Comparison Between Measured Mean Monthly Solar Insolation Data and Estimates from Swera Database for Salta City (Northwestern Argentina)

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ABSTRACT The lack of measured data for global solar insolation in the Argentine Northwest (ANW) was supplied using free-access databases available on the Internet. For Salta Capital metropolitan region, measured monthly mean global solar insolation and estimated monthly values from SWERA, SoDa and SSE databases are compared. The objective was to determine the degree of correlation of each database with measured values and the origin in found differences. SWERA data happened to be the best correlation, with the measured data (average RMSE% = 14%). The other databases have errors above 24 %, this being attributed to larger satellite grid cells. A linear model, developed using MLR, is presented. It offers better estimates than the databases (RMSE% of 6%), but only applies to Salta Capital.

KEYWORDS Global solar insolation, free access databases, Argentina, grid cell size.

Introduction

The lack of measured solar radiation data proves to be a subject of analysis for developing countries. In Argentina the potential areas to exploit the solar resource are located near the Andes Mountains (Figure 1), as the Argentine Northwest (ANW). The high altitude of these areas creates optimal atmospheric conditions of slight attenuation, on clear day, for the incoming extraterrestrial solar radiation. In fact, ANW is in one of the four regions on the planet having the most insolation [Meteonorm, 2006].

Within the extinct REDSOL program (RED SOLarimetrica, Argentine Radiometric network), solar radiation data were recorded at a few sites in ANW, which helped to draw solar radiation maps [Grossi Gallegos and Righini, 2007]. The Kriging technique was used to extrapolate values throughout Argentina, taking both measured and estimated data (the estimations were made using sunshine hours data and applying the Ångström-Prescott model [Ångström,1924; Prescott, 1940; Righini et al., 2005] the calculated error values were found to be variable (around 10%) taking into account the topography and distances between stations. But there are extensive zones in ANW, mainly the high-altitude terrains, for which no measured solar radiation data are available, but only the estimations made within REDSOL.

The possibility of using databases of solar radiation available on the internet is a solution to this problem. These databases use surface measured data, interpolations, models and satellite imagery to make estimates, and the errors these processes introduce in the estimates are not expected to exceed 10% for monthly mean values of global insolation and can be considered a good estimation tool. In general, as mentioned in [Bosch et al., 2010] it should be noted that the solar radiation data offered in free-access databases:

i) In the measurement case, they can come from differing measuring qualities and from different years.

ii) In the interpolation case, they can come from grids of differing densities in the input data and from different years.

iii) In the estimation case, it is important to take into account the model features (years of data and images used in the development), the characteristics of images (resolution and geometry) and the time periods of the used data.

It is clear that the free-access databases that generate their estimates on satellite measurements are neither absolute nor exact. However no other short-term solutions are in sight, to overcome the lack of solar radiation data in the ANW that use this freely available information. Therefore it was necessary to estimate the error in using these data. There are current papers where it is evident that the optimal exploitation of satellite data is achieved by comparing satellite data against measured data to develop or improve techniques to consider digital terrain models [Bosch et al., 2010] or methods to determine the best estimates within each database data for a particular site [Pagola et al., 2010].

An analogy to this situation can be found in [Belmonte et al., 2009]. Among others things in this work the authors built a contour map of the Lerma valley and estimated the average monthly values of global insolation on horizontal surface as a function of altitude, to assess the potential of solar energy in the valley, using the Page and Hottel models. But the estimation methodology does not consider the terrain surrounding each reference point, only its altitude: on the map, each grid point is considered as flat and unobstructed i.e. others points are not considered when the estimation of horizontal global radiation is performed. This paper is an important source of data (CAD map + GIS data layers + models estimations) but does not consider issues that precisely influence the estimation of solar radiation in mountainous terrain. In [Bosch et al., 2010] it is explained how the irregularities of the terrain influence on the estimation of the irradiance can be measured on one site.

In ANW, the mining industry is booming (principally in Jujuy, Salta and Catamarca provinces) and the possibility of having sufficient electric power based on solar energy is an attractive option to mining companies from the cost/benefits and environmental point of view [Mills, 2004; Rolim et al., 2009; Yao et al., 2009]: Currently, mining companies have a reputation for polluting the environment through the processes of mineral extraction and purification. Thus, the validity of global, direct and diffuse solar radiation data is particularly important for private industry, when considering that this data could be used in feasibility studies for the installation of solar power plants.

The present study is an analysis of monthly average values of global solar radiation for the metropolitan area of Salta Capital (SLA), covering three measuring stations. It compares the measured values of global solar insolation against estimates provided by the databases SWERA [SWERA, 2010], SoDa [SoDa, 2010] and SSE [NASA, 2010]. The aim is to establish the magnitude of the differences between measured and estimates and determine the validity of the analyzed data taken from the databases. It also seeks to establish the origin of the differences, if they come from the measured data or from the estimates by databases.

The Region under study

SLA is located in the northern part (bottom) of the Lerma Valley. This valley is placed in the centre of Salta province which is located in ANW (Figure 2). The climate of SLA region is temperate-warm, with sunny and rigorous winters and warm rainy summers [Lesino et al., 1983]. In the Köppen Climate Classification System, the climate of SLA is type Cwb: the temperate climate with dry winters is a climate characteristic of the highlands inside the tropics of Mexico, Peru, Bolivia and South Africa but is also found at sites with those characteristics outside the tropics.

The area under study is the metropolitan area of SLA, including the town of Cerrillos (Figure 2). The solar radiation data were recorded at three sites in the area mentioned above and their positions, as per Google Earth ®, are:

i) **SMN Salta**: lat - 24º50'41.83" long. - 65º28'43.63". 1237 m.a.s.l.

ii) **INTA Cerrillos**: lat - 24º53'36.06" long. - 65º28'25.37". 1257 m.a.s.l.

iii) **SNU**: lat - 24º43'44.15" long. - 65º24'34.17". 1237 m.a.s.l.

The SNU station is the most northern station, whilst SMN Salta and INTA Cerrillos are situated

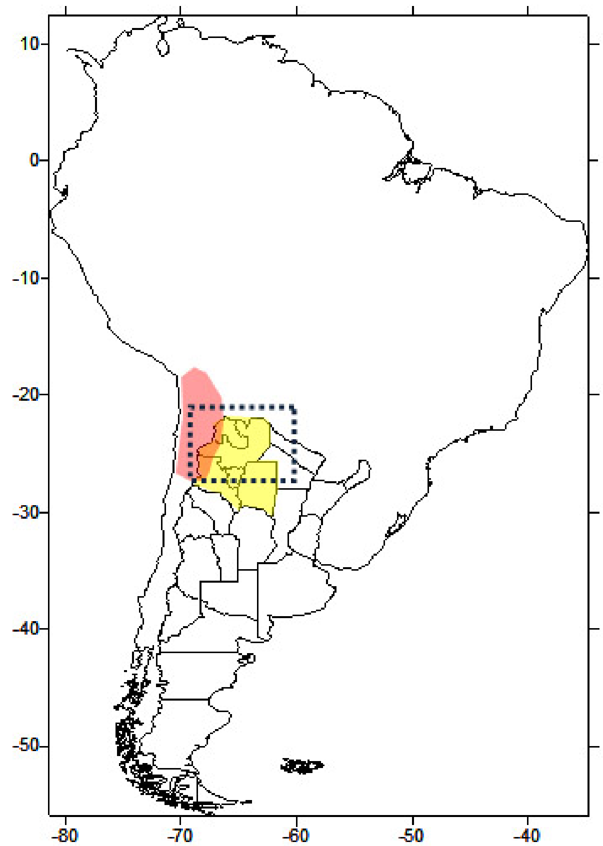

Figure 1 Map of South America and Argentina. The provinces in Argentina have been drawn and the ones making up the so-called Argentine Northwest have been highlighted in yellow. The region highlighted in red shows the highest solar radiation values (Meteonorm, 2006). The dotted box indicates the region shown in Figure 2.

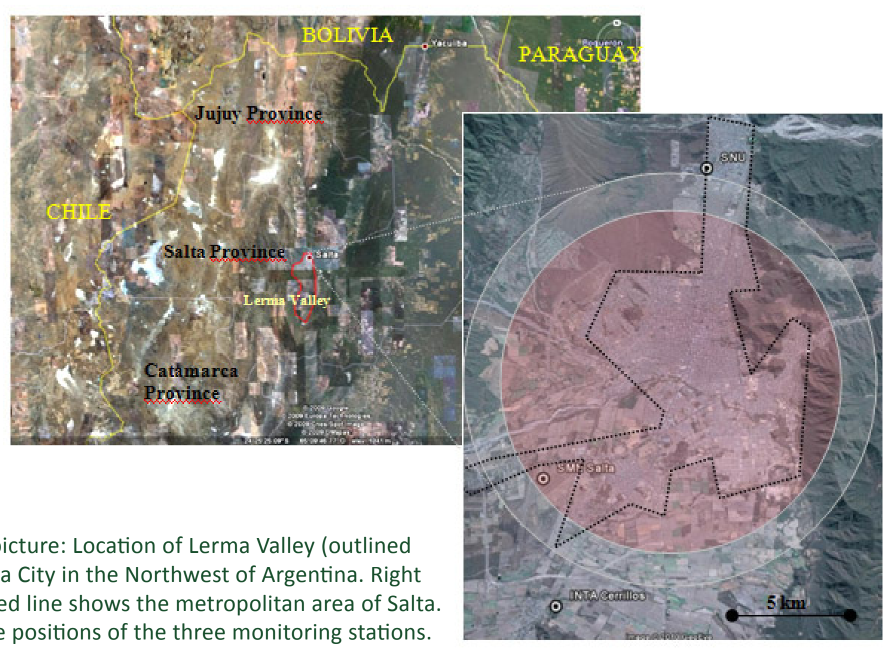

Figure 2 Left picture: Location of Lerma Valley (outlined in red) and Salta City in the Northwest of Argentina. Right picture: The dotted line shows the metropolitan area of Salta. It also shows the positions of the three monitoring stations.

southernly. SMN Salta and INTA Cerrillos are located 5 km from each other. SNU is 15 km from SMN Salta. The stations are located almost in a straight line north-south.

The solar radiation data

The measured data used in this paper is presented in four groups of averaged-time series: 1968 to 1976, 1982 to 1990, 1991 to 2000 and 2006 to 2007. The first and second time series include the averaged data of 9 years, the third period contains the averaged data of 10 years and the fourth comprises just 1 year of data: this is the most recent series of analyzed data. This last set of data began in May 2006 and finished in April 2007. There are two five-year intervals without reliable solar radiation data, between the first and second time period and between the third and fourth time period. The missing data represents 25 % of the total 1968-2007 period. These data are listed in Table 1.

The data for the 68-76 series were recorded by SMN (Servicio Meteorologico Nacional, National Weather Service) at the Salta airport station (SMN Salta) with bimetallic pyranograph. Those of 82-90 and 91-00 were recorded by INTA (Instituto Nacional de Tecnologia Agropecuaria, Agriculture Technology National Institute) at the Cerrillos station using an Eppley 8-48 pyranometer, while the data for 06-07 were recorded in the Salta National University campus with a Kipp & Zonen CM3 pyranometer. The errors associated with these instruments are up to 15% for bimetallic pyranograph (it is the instrument with greatest error, because of the mechanics of its operation) [Estol at al., 1976], up to 10 % for the pyranometer Eppley and up to 5% for the pyranometer CM3, considering daily values of global irradiance.

All the measurement data are on horizontal global solar radiation. The data measured in the SMN and INTA stations were registered as daily values of global solar irradiation (in MJ/m^2). The data measured in the UNSa station were registered as irradiances (in W/m^2) and then integrated as daily values of irradiation (in MJ/m^2).

Free-access databases

This paper considered the following free-access databases:

1) *SWERA (Solar and Wind Energy Resource Assessment)*: It is supported by several institutions worldwide (UNEP, NASA, NREL, RISØ, DLR, USGS, amongst others). SWERA products include Geographic Information Systems (GIS) and time series data, along with links to energy optimization tools needed to apply these data. In particular, the solar radiation data provided in the products were generated using the Climatological Solar Radiation model (CSR) developed by NREL [Maxwell et al., 1998; George and Maxwell, 1999]. This model was used to draw the USA solar radiation maps. The data used in this paper was presented as global, tilted, direct and diffuse mean monthly insolation values (csrsoamdata_232 file, cell # 1297102).Time period information, from 1985 to 1991.

2) *SoDa (Solar Radiation Data)*: Is a European commercial service that provides solar radiation information in several time formats (hourly, daily, weekly and monthly). It uses the HelioClim-3 database and Heliosat method as source, but much of its free data come from the SSE. The data used in this paper was requested as global mean monthly solar insolation values. The obtained free data cover only 2005.

3) *SSE (Surface meteorology and Solar Energy)*: "NASA, through its' Earth science research program has long supported satellite systems and research providing data important to the study of climate and climate processes. These data include long-term estimates of meteorological quantities and surface solar energy fluxes. These satellite and modeled based products have also been shown to be accurate enough to provide reliable solar and meteorological resource data over regions where surface measurements are sparse or nonexistent, and offer two unique features – the data is global and, in general, contiguous in time. Accordingly, NASA's Earth Applied Sciences program has provided the means to make these data available for government and public sector usage. To foster the usage of the global solar and meteorological data,

Table 1 Monthly average daily values of Insolation H, Temperature T, Relative humidity RH and effective sunshine hours n for Salta city metropolitan area.

Series	Month	H (MJ/m^2)	T (ºC)	RH (%)	n (hs.)
1968-1976	JAN	18.5	21.1	79	5.2
	FEB	17	20.1	83	4.7
	MAR	13.5	18.4	85	3.5
	APR	13	15.6	84	4.4
	MAY	11.5	12.9	81	5
	JUN	9.5	10.4	77	4.4
	JUL	11.5	9.9	71	6
	AUG	14.5	11.6	63	6.5
	SEPT	15	15.4	60	5.1
	OCT	18	18	61	5.8
	NOV	19.5	20.3	65	5.9
	DEC	19.5	21.3	71	5.7
1982-1990	JAN	20.8	21.2	78	6.5
	FEB	19.8	20.2	80	6.3
	MAR	16.2	19.4	82	5.2
	APR	13.7	16.7	81	4.7
	MAY	11.9	13	78	5.2
	JUN	10.9	10.3	75	5.6
	JUL	12.1	10.9	67	6.8
	AUG	14.7	12.9	63	6.8
	SEPT	17	14.8	60	6.9
	OCT	19.4	18.8	59	7.1
	NOV	20.2	20.6	66	6.6
	DEC	20.5	21.2	74	6.5
1991-2000	JAN	18	21.3	77	5.7
	FEB	16.9	20	80	5.6
	MAR	14.8	19.3	81	4.9
	APR	13	16.7	79	5.2
	MAY	10.4	13.9	78	5
	JUN	10.1	11.3	73	5.5
	JUL	10.6	9.9	69	6
	AUG	12.7	13.1	61	6.5
	SEPT	15.5	15.8	56	6.7
	OCT	17.2	19	60	6.6
	NOV	17.6	20	67	6.3
	DEC	19.8	22	68	7

Table 1 [continuation]

2006-2007	JAN	18.6	21.2	80	4.8
	FEB	18.6	21	80	5.7
	MAR	15.1	19.8	85	5
	APR	14.4	17.6	82	5.4
	MAY	10.8	12.5	80	4.3
	JUN	10.7	12.6	79	5.1
	JUL	13.1	13.3	67	7
	AUG	16.1	13.2	59	7.4
	SEPT	20.3	15.5	46	8.2
	OCT	18.8	20.6	64	6.9
	NOV	19.3	20.7	66	6.5
	DEC	22.6	22.5	74	7.4

NASA supported, and continues to support, the development of the Surface meteorology and Solar Energy (SSE) dataset which has been formulated specifically for photovoltaic and renewable energy system design needs…" [NASA, 2010]. The version analyzed was the 6.0 with data taken from 1983 to 2005.

Three databases were used as they were the only ones providing data for the region under study (Salta City, Northwestern Argentina). Other satellite online databases are also available, but the data they provide refer to regions in other continents. The following are free online databases providing data for Europe and Africa: CM-SAF (Climate Monitoring–The Satellite Application Facility on Climate Monitoring), DLR-ISIS (Deutschen Zentrums für Luft-und Raumfahrt-Irradiance at the Surface derived from ISCCP[1] cloud data), JRC-PVGIS (Joint Research Center–Photovoltaic Geographical Information System) and IRENA (International Renewable Energy Agency).

The results

In Figure 3 the measured and estimated values are shown of mean monthly global solar insolation **H** for SLA region.

Only SWERA forecasts approached the values measured in SLA region. Table 2 shows the RMSE% (Percentage Root Mean Square Error) and MBE (Mean Bias Error) of the estimated values for each database on the measured values.

In all series, the errors of SoDa and SSE database are significant higher than those of SWERA. The main cause may be the size of the satellite grid cell used in each case, as shown in Figure 4. The SSE satellite cell is about 80 km side, while that of SWERA is 40 km. side. The SoDa satellite grid cell is the same size as the SSE for the region analyzed because SoDa database are linked with SSE for mean monthly *free access* solar radiation data [SoDA, 2010].

The land encompassed by the SLA grid cell of SWERA is irregular: the Valley has an average height of 1200 metres above sea level; the western mountainous area has elevations above 2500 metres, while the eastern mountainous region has an average altitude of 1600 metres. In the case of the grid cell of SSE, the location west of the dotted blue line, has an average height of 3500 metres while to the east the average altitude is 1200 metres.

Statistical analysis

Given the differences between measured values and

1. International Satellite Cloud Climatology Project

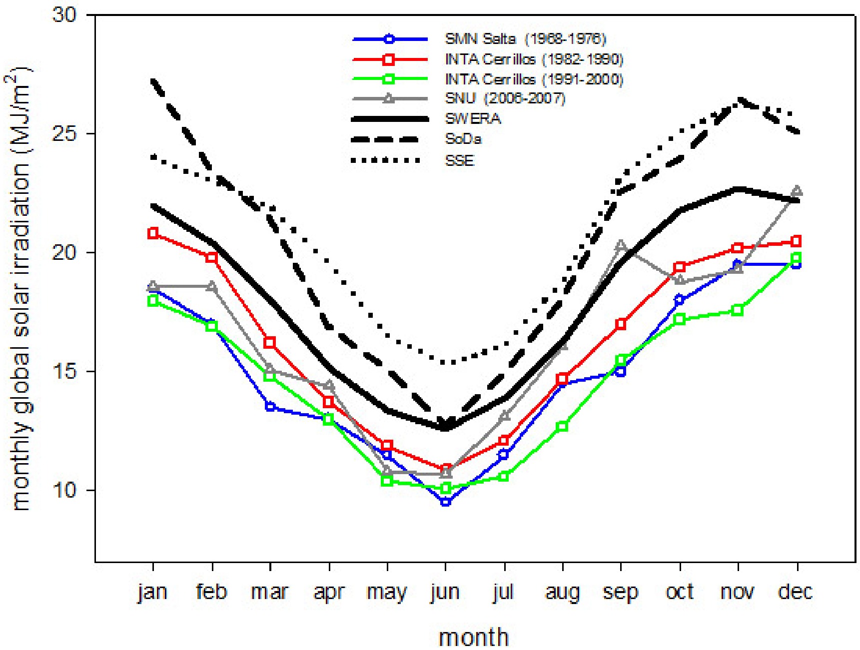

Figure 3 Monthly average values of global irradiance measured at the stations, compared with the estimated monthly average values from each consulted database. Note how the values predicted by SoDa and SSE differ significantly from the measured values.

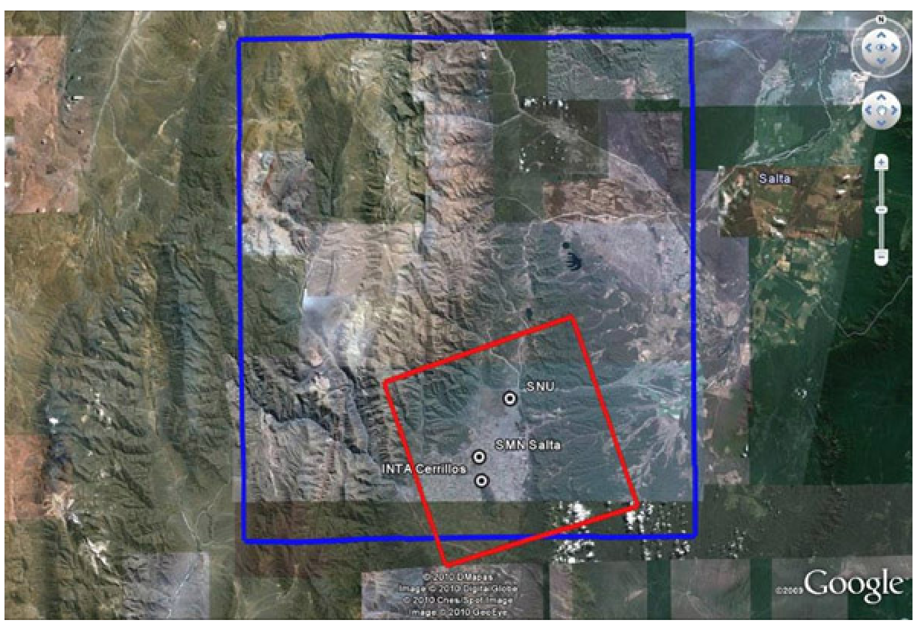

Figure 4 Comparison of satellite grid cell sizes used by SSE (blue) and SWERA (red) databases. The smaller size of the SWERA grid cell allows better spatial resolution, so improving estimates and reducing errors.

those estimated by different databases, it must be determined or at least estimated, which of the two sources of data (measurements or estimates) are more significant or valid. To determine the statistical significance of the data in each series, a t-Test was applied. Table 3 shows the p-values obtained. The entire series data (1968-2007) was also analyzed.

For t-Test, in Table 3, values marked in italics reject the null hypothesis, which implies that samples have the same mean, within the confidence interval

Table 2 Values of RMSE% and MBE between the average monthly values of global irradiance, measured in each series, with those provided by each consulted database. Note in all cases, the MBE is negative, indicating the measured values are lower than expected. Highlighted in bold are the minimum values of the entire table..

		1968-1976	1982-1990	1991-2000	2006-2007
SWERA	RMSE%	17.75	10.05	19.62	11.91
	MBE (MJ/m^2)	-3.09	-1.74	-3.46	-1.64
SoDa	RMSE%	28.54	21.56	30.2	22.71
	MBE (MJ/m^2)	-5.59	-4.24	-5.95	-4.14
SSE	RMSE%	29.81	23.42	31.32	23.48
	MBE (MJ/m^2)	-6.23	-4.88	-6.6	-4.78

Table 3 p-values calculated applying t-test and F-test to the monthly solar radiation data of each series and database. Figures in bold do not reject the null hypothesis, within a confidence interval of 0.01. Note the high values of probability that exists between the measured data and SWERA estimates for 82-90 and 06-07 series.

	Series	SWERA	SoDa	SSE
t - Test	1968-1976	0.047	0.023	0.011
	1982-1990	0.266	0.094	0.034
	1991-2000	0.026	0.014	0.007
	2006-2007	0.299	0.134	0.057
	1968-2007	0.108	0.009	0.001
F - test	1968-1976	0.730	0.311	0.104
	1982-1990	0.947	0.218	0.070
	1991-2000	0.667	0.346	0.124
	2006-2007	0.994	0.172	0.049
	1968-2007	0.783	0.262	0.696

of 0.01. An F-Test was also performed to determine whether previous differences had statistical significance, using the same confidence interval as the t-Test. In Table 3, the figures in bold do not reject the null hypothesis, which implies that samples have equal variances or standard deviations. The p-values of the F-test in Table 3 show that *homoscedasticity* exists (equal variances) between the comparative data giving statistical significance to t-Test results.

That two samples do not have equal means indicates they may not come from the same population. In other words, if they look similar it is more by chan-

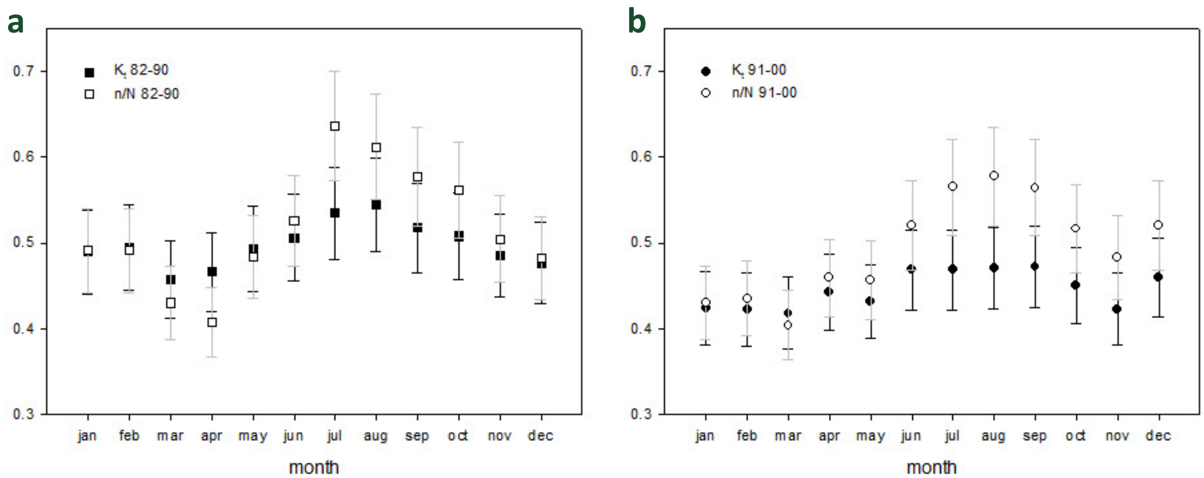

Figure 5 Comparison of monthly clearness index Kt and relative sunshine hours n/N for series 82-90 and 91-00. The errors bars have been added.

ce than by causative factors. That two samples have equal variance indicates that the dispersion around the regression line is the same for different values of abscissa. The observed values tend to fall into an area that could be defined by two parallels to the regression line. For more details of these statistical tests, see [Walpole et al., 2007].

From the figures in Table 3, it can be seen that the monthly values in the databases are less representative compared with average monthly values of global insolation in the 68-76 and 91-00 series, when compared with the values of the 82-90 series and 06-07 series, for which only SWERA data are statistically consistent. The 91-00 series presents the lower p-values for both tests, indicating the presumable existence of a problem in the measured values of this series. This fact is discussed later. Overall, it appears that the SWERA database best correlates with measured values in the SLA region.

Discussion of results

1) In the data of monthly average global solar insolation measured in the SLA region there are two series that correlate as expected with SWERA estimates; 82-90 and 06-07 (see Figure 2 and Table 2). For these two series CSR model results representative for estimating monthly average global insolation **H** in SLA region, with a RMSE% up to 11% (the value of error stated by its designers was 10% for U.S. data [Maxwell et al., 1998]). The other two series, 68-76 and 91-00 do not correlate with SWERA data because the measured radiation values were found to be significantly lower than those of the other series. This situation is confirmed from the statistical viewpoint (see Table 3). The others database, SoDa and SSE, have very low rates of correlation with respect to measured data.

Calibration loss was suspected of the sensor used in the 91-00 series. To remove or prove this suspicion, the average monthly clearness index values $\mathbf{K_t}$ were analyzed, this relates the global insolation **H** with the global extraterrestrial insolation $\mathbf{H_0}$ as $\mathbf{H/H_0}$, and relative sunshine hours **n/N**. Where **n** is the amount of measured absolute sunshine hours and **N** is the astronomical possible value, of each monthly value in 82-90 series and 91-00 series, to establish the feasibility that an actual error in the radiation sensor exists using the following reasoning: if the variations in the insolation in consecutive months are not in-keeping with similar variations in sunshine hours, it is very likely that there is a problem with the sensor. Because both absolute sunshine hours **n** as global irradiation **H** are seasonal variables, their normalized counterparts are used to perform the comparison. Thus, despite the redundancy, we can compare magnitudes that are comparables.

In Figure 5.a the clearness indexes $\mathbf{K_t}$ are shown and the relative sunshine hours **n/N** for the series 82-

90 and the series 91-00 in Figure 5.b. RMSE% of the K_t values between series is 12.74% whilst the RMSE% for relative sunshine hours **n/N** is 8.52% (D RMSE% = 4.22%). These percentages values show that the differences between series for the analyzed variables (K_t and **n/N**) do not indicate a main calibration problem in the pyranometer, since the RMSE% values for K_t and **n/N** in series 82-90 and 91-00 are in the same order of magnitude. There is evidence of a decrease in values between the two sunshine hours series analyzed, so the loss of calibration is not the main reason for the low irradiance values measured in the series 91-00.

2) SSE and SoDa databases exhibit noticeable differences with measured data. The possible reason for these differences lies in the grid cell size and in the different meteorological input data used by each database to make estimates. These databases use estimates made with models using information on cloud cover, atmospheric water vapour and trace gases, and the amount of aerosols in the atmosphere to calculate the insolation falling on a horizontal surface. Ground measurements are used to validate the data where possible. The modeled values are always compared to a true measured value within the grid cell and the errors are due to the uncertainties associated with meteorological input to the model. The local cloud cover can vary significantly even within a single grid cell as a result of terrain effects and other microclimate influences. Furthermore, the uncertainty of the modelled estimates increases with distance from reliable measurement sources and with the complexity of the terrain.

For example, in South America there is only one station within the NASA's Baseline Surface Radiation Network (BSRN), used by SSE to validate satellite solar radiation measurements. It is located on the east coast of Brazil, at Florianopolis, and within World Radiation Data Center (WRDC) stations. The closest one to SLA is located 220 km away and has only incomplete global radiation data from the decade of the seventies. Therefore, the quantities of measured solar radiation data used to validate the estimates of SSE may be insufficient.

As mentioned before, the grid cell size is especially important if the region covered has mountains. Mountains influence cloudiness and precipitation in a region because they can disrupt the movement of cold or hot air masses causing significant climatic differences (mainly in temperature and relative humidity) at sites located before and after them. Mountains may help or prevent condensation, according to the side on which the predominant air mass impacts, determining whether a region is wet or dry.

Also, the larger size of SSE grid cell estimates values of temperature, relative humidity and precipitable water that were not representative for all sites inside the grid cell. RMSE% between the values of precipitable water quantity provided by SSE for SLA cell, estimated using the equation 1 arrives at 50%, i.e., the amount of water vapour estimated for SLA is twice that estimated by SSE. This is due to the characteristics mentioned above on the altitudes of the region covered by the grid cell for SLA. SWERA's grid cell is smaller than SSE, so it is expected that the error in those estimations will be lower than for SSE database. This assumption is fulfilled.

$$w = 0.00493 RH.T^{-1} \exp\left(26.23 - 5416T^{-1}\right) \quad \text{Eq. (1)}$$

3) The authors have developed a model, using Multiple Linear Regression, based on monthly average meteorological data of Table 1, found that the following expression.

$$H_{MLR1} = 0.75T\text{-}0.05RH\text{+}1.18n\text{-}0.02 \quad \text{Eq. (2)}$$

provides estimates of monthly average values, with an excellent level of correlation with the values measured (R^2= 0.92). RMSE% calculated with data from the four series is much smaller than those of Table 2. Again there is a considerable discrepancy for the series 91-00, compared to the others (Table 4). But the linear model estimates are strongly influenced by the value of the temperature **T**, which alone explains 79.3% of the variance of the variable global insolation **H**. This percentage was estimated by calculating the

Table 4 RMSE% between measured data and MLR model estimations. RMSE% calculated with data from the four series' is much smaller than those of Table 2. Again, there is considerable discrepancy for the series 91-00, compared to the others.

	1967-1976	1982-1990	1991-2000	2006-2007
RMSE%	3.97	3.94	8.88	6.26

correlation index between the measured global irradiation values **H** in Table 1 with the estimated, using the following equation.

$$H_{MLR2} = 0.76T + 2.92 \quad \text{Eq. (3)}$$

The correlation index for temperature **T** and global insolation $\mathbf{H}_{MLR2}$ is $R^2 = 0.73$.

Since this model does not contain expressions that relate to physical processes but only correlations of meteorological variables, their use is only applicable to SLA region.

Conclusions

For the Salta city region (northwestern Argentina), measured values of monthly average global solar irradiation were compared against values available from three free-access databases: SWERA, SoDa and SSE. The measured data was divided into four series covering 29 years. SWERA data happened to be the best correlation, with the measured data having an average RMSE% of 14% for the four series analyzed. The other databases have errors above 24 %, and that bigger error is attributed to larger satellite grid cells.

Series 68-76 and 91-00 have major differences with the monthly average values estimated by SWERA because the measured values are lower than expected. The causes of this phenomenon cannot be attributed solely to loss of calibration of the pyranometer as during that period there was a reduction in the measured relative sunshine hour values.

For the SLA region an empirical model was developed, based on temperature T, relative humidity RH and absolute sunshine hours n, which provides results with lower RMSE% than those with SWERA. However, this empirical model is strongly influenced by the temperature value.

It is clear that some solar radiation databases offer very accurate results in their estimates even for mountainous areas, resulting from the reduction in the area of satellite grid cell. In particular SWERA database values are so accurate that they even detect errors in the irradiance values measured on the ground. This particular database results in a powerful tool to estimate global solar radiation in the SLA region and in ANW. However, these models must still be tested against measured data at high altitude sites to support its performance and error estimate.

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References

Ångström A. (1924). Solar and terrestrial radiation. Q. J. R. Meteorol. Soc. 50, 121-125.

Belmonte S., Nuñez V., Viramonte J. G., Franco J. (2009). Potential renewable energy resources of the Lerma Valley, Salta, Argentina for its strategic territorial planning. Renewable and Sustainable Energy Reviews 13, 1475–1484.

Bosch J. L., Batlles F. J., Zarzalejo L. F., López G. (2010). Solar resources estimation combining digital terrain models and satellite images techniques. Renewable Energy 35, 12, 2853-2861.

Estol, R., Gross, S., Renzini, G. Calibración del instrumental de medición de radiación solar en Argentina. (1976). *Atas do 2° Congresso Latino-Americano de Energia Solar* vol. I, 31-42, João Pessoa, Paraiba, Brasil.

George R., Maxwell E. (1999). High Resolution maps of solar collector perfomance using a climatological solar radiation model. Proceedings of the 1999 American Solar Energy Society Annual Conference. Portland , Maine.

Grossi Gallegos H., Righini R. (2007). Atlas de energía solar de la Republica Argentina. Ed. Universidad Nacional de Lujan – SECYT (in spanish).

Lesino G., Giménez E., Castro Padula L. (1983). Análisis del confort higrotérmico y evaluación de los recursos climáticos naturales en el NOA. 8th ASADES Proceedings, 49-57.

Maxwell E., George R., Wilcox S. (1998). A climatological Solar Radiation model. Proceedings of the 1998 American Solar Energy Society Annual Conference. Albuquerque , NM.

Meteonorm (2006). www.meteonorm.com

Mills D. (2004). Advances in solar thermal electricity technology. Solar Energy 76, 19-31.

Pagola I., Gastón M., Fernández-Peruchena C., Moreno S., Ramirez L. (2010). New methodology of solar radiation evaluation using free access databases in specific locations. Renewable Energy 35, 12, 2792-2798.

Prescott J. (1940). Evaporation from a water surface in relation to solar radiation. Trans. R. Soc. Sci. Aust. 64, 114-125.

Righini R., Grossi Gallegos H., Raichijk C. (2005). Approach to drawing new global solar irradiation contour maps for Argentina. Renewable Energy 30, 1241-1255.

Rolim M, Fraidenraich N, Tiba C. (2009) Analytic modeling of a solar power plant with parabolic linear collectors. Solar Energy 83, 126-33.

Walpole R., R. Myers , S. Myers, K. Ye. (2007). Probabilidad y Estadística para Ingeniería y Ciencias. Ed. México. Pearson- Prentice Hall.

Yao Z., Wang Z., Lu Z., Wei X. (2009). Modeling and simulation of the pioneer 1MW solar thermal central receiver system in China. Renewable Energy 34, 11, 2437-2446.

Web page

Meteonorm (2006). www.meteonorm.com.

SWERA (2010). swera.unep.net/. Last entrance: 10/2010.

SoDA (2010). www.soda-is.com/. Last entrance: 10/2010.

NASA (2010).eosweb.larc.nasa.gov/sse/. Last entrance: 10/2010.