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THREE YEARS OF OBSERVATIONS ON GLOBAL SOLAR RADIATION AT MĂDÂRJAC WEATHER STATION (270 m) - CENTRAL MOLDAVIAN PLATEAU

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Abstract. This study is based on 3 years of hourly observations of global solar radiation (2014-2016), at a new weather station installed in the region of Central Moldavian Plateau, at Mădârjac (47.05˚N, 27.25˚E, 270 m). The main characteristics of annual, monthly and daily regime of global radiation were emphasized using for comparison similar data from Iașioficial weather station. Smaller annual amount of global solar radiation than those observed in previous studies were observed, reaching 4734 MJ/m^{2}in Iași and 4454 MJ/m^{2}in Mădârjac.An altidudinal gradient of global solar radiation close to 140 MJ/m^{2}was identified for the hilly region of Moldova. Despite the overall higher values in Iași, 30% of days indicates higher values of this parameter at Mădârjac weather station. These results can be used for the evaluation of the photo-voltaic potential in the region, but also to understand the altitudinal differences of solar radiation in the hilly region in Moldavia, since the only long-range actinometric stations from this part of Romania, Iași and Galați, are located at low altitudes.

Introduction

Radiation measurements in Romania were very sparse before the onset of automatic weather stations after2000. For this reason, the evaluation of solar radiation was classically based on 8radiometric stations covering theentire Romania.The region of Moldova was covered just by the radiometric stations of Iași and Galați, both at low altitude, hilly and montainous area being deprived of such observations,being considered that this meteorological

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element is characterized by a homogenousspatial distribution, even if it is obviousthat this two points of observation are not enough for such a large territory (Oprea and Costache, 2005). Since the spatial distribution of this climatic element is more complex than it is generally considered, being influenced mainly by the characteristics of the local horizon and cloud cover (Andrițoiu and Diaconescu, 1963, Buiuc, 1984, Sima and Ciocoiu, 1986), the evaluation of global solar radiation - formed by the sum of direct and diffuse radiation - was mostly based onAngström formula. This formulaoffers the possibility to evaluate global solar radiation as a function of sunshine duration measured by heliographs.This was the main method used in Romania to estimate the global solar radiation (Țâștea, 1961,Neacșa and Popovici, 1969, Oprea and Costache, 2005). Additionaly, some authors estimate this parameter on the basis of other functions integrating sunshine duration and opacity of the atmosphere (Buiuc, 1984). Also, for more complex terrain, in order to evaluate the global radiation depending on the morphometric details of the relief, Kämpfert-Morgen nomogram has been used (Patriche, 2005, Sfîcă and Patriche, 2007). In this context, the development of new studies focusing on direct measurements and evaluation of global solar radiation represents nowadays a very important topic in the field of applied meteorology.

1. DATA

After the installation of automatic weather station solar radiation measurement are denser, but their capacityto cover with data all the altitude intervals remains very weak. For that, nowadays, there is a great demand fornew pointsof observation. In this idea, from March 2013 was installed at Mădârjac (270 m) in Moldavian Central Plateau, a weather station which measure among a serie of weather elements also global solar radiation at hourly level. The study region presents distinct physico-geographic considitions (Patriche, 2005) which can be considered representative from the point of solar radiationfor the hilly region of Moldova extended between 200 and 500 m altitude.

This work presents the main results of the measurement for 2014-2016 and compares these observations with similar observations from Iași official weather station of Romanian National Meteorological Administration during the same period. The weather data is installed in proper terrain conditions with open horizon for solar radiation measurements (Fig. 1). The data logger offers data in kWh/m^2 which have been converted in this study to MJ/m^2(1kWh/m^2 = 3,6 MJ/m^2). Taking to account the small errors parameters for the solar radiation data logger, Delta-T devices deliver observations which can be considered fully compatible with those from the data logger used in the Vaisala logger from Iași weather station. The data are archived hourly (official winter time) and organised in the study at annual, monthly, daily and hourly levels.

Fig. 1 - Mădârjac Delta-TWeather Station (left) and its radiation sensor (right)

2. RESULTS AND DISCUSSION

Annual and monthly level.At annual level, for 2014-2016, the mean annual global radiation amount reaches 4734 MJ/m^2 at Iași and 4454 MJ/m^2 at Mădârjac (Tab. 1), values which are smaller than those obtained on longer time scale for Iași (Neacșa and Popovici, 1969, Oprea and Costache, 2005). Beyond the smaller length of observation periods,this could be explained by a general decrease of global solar radiation observed on Romania in the last decennies, attested if we compare the data from Neacșa

Tab. 1 - Global solar radiation at Iași and Mădârjac (MJ/m^2) for 2014-2016

	2014	2015	2016	Mean
Iași -70m	4560	4875	4766	4734
Mădârjac - 270 m	4145	4619	4598	4454
Difference	415	256	168	280

and Popovici(1969), Oprea and Costache (2005)and Oprea (2008). As well, the fact that our results are based on direct measurements can represent a possible cause for these different values, aspect which needs to be clarify in the future. Also, the changes in the local horizon of weather stations, which can modify the sunshine duration, represents another possible cause of this decrease of this global solar radiation in the last years.The lower value of the multiannual global radiation in Mădârjac is related to the role of higher altitudes for the increase in cloud coverand the decrease in opacity due to air pollution.Therefore, the average multiannual value is lower in Mădârjac than in Iaşi.

The monthly maximum of July overpass 650 MJ/m^2 in both points while the minimum from December or January remains above 100 MJ/m^2(Tab. 2).The minimum is reached in January at Mădârjac and in December at Iași, the situation being determined by the high frequency of low stratiform clouds during the cold season, but also by the overall higher relative humidity in the lower layers of the troposphere which plays the most important role for the extinction of direct solar radiation (Sandu et al., 1991).Also, it is known that due to low Sun elevation above the horizon during the winter solstice time the amount of global radiation represents just 20-30% of values being recorded in June for a overcast sky (Andrițoiu and Diaconescu, 1962). In fact, this values recorded in December or January are among the lowest global solar radiation values observed in winter in Moldova, but also in Romania (Oprea, 2008).It should be underlined that while Iași displays a normal annual global radiation regime for Romania with monthly minimum during December (Bâzâc, 1983), at Mădârjac the minimum is recorded during January.

December is the only month in which the average values of global radiation from Mădârjac exceeded those from Iași. This is due to the thermal inversions in the low area, from Iași, in December. In January, in predominantly anticyclonic regime, both stations are frequently embedded in the thick air layer of total thermal inversions in the anticyclonic air mass, both stations being in the same conditions from this point of view.

Tab. 2 - Monthly regime of global radiation (MJ/m^2) at Iași and Mădârjac for 2014-2016

	J	F	M	A	M	J	J	A	S	O	N	D
Iași	120	178	344	480	629	692	707	627	456	253	136	112
Mădârjac	114	169	307	442	604	642	648	603	440	238	123	123

At annual level, a mean difference of 280 MJ/m^2 is observed between Iași and Mădârjac for 2014-2016 which indicates a vertical gradient of 140 MJ/m^2 per 100 m for Central Moldavian Plateau. We should remind that the vertical gradient within the boundary layer under 500 m altitude is considered to be negligible in Romania (Oprea and Costache, 2005).

Actually, from September to February, the differences between Iași and Mădârjac are very small or even negative (Fig. 2), emphasizing the role of amore uniform distribution of water vapor pressure in altitude (Sandu et al., 1991). Associated with that, the higher frequency of thermal inversion in the region that leads to the formation of low stratiform clouds contribute to this uniformisation.

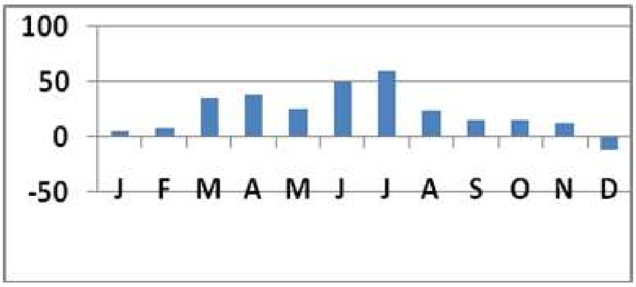

Fig. 2 - Monthly differences of global radiation (MJ/m^2) at Iași and Mădârjacfor 2014-2016

From March to July (Fig. 2) the more active atmospheric circulation disrupts the consistency of stratiform clouds inducing higher differences between Iași and Mădârjac. The lower/higher differences from May/July is a function of total cloud cover in the region of Moldova. The maximum from July and August in both points represents a common fact for temperate zone, being caused by a steep increase of direct solar radiation, which weights more than 50% from global solar radiation (Buiuc, 1984).

Daily and hourly level.Hourly variations of global radiation during the day follows at Mădârjac a normal pattern, with maximum values at 12 AM at annual level and in July and 13 AM in January (Fig. 3). The delayed maximum in January is caused by the propagation of stratiform morning clouds during the midday. The midday maximum is 4 time higher in July than in January, reaching 75 MJ/m^2.

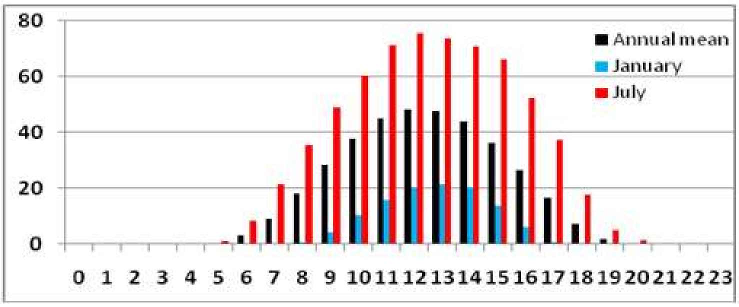

Fig. 3 - Mean hourly amount of global radiation (MJ/m^2) at Mădârjac weather station (2014-2016)

During the ***cold season*** negative difference between Iași and Mădârjac are more frequent at daily level (Fig. 4). This situations are recorded mainly underanticyclonic regime when stratiform clouds and fog are covering the low lands.For instance, on 23 of December 2016 (Fig. 3b), solar radiation was totally obscuredat Iași weather station while at Mădârjac the sky was clouds free. This represents a common phenomenon during the cold season in the region of Moldova, as shown by Sfîcă (2010) for Siret corridor, with a prevalence in November and December, a period during which compact cloud cover can reduce with 50% the total global radiation flux (Oprea, 2008).

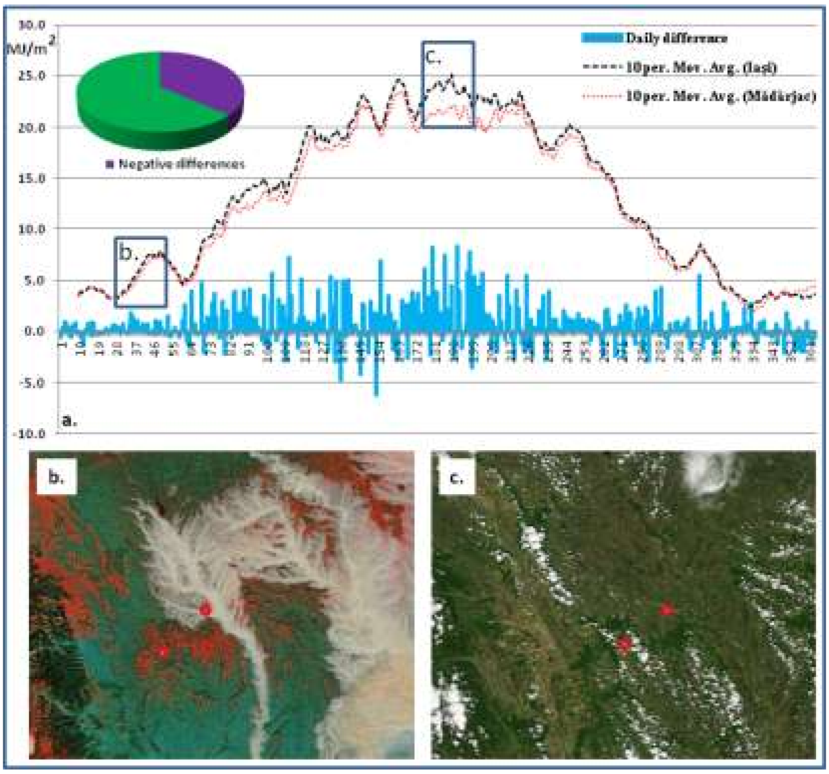

Fig. 4 - Daily differences of global radiation (MJ/m^2) at Iași and Mădârjac for 2014-2016 and satellite images representative for the main types of daily differences

It is known that because of the disinct characteristics of optical depth of the atmosphere during winter the lowlands receive less global solar radiation than the higher grounds (Bâzâc, 1983).As a direct consequence of this fact, at annual level, more than 130 days present negative differences between global solar radiation at

Iași and Mădârjac. These negative difference lead to a uniformisation of global solar radiation between the lowlands (Moldavian Plain, Prut, Bârlad and Siret valley) and the higher hills in the region of Central Moldavian Plateau. Despite this role of low stratiform clouds for the occurence of these negative difference, the highest negative difference - reaching 6-8 MJ/m^2 - are recorded in May - July. Inthis case, the explanation is given by large disparities in the distribution of cloud cover during interval dominated by convective instability in the region.

For the ***warm season*** positive difference between Iași and Mădârjac are prevalent and this is mainly caused by the development of cumuliform clouds covering the hilly region of Moldova, while the lowlands are cloudsfree (Fig. 4c). At annual level these situations occur mostlyin summer, imposing positive daily difference above 5 MJ/m^2 between Iași and Mădârjac. These situations are persistent for the late June, Jully and even the beginning of August, with a large contribution to the annual global solar radiation differencesbetween the these point.

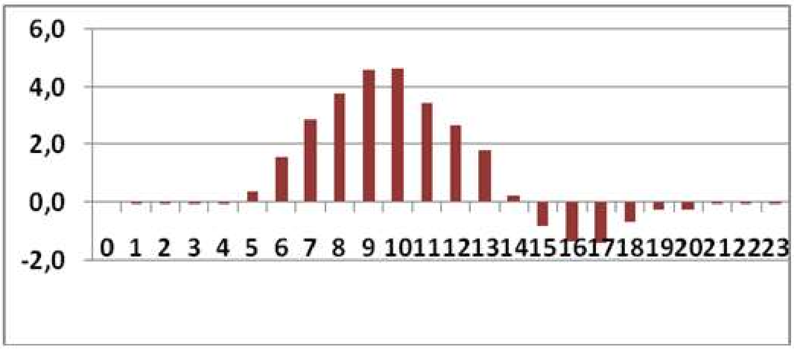

Fig. 5 - Hourly differences of global radiation (MJ/m^2) at annual level between Iași and Mădârjac for 2014-201

The differences at hourly level between Iași and Mădârjac reveal some intriguing aspects. While normally positive values prevail from 5 AM to 14 PM, from 15 to 20 PM negative values are dominant (Fig. 5). Normally, positive difference should persist throughout all day. So, the explanation of this anomaly could be given by some underestimation of the global solar radiation in theafternoon hours at Iași weather station due to the characteristics of the local urban horizon.

Conclusions

New measurements of global radiation were preformed in a geographical regionwhich is not covered by official observation, at Mădârjac (270 m)in CentralMoldavian Plateau. Our results show smaller values of mean annual global solar radiation than in previous studies for Iași, and a very important role of stratiform and cumuliform clouds in the repartition of this radiative parameters in the region.

The results of this measurement campaign can improve the image of the amount and distribution of global radiation in Romania, which is a very important fact for a precise evaluation of the photo-voltaic potential in this area. Also, it emphasize the necessity for more observations on solar radiation, in order to arrive to a full picture of this climate element.

In terms of photo-voltaic potential, these general global radiation characteristics presented above could sustain a production of electric energy for a regular solar panel varying at 12 AM from 23kWh in July (32kWh for Iași) to 6 kWh (similar to Iași) in January.

Aknowledgement. The weather station of Mădârjac was installed during the implementation of the project „ ***Complex landslide monitoring system using traducers based on new materials and technologies***, PN-II-PT-PCCA- 2011-3.2-0975, nr. 63/2012, project coordinator Prof. PhD. Cristian Zeț

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