Evaluation of the Solar Radiation in a Seismic Zone

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Abstract. The solar radiation affects the life on Earth and it is important in meteorology, climatology, solar energy, agriculture, hydrology and seismology, too. The Sun warms the earth which reflects a part of the energy. An effect of tectonic stress increases the ground temperature that is radiated into the atmosphere. We study the possibility to use the variation of reflected energy in correlation with seismicity, radon concentration, CO₂ emission, ULF radio waves, telluric currents, air ionization, temperature in borehole and acoustic noise. In this case, the solar radiation is a precursor factor. This research is important to study the effects of climate change. Analyzing the solar energy budget we find information about the atmosphere: aerosols, ozone, sulfur dioxide, carbon dioxide, nitrogen dioxide and pollution. Our multidisciplinary network (AeroSolSys) monitors Vrancea, a Romanian area characterized by deep earthquakes. For this study, we use two stations, Ploștina and Vrancioaia, where we have a net radiometer and a pyranometer. The first sensor includes two pyranometers (up and low) and two pyrgeometers (up and low), a Pt-100 and a Thermistor. The spectral range covers both the Solar Radiation, 0.3 to 3 micrometers, and the Far Infrared Radiation, 4.5 to 42 micrometers. In this case, we measure and determine the temperature of sensor necessary for pyrgeometers, pyranometer short-wave radiation up and low EyU - EyL, pyrgeometers long-wave radiation up and low EgU - EgL, Albedo, net solar radiation NSR, net far infrared radiation NFIR, net total radiation NTR, sky temperature SkyT and, land surface temperature LST. In Vrancioaia, we have a pyranometer with range 0.3 – 2.8 micrometers and max 1600 W/m². Two video cameras monitor the sky and the measurements are correlated with meteorological equipment installed in each location. We use information about solar activity from NOAA satellites and Copernicus CAMS. The humidity of ground is important in energy budget and it is estimated from meteorological data and telluric currents. The interval of analysis is 3 hours, between 2016.01.01 – 2018.05.31. It is difficult to notice the effect of tectonic stress since the daily and seasonal variations of solar radiation are high but global warming is obvious. Solar radiation monitoring helps us to understand other phenomena like radon emission or air ionization.

1. Introduction
First of all solar radiation study is important for life on Earth. Along with the term solar radiation, irradiation and irradiation are used in many scientific works. Irradiance is the solar power expressed in W/m² and irradiation is solar energy expressed in Wh/m². Our study is based on pyranometers for
measuring the irradiance and pyrgeometers for Far Infrared Radiation. We are looking after anomalies that could be caused by tectonic stress. Many articles on solar radiation aim to assess the energy potential in a location for the installation of a photovoltaic (PV) plant. The design of a solar power system needs a study of the place. The simplest way is to install a pyranometer but there are many methods for estimating the solar radiation. In some cases, a fuzzy algorithm is used ‘to track complicated dependencies between different variables’: sunshine duration, air temperature, precipitation, relative humidity [1], [2]. European Commission elaborates Photovoltaic Geographical Information System (PVGIS) to estimate the solar radiation intensity in order to develop green energy. The satellites are used for this purpose but the result is an estimation because the atmosphere introduces many errors [3], [4]. Many empirical models are used to evaluate the monthly average daily global solar radiation, an essential parameter in design photovoltaic plant. A.M. Muzathik et al. selected Angstrom-Prescott model [2], A. B. Jemma, et al. used Linear model, Quadratic model and Cubic methods [5], other five models for estimating clear-sky solar radiation by R. L. Annear, and S. A. Wells with application in water quality [6]. Department of Ecology, State of Washington (https://ecology.wa.gov/), developed models and tools for water quality improvement that includes solar radiation evaluation. SloRad is an Excel/VBA application that uses Bird, Bras, and Ryan-Stolzenbach models for calculating solar radiation. Recently we use Cumulus software for our meteorological stations that determinate with Ryan-Stolzenbach method [6] maximum solar radiation value at the current date and time in a location. Many parameters are used for developing an empirical relation for evaluating the solar radiation in a location: extraterrestrial radiation, sunshine hours, relative humidity, ambient temperature, soil temperature, number of rainy days, altitude, latitude, cloudiness [7], ozone, and aerosols optical depths. Our interest in these methods is to determinate the anomalies produced by tectonic stress.

![Figure 1. The global annual mean energy budget of Earth [8], 2000 – 2010, W/m²](image)

Many articles refer to the solar energy budget correlated with climate change and increasing concentrations of greenhouse gases. Figure 1 presents the solar (yellow) and infrared (pink) fluxes
Sensible, latent heating and outgoing longwave radiation could be affected by tectonic stress (increasing land temperature, aerosols, radon, air ionization, CO₂, CO). We monitor a part of these parameters and try to find anomalies correlated with seismicity. Analysis of energy budget and its relationship to climate change started a few years ago. Until now, global warming has visible effects, and ground-satellite investigations have developed a lot. In 2008, J. T. Fasullo and E. Kevin analyzed the annual cycle of energy, climate system, storage-release in the atmosphere, ocean and land surface. They used the Earth Radiation Budget Experiment (ERBE) and Clouds and the Earth’s Radiant Energy System (CERES). Their analysis was developed in “Earth’s Global Energy Budget” [9] and the conclusion is that “shortwave energy is transformed into sensible heat, latent energy, potential energy, and kinetic energy before being emitted as long wave radiant energy”. This cycle is affected by tectonic stress.

We use information from a multidisciplinary network (AeroSolSys) located in Vrancea seismic area which is a part of National Institute of Earth Physics (NIEP) from Romania. Using solar radiation in a seismic area is a new approach to assessing the effects of tectonic stress.

2. Monitoring Network, Seismic Area, Equipment

Figure 2 presents the photovoltaic power potential in Romania, Vrancea seismicity and the monitoring locations (BISR, ODBI, PANC, VRI, PLOR7 or PLOR or PLST, COVR, MLR, NEHR, and LOPR). AeroSolSys monitors seismicity, telluric and magnetic field, electric-electrostatic field, radio ULF waves, air ionization, radon concentration, solar radiation, infrasound, light and acoustic phenomena, meteorological data, air-ground (borehole) temperatures, and satellite data with application in the Vrancea seismic area. We use two sensors for measuring the solar radiation and in one case the Far Infrared Radiation (Figure 3). We evaluate the cloud attenuation parameters with two video cameras that record continuously the sky (Figure 4). We monitor clouds that form in seismic areas due to tectonic stress. The increasing of land surface temperature could be a cause. In this case, the energy balance is changed. The pyranometer SMP3 (Figure 3 left) is useful in photovoltaic application. Better data quality and more information are obtained with CNR4 from Kipp&Zonen. (Figure 3 right). It includes two pyranometers (0.3 to 3 µm) and two pyrgeometers (4.5 - 42 µm), a Pt-100 and a thermistor.
Figure 2. Multidisciplinary monitoring network, seismic energy, hypocenters distribution in Vrancea area

Figure 3. Pyranometer SMP3, Net Radiometer CNR4 Kipp&Zonen

Each multidisciplinary location has a meteorological station La Crosse Technology WS2355. NIEP developed a new more preformat network with Davis Vantage Pro2 equipment. Weather stations help us to correlate our measurements with atmospheric conditions. A special temperature sensor works in Plostina station since 2007. It is a K thermocouple in a 1 cm x 1 cm piece of copper and it is oriented to the south. We have tried to find a simple and cheap solution for assessing solar radiation and the presence of clouds (plst2_Taer signal in Figure 10 and PLST in Table 1). In the same station, we have Boltek EFM-100 equipment for atmospheric electric field monitor and lightning detection. The telluric field measurements, radon and air ionization are correlated with these data (plst2_PLT0, plst2_PLT0, Figure 10).
Figure 4. Solar monitoring in PLOR7 station

The multidisciplinary network (Figure 2) includes seismic, telluric – magnetic field, infrasound, weather stations, radon, ionization, CO₂, solar radiation, etc. equipment, and belong to NIEP – Romania (National Institute for Earth Physics).

3. Methods and Data Analysis
We measure upward-facing and downward-facing solar short wave radiation and long wave far infrared (thermal) radiation and calculate Albedo, net solar radiation NSR, net far infrared radiation NFIR, net total radiation NTR, sky temperature SkyT and, land surface temperature LST. We correlate these data with meteorological information, too. In Plostina station we monitor the air ionization and radon concentration. Figure 5 – Figure 8 presents the Albedo evolution in 3 hours’ time in spring, summer, autumn and winter 2017. The CO₂ is determinate in NEHR station (Figure 9) with a minimum in the interval of 9-17 hours and summer period and it is correlated with solar radiation. We compare real albedo with data from CAMS service (Figure 10 and Figure 11). “Copernicus Atmosphere Monitoring Service (CAMS) McClear Clear-Sky Irradiation service delivers time series of irradiation that would be observed in a specific site in the world under cloud free conditions, with a time step ranging from 1 min to 1 month. The Global, Direct and Diffuse Horizontal Irradiation, as well as the Beam Normal Irradiation, are provided”, http://www.soda-pro.com/web-services/radiation/cams-mcclear. “The SoDa Service is a broker to a list of services and webservices related to Solar Radiation proposed by several providers in Europe and abroad”, http://www.soda-pro.com/home.
SODA Albedo (Figure 11) indicates a maximum in winter season, hours 3-5 and 15 – 17. The maximums in the time intervals correspond to those in the figures 5 – 8 but there are some anomalies. In 17/04/22 (Figure 5), 17/08/01 (Figure 6), 17/12/04 (Figure 7) with +/- 3 days in interval 5 – 17 hours we have maximum values. These moments overlap with Vrancea seismicity (Figure 13): 17/05/19 4.7R, 17/08/02 4.9R and 18/03/14 4.6R.
Figure 9. CO₂ spring 2016, Nehoiu – NEHR station

Figure 10. SODA – McClear user interface for data download

At the top of the atmosphere, the global energy balance is evaluated with satellites [8]. In Figure 12 we have an example from METEOSAT-10, infrared 10.8 µm. Figure 13 presents the relation between many solar parameter, seismicity and NOAA information about the geomagnetic field and solar activity. Signals represent: pst2_PLT0 - pst2_PLT1 telluric field, pst2_Taer temperature in air, plst2_In - plst2_Ip positive and negative air ionization, PLORmto_TRN total rain, PLOR_Tf temperature in borehole at 40 m, PL7S_EyU solar radiation, PL7S_Albedo is EyL/EyU, PL7S_LST[C] land surface temperature, VRId_Radon radon concentration in Vrancioaia station, DGDnoaa and DSDnoaa geomagnetic and solar activity from NOAA, NhCO_Iop air positive ionization in Nehoiu station, NhCO_CO2 is the CO₂ concentration in the same station, and Mdpvs_M magnitude in Richter.
Figure 11. Albedo representation from SODA webservices

Figure 12. METEOSAT-10, infrared 10.8 µm
Figure 13. Solar radiation, radon, air ionization, NOAA, CO$_2$, seismicity, 2016 – 2018/05
We observe in Figure 13 a correlation between albedo and radon concentration. The evolutions are periodically and represent annual variations. A high variation of telluric field (16/06/27) is correlated with air ionization plst2_In and plst2_Ip. We observe a decrease of CO$_2$ (NhCO$_2$) in Nehoiu (Buzau river valley) and of temperatures in few monitoring stations. Table 1 and Figure 14 present the average annual temperature measured by our meteorological stations. PLST represents the temperature measured with a thermocouple oriented to the south that it is used for evaluating the solar radiation. We expected an increase in temperatures caused by global warming but in EFOR, ODBI and VRI is obviously a decrease each year. This station has the same meteorological equipment type.

**Table 1.** Minimum, average and maximum annual temperature in monitoring stations

| Station | 2014, $^\circ$C | 2015, $^\circ$C | 2016, $^\circ$C | 2017, $^\circ$C |
|---------|-----------------|-----------------|-----------------|-----------------|
|         | Min  | Avg  | Max  | Min  | Avg  | Max  | Min  | Avg  | Max  | Min  | Avg  | Max  | Min  | Avg  | Max  | Min  | Avg  | Max  | Min  | Avg  | Max  |
| EFOR    | -13.10| 14.20| 42.20| -14.70| 14.32| 48.90| -12.20| 13.28| 37.90| -16.20| 12.76| 34.80|      |      |      |      |      |      |      |
| NEHR    | -9.00 | 19.44| 36.10| -7.10 | 15.40| 38.10| -15.20| 10.58| 38.50| -18.70| 12.42| 39.90|      |      |      |      |      |      |      |
| ODBI    | -10.5 | 12.87| 35.50| -19.10| 12.93| 38.90| -13.10| 12.46| 36.40| -13.10| 12.33| 41.10|      |      |      |      |      |      |      |
| PLOR    | -17.00| 10.54| 34.90| -16.90| 11.36| 36.80| -14.90| 10.80| 37.90| -17.50| 10.84| 40.20|      |      |      |      |      |      |      |
| PLST    | -24.57| 12.00| 35.62| -19.35| 11.42| 60.29| -16.67| 15.77| 56.51| -18.01| 16.22| 58.97|      |      |      |      |      |      |      |
| VRI     | -30.00| 12.00| 36.50| -19.80| 11.57| 42.20| -17.90| 10.98| 38.7 | -20.10| 10.71| 41.60|      |      |      |      |      |      |      |

![Figure 14. Average annual temperature in monitoring stations](image-url)

This example shows the precursor signals that make the dogs bark. In this case, the main source is the P wave that causes a vibration of the ground and the effect of acoustic waves.

### 4. Conclusions

In our study, we are looking after a relation between solar radiation and seismicity. We found albedo anomalies correlated with seismicity (Figure 5 – Figure 7, in spring, summer and autumn). The position of solar radiation sensors is not quite in an epicenter area but the result is a new approach. The study is useful in monitoring global climate changes too and it has shown the dependence of other
factors on solar radiation (radon, CO2, air ionization, tellurium field). Only a multidisciplinary network allows correlation of events and ensures a reliable forecast.

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