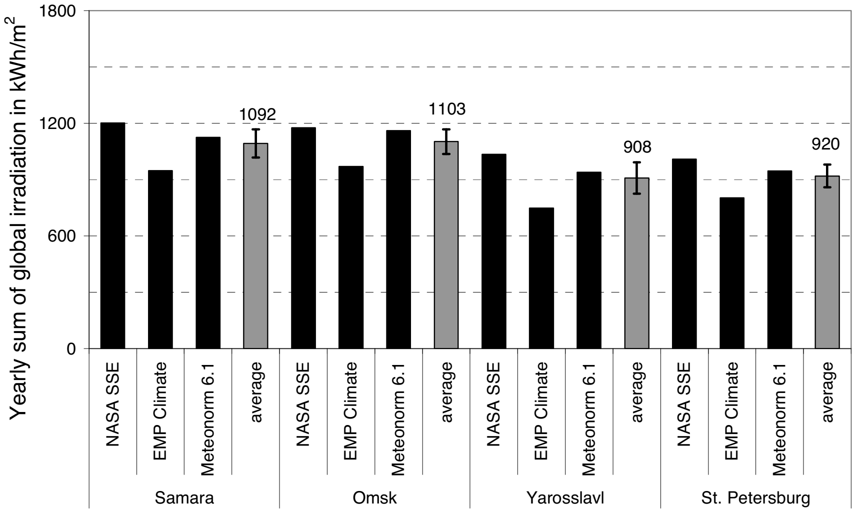

Fig.8: Comparison of the yearly sum of horizontal irradiation of Samara, Omsk, Yarosslavl and St. Petersburg.

4. Conclusion

This paper presents a first cross-comparison of databases for solar resources in Central Asia and Russia. It has not been the aim to identify the best database, but to identify areas of high disagreements between the databases. Two maps have been computed to present the yearly averages of horizontal irradiation as well as the standard deviation in order to visualize the differences between the databases on a regional level. Differences on a local level have been determined for eight cities in the region. The disagreement between the databases is up to 30 % and the standard deviation of the average value is up to 11 %.

In general, it is not known which data source provides the 'true' irradiation value for any place on earth. Therefore, it is recommended to use the average value of the available data sources for e.g. yield predictions. Furthermore, the uncertainties can be reduced by building a weighted average with the help of indicators like time interval and spatial resolution of the data sources. The use of the average +/- the standard deviation can be recommended for minimum and maximum estimates.

References

[1] M. Šúri et al., (2008). First steps in the cross-comparison of solar resource spatial products in Europe, Proceedings of the EUROSUN 2008, Lisbon, Portugal

[2] T.P. Fluri and T.W. von Backström, (2009). Comparison of solar resource assessments for South Africa, Proceedings of ISES Solar World Conference 2009, Johannesburg, South Africa

[3] D. Renné et al., (2006). Solar resource knowledge management: a new task of the international energy agency, Proceedings of the ASME solar energy division, International solar energy conference SEC, Denver, USA

[4] C. Hoyer-Klick et al., (2008), Management and exploitation of solar resource knowledge, Proceedings of the EUROSUN 2008, Lisbon, Portugal

[5] R. Perez et al., (2001), Solar Resource Assessment: A Review. In Gordon J. (Ed.): Solar Energy - The State Of The Art: ISES Position Papers. James and James publisher.

[6] S. Cross, D. Mayer, L. Wald, (2004). The Availability of irradiation data, Report IEA-PVPS T-04:2004

[7] M. Šúri, (2007). Solar resource data and tools for an assessment of photovoltaic systems. In A. Jäger-Waldau (editor), Status Report 2006, Office for Official Publications of the European Communities, Luxembourg, pp. 93-98

[8] R. Perez, A. Zelenka, M. Kmiecik, R. George and D. Renné, (2001). Determination of effective accuracy of satellite-derived irradiation in central United States, Proceedings ASES Annual Meeting, Washington, USA

[9] G. Seiz, N. Foppa, (2007). Nationales Klima-Beobachtungssystem (GCOS Schweiz). Publikation des Bundesamtes für Meteorologie und Klimatologie, MeteoSchweiz und ProClim, 92 S.

[10] H. Gilgen and A. Ohmura, (1999). The Global Energy Balance Archive, Bulletin of the American Meteorological Society, Vol. 80, No. 5, pp. 831-850

[11] H. Hegner, et al., (1998). Baseline Surface Radiation Network, Technical Report 2

[12] NREL, (2007). National Solar Radiation Database – User's Manual, NREL/TP-581-41364

[13] NASA SSE, (2009). Surface meteorology and solar energy (SSE) release 6.0 - Methodology Version 2.4

[14] E. Lorenz, (2009). Overview on solar resource products, Mesor training seminar, Intersolar Trade Fair, Munich, Germany

[15] R. Meyer et al., (2008). Combining solar irradiance measurements and various satellite derived products to a site specific best estimate, SolarPages Symposium, Las Vegas, USA

[16] MESOR, Management and Exploitation of solar resource knowledge, http://mesor.org

[17] K. Trenberth et al, (2010). Atmospheric reanalyses: A major resource for ocean product development and modeling. Proceedings of OceanObs, Venice, Italy

[18] Meteotest, (2009). Meteonorm Version 6.0 – Handbook part I and II, Version 6.1.0.15

[19] ECMWF, (2009). ERA report series – The ERA-Interim archive Version 1.0

[20] Mines-Paris Tech, (2000). The European solar radiation atlas – Vol. 2: Database and exploitation software