Spatial patterns of global radiation changes and trends over Europe

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Abstract. In the study, we analyse spatial patterns of inter-annual and decadal variations of global radiation, including trials to explain these variations by spatial analysis of cloudiness and aerosol content, as well. In the first part of the study, spatial distribution of the inter-annual variations of global radiation is analyzed, mapped and also classified by hierarchical cluster analyses. The European continent is represented by 66 stations of the ground-based dataset of Word Radiation Data Center (WRDC) for the period 1975-2006. The objective regions of global radiation are compared with those formed by the signs and magnitudes of the linear trend values established for the observed 32 years period of monotonous global warming. In the second part of the study, cloudiness variations and trends are similarly analysed based on the Extended Edited Cloud Reports Archive (EECRA) dataset for the same period and stations, together with a five times more dense set of stations. Patterns of cloudiness variations and trends are compared between each other, and also with those obtained from the global radiation.

Key words

solar radiation, cloudiness, aerosol extinction, climate change, Europe.

Introduction

Solar radiation, directly and indirectly providing the majority of our energy sources, varies in space and time due to fluctuations and changes of atmospheric composition. The cloudiness and aerosol concentration is considered as the two main factors in the atmospheric radiation transfer.

In the recent decades a large number of studies have reported changes in global radiation (solar energy reached at the surface) radiation over Europe based on empirical and model calculations. As a result, the concept of global dimming (STANHILL and COHEN, 2011) and global brightening (WILD et al., 2005) has been introduced in the literature which refers to the decrease and increase of global radiation, respectively. NORRIS and WILD (2007) examined global radiation data from 75 European station and show a decline in solar radiation with 3.1 W/m^2/decades in the period of 1971-1986 and then a solar radiation increases from 1987 to 2002 by 1.4 W/m^2/decades. CHIACCHIO and WILD (2010) pointed out that the global brightening phenomenon is characterizing primarily in the springs and summers in Europe.

However joint analyse of changes in global radiation, cloud cover and aerosol content can be found in smaller number in the literature, mainly because of the lack of the observations. In Europe CHIACCHIO and WILD (2010) quantified the relationship between global radiation and cloud cover based on the NAO index and found significant relationship only during wintertime. STJERN et al (2009) investigated 11 stations in Northern Europe and found that the monthly changes in global radiation and in cloud cover do not establish opposite sign in each case. NORRIS and WILD (2007) also report changes with similar sign in changes is global radiation and cloudiness. LIEPERT (2002) showed that the decrease of the global radiation in the period of 1960-1990 one hand can be explained by the cloud optical thickness increase (inducing 18 W/m^2 solar radiation reduction), on the other hand by the direct effect of aerosols (inducing 8 W/m^2 solar radiation reduction).

In this study we investigate the reasons of the mosaic patterns characterizing the spatial distribution of the trends in global radiation over Europe based on empirical relations between global radiation and cloudiness. The effect of aerosols on global radiation change is also taken into consideration indirectly. The same effect expressed by the water vapour content has also been computed, but its value has been found mach smaller compared to the effects of cloudiness and aerosol variations. In some of these aspects, the limited extent of the present report does not allow to prove everything in this study.

Data and methods

The monthly data of ground-based global radiation data are available from the World Radiation Data Center (WRDC) representing the European continent by 66 stations for the period of 1975-2006.

The synoptic visual cloudiness data is available from the CDIAC international database, namely from the Cloud Climatology for Land Stations Worldwide (EASTMAN és WARREN, 2012). In this study the monthly averaged total cloudiness data have been used for 174 stations. In the case of stochastic analyses 50 stations represents the continent having available data for global radiation as well for the period of 1975-2006. Both databases have been homogenized by MASH method (SZENTIMREY, 2003).

In order to elaborate analyses regarding global radiation multiannual changes two statistical methods were applied. The main statistical method consists in simple linear regression model including the b (slope) coefficient estimation. This model is applied in linear trend analyses where the global radiation is denoted as dependent variable and the time is the independent variable. In each case of trend analyses the hypothesis test of β (equal to 0) was elaborated at 95% significance level. Linear regression model is also used in stochastic analyses estimating the statistical relationship between global radiation and cloudiness. The regression model was tested by the normality and autocorrelation of the residuum.

Results

Changes in global radiation

In the first step we analyzed the linear trends in global radiation based on homogenized WRDC data, in the period of 1976-2006 for 66 stations in Europe (Fig. 1). Linear trends of ground-based data show overall positive changes parallel with increase in temperature over Europe characterizing the investigated period (Jones et al., 2013). 39.3% of the stations are showing significant positive changes and only 1.5% of the stations indicate negative trends. The relative decadal annual change in global radiation is 2.38% (3.38 ±0,33 W/m^2). Fig. 1 shows a mosaic-like spatial distribution of the trends detected in global radiation indicating an increase in solar radiation mainly in the central part of the continent.

Figure 1. *Spatial distribution of trend detected in global radiation in the period of 1975-2006, blue circle – negative significant trend, blank circle – no significant trend, red circle- positive significant trend*

Based on multiannual global radiation means, 4 solar regions have been delimited in Europe by K-mean method (Fig. 2). These regions show strong zonality and different magnitudes of global radiation changes. Zones with the highest number of stations showing significant trends are located in the centre/south-eastern part of the continent (No. 2., more then 60%) and in the southern part (No. 4., more then 40%) of the continent, showing positive significant change in solar radiation. 30% of the stations in the central / north-eastern part of the continent (No. 1) show also positive changes is global radiation, while no significant changes in global radiation is detected in the northern part of the continent (No. 3). Taking into account the magnitudes of the changes, the positive decadal changes of the central part of the continent are +4.1±0.25 Wm^{-2} (south-eastern) and 3.47±0.24 (north-eastern) Wm^{-2}. Slight positive changes are detected in the southern part of Europe, with values of 0.66±0.26 Wm^{-2}/decade. The relative changes of global radiation (compared to the 32 years' means) are 2.78, 2.93 and 0.38%/decade, respectively.

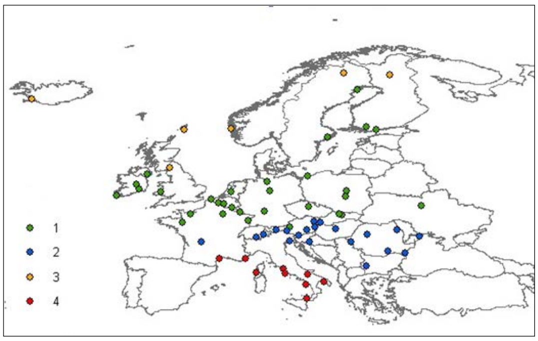

Figure 2. *Global radiation zones in Europe*

Table 1. *The sign and magnitude of global radiation changes of the global radiation zones separately in Europe (1975-2006)*

Zones	Stations (number)	Significant trends (number)	Trends W/m^2 /decades	Trends %
1	30	9 (**30.0%**)	3.47 (±0,24)	2.93
2	21	14 (**66.7%**)	4.10 (±0,25)	2.78
3	6	0 (**0.0%**)	**-**	**-**
4	9	4 (**44.4%**)	0.66 (±0,26)	0.38

Changes in cloudiness

The changes in cloud cover are also estimated using the linear trend approach. Europe is represented by homogenized visual cloudiness data from 174 stations (Fig. 3). On annual average 14.8% of the stations show significant trend in total cloud amount 10.34% with negative and 4.59% with positive sign.

In Fig. 1, positive changes of the global radiation characterise the central and north-eastern parts of the continent, but these areas do not exhibit negative changes in cloud cover. Note that only significant cases are visualized, the smaller changes may exhibit better relationship between the two variables.

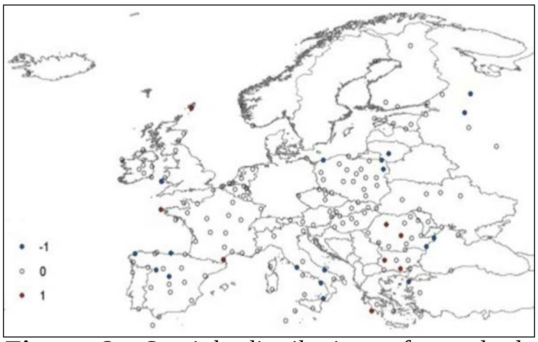

Figure 3. *Spatial distribution of trend detected in cloudiness in the period of 1975-2006, blue circle – negative significant trend, blank circle – no significant trend, red circle- positive significant trend*

Relation between changes in global radiation and cloudiness

To analyze simultaneously the trends in global radiation and cloud cover only stations where data are available for both parameters are taken into account. This condition was fulfilled by 50 European stations (Fig. 4). The sporadic distribution of global radiation changes can be explained mainly by the similarly mosaic variation of cloudiness. In June 80% of the stations show significant correlation between monthly global radiation and cloudiness data at 95% probability, in the case of February this value is 100%. In the case of the annual data the correlation coefficient is 0.61, also significant at 95% probability.

In the same time the simultaneous annual variability of global radiation and cloudiness with opposite sign is indicated only in the 60% of the cases. The difference is present in the percent of stations showing opposite changes as well: 32% of stations are denoting significant positive changes in global radiation, but in the same time only 14% of the stations indicate decrease in cloudiness. Decrease in global radiation occurred in 10% of the stations, while 6% of the stations show increase in cloud cover.

On monthly basis, we find September showing the largest percentage of stations where both variables are significant with opposite trend, in May and June of changes has the same sign. Fig. 4 shows the spatial distribution of the changes in global radiation and cloudiness with similar and opposite sign indicating one-way changes mainly in southern and south-eastern part of the continent. Fig. 5 represents the relative decadal changes is global radiation parallel with the relative decadal changes in cloudiness. The cloudiness change do not explain the changes in solar radiation mainly in the second part of the year.

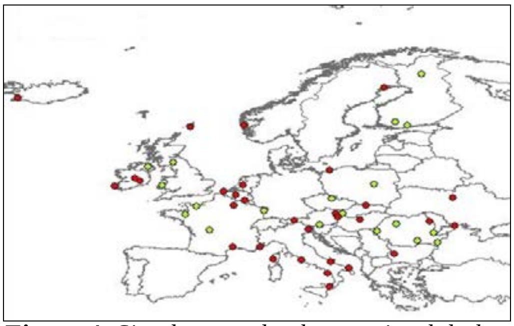

Figure 4. *Simultaneously changes in global radiation and cloudiness. Green circle – opposite sign, red circle – similar sign*

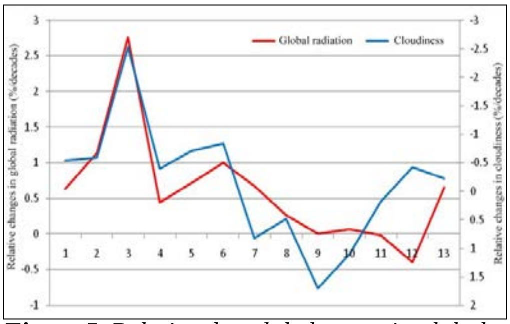

Figure 5. *Relative decadal changes in global radiation and in cloudiness at 50 European stations, 1975-2006*

Conclusions

The sign and magnitude of multiannual changes in global radiation have been determined for 66 European stations for the period of 1975-2006 indicating an increase in global radiation mainly in the central and south-eastern parts of the continent. The mosaic-like distribution of global radiation changes can be explained mainly by the similar variation of cloudiness. In the same time the simultaneous annual variability of global radiation and cloudiness with opposite sign is indicated only in the 60% of the cases. Mainly over the second part of the year clouds do not explain the changes in global radiation. It should be considered that other atmospheric parameters, like aerosol, have an important role in the multiannual change in global radiation.

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