COMPARISION OF SATELLITE ESTIMATION OF SOLAR INSOLATION IN ALBANIA WITH THEIR GROUND ESTIMATIONS

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Abstract. Reliable evaluation of efficiency and feasibility of a successful application of a technology which uses solar energy, among others, depends on the availability of accurate data. Unfortunately valid data from meteorological stations for regions of interest are quite rare in Albania. In these cases, use of Solar Radiation Database of NASA would be a satisfactory solution for different case studies. The main objective of this study is to compare data provided by Database of NASA with available ground data for regions covered by national meteorological net. There are several known limitations to satellite based measurements of solar radiation: A number of methods exist for conversion of sunshine duration and solar radiation. Each has a range of data input requirements. All measurements are essentially made at the top of the atmosphere and require atmospheric models to estimate the solar radiation at the ground. NASA estimates that their measurements of average daily solar radiation have a root-mean-square deviation RMSD error of 35 W/m^2 (roughly 20% inaccuracy). Unfortunately valid data from meteorological stations for regions of interest are quite rare in Albania. In these cases, use of Solar Radiation Database of NASA would be a satisfactory solution for different case studies. Using a statistical method allows to determine most probable margins between to sources of data. Comparison of mean insulation data provided by NASA with ground data of mean insulation provided by meteorological stations show that ground data for mean insolation results, in all cases, to be underestimated compared with data provided by Database of NASA. Converting factor is 1.149.

Keywords: solar radiation data, satellite data, statistical method, comparison, solar ground data.

1. INTRODUCTION

Satellite-based solar radiation estimates have recently been incorporated into the 1990–till now, update to the 1961–1990 U.S. National Solar Radiation Database (NSRDB). The National Aeronautics and Space Administration (NASA) also supplies satellite-based estimates of solar radiation. **[1] [2].** The usefulness of such data with respect to solar resources for site selection and designing solar energy conversion systems is often questioned. The availability of data at several ground stations provides an opportunity to compare historical satellite-based estimates of solar resources with measurements carried by ground stations. The NASA SSE website produces MMDT representing the averages of the NASA 22-year period records. Solar radiation measurements from NASA satellites provide the only source that is truly global in coverage **[2] [6].** Data is available in near-real time for daily averages at 3 hour intervals. It can be accessed free of charge from NASA's POWER (Prediction Of World Energy Resource) website. A gridded form of the NASA data for 2003-2005 is available **[3]** from NREL (SUNY 10km data). This satellite data is also post-processed and distributed in near-real time by various data resellers. Advantages of Satellite data are the spatial resolution, long term data (more than 22 years old), no ground sites necessary, low costs, effectively no failures. **[9]** There are several known limitations to satellite based measurements of solar radiation: Cloudiness, atmospheric transmission, latitude and orientation of the Earth relative to the Sun, time of day, slope and aspect of the surface determine the spatial and temporal distribution of irradiance incident on a surface. A number of methods exist for conversion of sunshine duration and solar radiation. Each has a range of data input requirements. Other limitations of satellite data are: The sensors generally cannot distinguish between clouds and snow cover. The measurements are less accurate near mountains oceans or other large bodies of water **[4].** All measurements are essentially made at the top of the atmosphere and require atmospheric models to estimate the solar radiation at the ground. NASA estimates that their measurements of average daily solar radiation have a root-mean-square deviation RMSD error of 35 W/m^2 (roughly 20% inaccuracy). The World Climate Research Program estimated that routine-operational ground solar radiation sites had end-to-end inaccuracies of 6-12%, with the highest quality research sites in the range of 3-6% inaccuracy **[2]**. Other researchers comparing NASA solar radiation measurements to ground-based sites have found comparable results (19% average error in the daily data). It is evaluated that quality ground-based sites are clearly more accurate than the satellite models, as long as they are well-maintained. Ground solar radiation sites had end-to-end inaccuracies of 6-12%, with the highest quality research sites in the range of 3-6% inaccuracy. There is no way to measure definitively the accuracy of any solar radiation data, but can be compare it to known high-quality data and make reasonable estimates **[7].** Ground measurements have high accuracy (depending on sensors), high time resolution. On the other side they have high cost of installation, soiling of the sensors and could not gain data for the past. **[9] [5].** To this end, we compared our data to solar radiation measurements, and daylight solar hours for some location in Albania spread out all over the country.

2. METHODS OF STUDY

The monthly averaged daily radiation, monthly averaged daylight hours were obtained from the Archives of Institute of Meteorology in Albania. The data obtained covered a period of last 7 years, These values are statistically sufficient to make a comparison with data provided by NASA.

a. In the literature, several statistical test methods are used to evaluate the performance of the models of solar radiation estimations. Among these, correlation mean bias error (MBE), root mean square error (RMSE), and the t-statistic (t-stat) errors are the most widely used ones. **[1], [3] ,[8].**

The mean bias error (MBE) provides information on the long-term performance of the correlations by allowing a comparison of the actual deviation between calculated and measured values term by term.

$$MBE = \sum_{k=0}^{n} J_k - X_k) /\mathrm{n}$$

Where J_k is the estimate of one of the methods and X_k is the estimate of other method for the same event. In our case J_k stands for ground estimation and X_k stands for NASA estimations The root-mean-square error (RMSE) is a frequently used measure of the differences between values predicted by a model or an estimator and the values actually observed from the thing being modeled or estimated. RMSE is a good measure of precision. The value of RMSE is always positive, representing zero in the ideal case.

$$RMSE = \sqrt{\sum_{k=o}^{n} \frac{\left(J_k - X_k\right)^2}{n}}$$

MBE detect and evaluate any systematic difference between two sets of data, it is a parameter that can be user to convert estimates given by each of the methods to each other. A low value of MBE indicates that both methods gives equivalent estimates (systematic error is small). On the other hand, RMSE evaluate statistical distribution of value of systematic difference between two sets of data.

In order to determine if two measuring methods provide estimations that can be considered statistically different we used the t-statistic.

$$t - stat = \sqrt{\frac{(n-1)MBE^2}{RMSE^2 - MBE^2}}$$

Data of solar radiation on horizontal surface used for comparison are data from different stations located in different regions of the Albania (Source INEUM), and data by NASA satellite based models. Another set of data was provided on line by a ground meteorological station located at the Faculty of Electrical Engineering in Polytechnic University of Tirana. Data are illustrated in charts for monthly averaged values, daily averaged values. (SOURCE FIE, UPT, Tirana www.fie-dsef.net;. NASA data for Tirana. (Latitude 41,328, Longitude 19.819 was chosen. SOURCE: Atmospheric Science Data Center, http://eosweb.larc.nasa.gov/sse

3. RESULTS AND DISCUSSION

In Table 1, 2 and are shown monthly total insulation in kWh/m^2 and. The data are for each month of the year and in total of seven years average. Data are collected from stations located in the cities. The instrument used for these data was a Campbell-Stocks one. These data are calculated for a period of 7 years, already by the Source INEUM. **[10]**

Table 1:
The monthly amount of total insolation *(kWh/m^2/m)*, *Source INEUM*

Month/ *City*	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Shkodra	55.39	68.06	102.42	128.98	162.99	182.70	200.04	174.66	135.57	91.24	64.42	55.81
Tirana	60.97	72.79	103.85	130.61	172.70	194.83	207.31	189.67	142.16	102.11	67.98	60.12
Fier	67.32	77.99	121.79	156.25	196.23	215.14	226.32	212.10	157.96	112.16	76.12	67.15
Vlora	70.06	71.22	101.97	144.38	179.98	204.44	221.69	208.89	163.21	118.22	83.41	79.34
Durres	70.61	77.02	102.56	142.91	174.07	192.44	214.45	200.17	166.62	118.22	79.92	71.79
Kuçova	70.64	74.71	97.91	137.49	175.41	195.11	213.82	199.54	161.62	111.27	77.60	72.96

Table 2:
Monthly average of insolation, *kWh/m^2/month*), *Source NASA*

Month/ *City*	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Shkodra	53.63	68.6	110.36	129	167.4	192.3	205.84	180.11	128.7	89,28	51.9	43.4
Tirana	59.52	77.0	128.65	157.5	204.29	229.2	239.32	205.84	152.7	105.09	61.2	48.05
Fier	61.69	79.8	130.2	157.2	203.05	227.1	237.46	205.22	152.4	106.64	63.6	49.6
Vlora	61.69	79.8	130.2	157.2	203.05	227.1	237.46	205.22	152.4	106.64	63.6	49.6
Durres	61.38	81.76	133.92	164.4	210.18	229.2	237.77	208.01	152.4	105.4	63,3	52.39
Kucova	61.69	79.8	130.2	157.2	203.05	227.1	237.46	205.22	152.4	106.64	63.6	49.6

Table 3:
Results in comparison of models that estimate Satellite and Ground data

Location	**MBE in *kWh/m^2***	**RMSE in *kWh/m^2***	**t-stat**	**Degree of freedom n**	**Critical Values t-statistics Significance level 0.05%**
Shkodra	0.15	7.09	0.069	11	1.796
Tirana	-13.60	20.68	2.896	11	1.796
Fier	1.05	9.10	0.384	11	1.796

Vlora	-2.26	18.12	0.417	11	1.796
Durres	-7.44	22.05	1.190	11	1.796
Kucova	-7.17	19.92	1.276	11	1.796
All above regons	-4.88	17.19	2.490	71	1.666

Results of MBE in Table 3 show that for most of the cities and the country as a whole have negative values. This means that ground estimations, in general, are smaller than NASA estimations. The differences vary from highest value 13.6 kWh/m^2 per month for city of Tirana to 4.88 kWh/m^2 per month for all regions analyzed. However, considering calculated values of RMSE and t-stat, only MBE calculated for city of Tirana is statistically relevant (t-stat = 2.896 is much greater than critical value of t-stat = 1.796, for a confidence 95%), which a prove that there is a difference between ground estimates and NASA estimates. The significance level, α, is most commonly used, it is significance level is taken α = 0.05. In above mention cases the absolute value of the test statistic is greater than the critical value (0.975), and then we reject the hypothesis that ground estimates and NASA estimates are identic. NASA estimates are greater than ground estimates by 13.60 kWh/m^2 per month. However, we cannot confirm the same thing for other regions. Nevertheless if we consider the data for all six regions, which makes sense, we can agree that there is a difference of 4.88 kWh/m^2 per month, which can be used to convert ground estimates to NASA estimates, and vice versa. Considering that mean monthly insolation calculated from ground estimation is 131,4 kWh/m^2 per month, the correction in percent is only 3.7%. The mean bias error MBE, being a systematic error, varies in a wide range from -13.6kWh/m^2 per month in Tirana to 1.04 in Fier (the negative value shows underestimation by the model used for determination of data). **[8]** Also, the root mean square error (RMSE) varies in a wide range, between 22.04kWh/m^2 in Durres and 7.08kWh/m^2 in Shkodra. Both indicators suggest that set of data records provided by INEUM may have been object of inaccurate human reporting.
To check the above hypothesis, it is the possible human interference in the alteration of data records for solar insolation provided by INEUM; we compared the data of solar insolation provided online by a meteorological station "DAVIS", installed in the Electrical Engineering Faculty in comparison with NASA solar radiation. Meteorological station "DAVIS", active from April 2008, provides and registers, among other, data for solar insolation every 15 minutes. Even the period considered is not very long, comparison of estimates will give useful information, which can become more accurate in a second time. In table 4 are shown measured data for solar insolation recorded by meteorological station "DAVIS" for years 2008, 2009 and 2010 together corresponding data recorded by NASA.

Table 4:

Monthly averaged value in $kWh/m^2/month$												
Month/ Year	JAN	FEB	MAR	APR	MAY	JUNE	JULE	AUG	SEPT	OCT	NOV	DEC
2008	---	---	---	101.36	182.48	194.73	216.16	197.43	129.78	111.82	64.00	53.861
2009	42.584	71.967	102.03	137.88	200.03	181.97	222.53	197.37	138.9	90.059	54.776	33.596
2010	46.684	47.183	117.54	141.26	166.52	193.11	221.2	194.24	130.54	88.08	35.90	40.46
Mean	44.63	59.57	109.78	126.83	183.01	189.93	219.96	196.34	133.07	96.65	51.55	42.63

NASA	59.52	78.375	128.65	157.5	204.29	229.2	239.32	205.84	152.7	105.09	61.2	48.05
Averaged value of solar radiation per day, in kWh/m^2/d												
Year	JAN	FEB	MAR	APR	MAY	JUNE	JULE	AUG	SEPT	OCT	NOV	DEC
2008	---	---	---	3.37	5.88	6.49	6.97	6.36	4.326	3.607	2.133	1.73
2009	1.374	2.57	3.29	4.59	6.45	6.06	7.17	6.36	4.63	2.90	1.82	1.08
2010	1.50	1.68	3.79	4.70	5.37	6.43	7.13	6.26	4.35	2.84	1.19	1.30
Mean	1.43	2.12	3.54	4.22	5.9	6.32	7.09	6.32	4.43	3.11	1.71	1.37
NASA	1.92	2.75	4.15	5.25	6.59	7.64	7.72	6.64	5.09	3.39	2.04	1.55

Mean monthly and daily of solar insolation; SOURCE FIE, UPT and NASA

Table 5

Results in comparison of measured data for solar insolation recorded by meteorological station "DAVIS" and solar insolation estimates provided by NASA

Location	MBE	RMSE	T-stat	Degree of freedom n	Critical Values t-statistics Significance level 0.05%
Monthly insolation	-17.977	20.23	6.43	11	1.796
Daily insolation	-0.594	0.67	6.34	11	1.796

In table 5 are shown results in comparison of measured data for solar insolation recorded by meteorological station "DAVIS" and solar insolation estimates provided by NASA. **[11] [12]** Values of t-statistics for monthly insolation and daily insolation are 6.43 and 6.34 respectively, much greater than critical values of t-statistics for significance level 0.05%, 1.796. This is clear evidence that ground data are underestimated compared with satellite estimates.

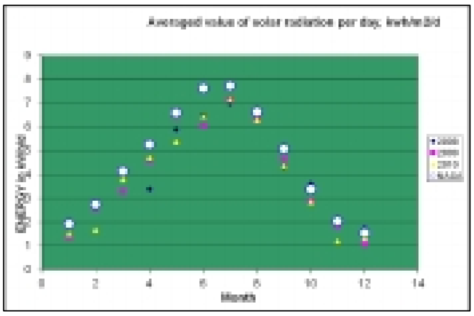

Figure 1: Plot of mean daily insolation in kWh/m^2/day, ground measurements and NASA estimates

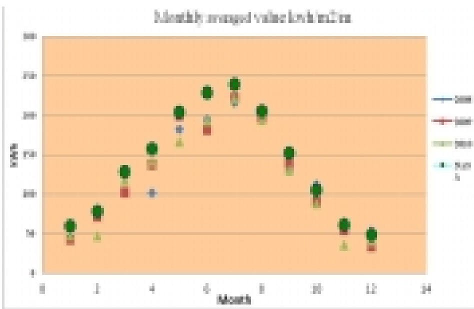

Figure 2: Plot of mean monthly insolation in kW/m^2/month, ground measurements and NASA estimates

Considering that mean monthly insolation and mean daily insolation for ground measurements are 121.2kWh/m^2 per month and 3.97kWh/m^2 per day, respectively, converting factor of ground estimation to satellite estimation would be 1,149. The mean difference between ground estimates and satellite estimates is 14.9%, which is a value very near to evaluation carried by NASA. **[3]**

In Figure 1 and in Figure 2 is plotted mean monthly insolation and mean daily insolation for ground measurements and NASA estimates. Both figures clearly visualize the fact that satellite estimates are overestimated compared with ground measurement values.

3. CONCLUSION

In this study we evaluate and compare solar insolation estimation data provided by NASA satellites with data of measurements made by ground meteorological station in Albania. Statistical evaluations show that data records of measurements carried by INEUM are underestimated around 3.7%. However, considering very high value of dispersion of values measured for different regions, there reasonable doubts of human errors in alteration of data records.

Comparison of data of solar insolation provided online by a meteorological station which provides and registers, among other, data for solar insolation every 15 minutes with NASA estimations, showed that the mean difference between ground estimates and satellite estimates is 14.9%, which is a value very near to evaluation carried by NASA for Solar Radiation. This result suggests a careful approach to the use of data for solar insolation provided by individual measurements and registration.

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