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Multi-annual variability of global solar radiation in the agricultural area of Lower Silesia (SW Poland) and its relationship with the North Atlantic Oscillation

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Abstract. In this paper, the long-term variability of global solar radiation in the agricultural area of Lower Silesia is analyzed based on a 56-year long (1961-2016) measurement series recorded at the Agro- and Hydro-meteorological Wrocław-Swojec Observatory (SW Poland). Yearly and monthly global radiation sums with their extreme and mean values were compared with radiation data from Warsaw (Central Poland) and Potsdam (East Germany). The dynamics of variability between consecutive months, seasons and years was also taken into account. The conducted positive trends show a significant increase in the investigated global radiation sums for Lower Silesia and also for Central Poland and the eastern part of Germany. The trends are strongly related to long-term macro-circulation changes in the North Hemisphere, particularly with the phases and sub-phases of the North Atlantic Oscillation (NAO). The relations between the investigated values of global solar radiation and these macro-circulation patterns are very complicated and they very often have an asynchronous character. The first, juvenile stage of the NAO positive phase (the 1970s and 1980s), when annual sums of global solar radiation in Wrocław-Swojec reached only the average level of about 3 700 MJ·m^{-2} and warm half-year about 2 800 MJ·m^{-2} respectively, was cloudy and rainy. This period was distinctly different than the advanced stage of one (the 1990's and later years) with bigger sunshine duration and smaller annual precipitation, when the adequate radiation sums amount to 3 900-4 000 MJ·m^{-2} and 3 000-3 100 MJ·m^{-2} respectively.

Keywords: global radiation, multi-annual variability, climate change, NAO

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1. Introduction

The increasingly widespread use of sustainable sources of clean energy, such as solar energy, which is an alternative of fossil fuels, calls for a comprehensive nationwide identification of such resources. Detailed analysis, taking into consideration the varying volume and dynamics of the resources on both a regional and local scale, is needed, particularly in the context of climate change. Such analysis is possible for the agricultural area of the Lower Silesia region due to the availability of multi-annual data obtained from measurements of global radiation. The present paper is a continuation of the previous studies of the authors (e.g. Bryś 2006, 2007, 2013, 2015, 2017; Bryś, Bryś 2002, 2003, 2007), with an attempt to determine the parameters and dynamics of the solar features of the climate of Lower Silesia based on radiation trends in Poland.

Past studies on the solar radiation variability in Poland have mainly been based on sunshine duration data (Górski, Górska 2000; Koźmiński, Michalska 2005; Kuczmarska, Kuczmarski 1998; Kuczmarski 1990; Marciniak, Wójcik 1991; Matuszko 2009, 2014; Morawska-Horawska 1985, 2002; Podstawczyńska 2003, 2007; Podogrocki, Słomka 1993). The influence of circulation and climatic conditions on these distributions was presented in detail by Paszyński and Niedźwiedź (1991), Woś (1999, 2010), Kożuchowski et al. (2000).

A similar analysis for the south-western part of Poland, particularly the Wrocław and Sudety Mts., based on atmospheric circulation, was performed by Bryś (2007), Dubicka (1994, 1998), Dubicka and Karal (1994), Dubicka and Limanówka (1994), Dubicka and Migała (1997), Dubicka and Pyka (2001), Dubicka et al. (1995). The relationship between the structure of solar radiation and sunshine duration in Wrocław was presented by Bryś and Bryś (2003, 2007).

The temporal variability and spatial distribution of global solar radiation in Poland based on selected stations of the Polish actinometrical network for different years from the period of 1961-1995 were analyzed in the works of Bogdańska and Podogrocki (2000), Podogrocki (1984, 1989, 2001, 2007). The study of the annual distribution of global radiation in Wrocław and its variability in the years 1961-1980 in relation to macro-circulation weather conditions was made by Dubicka (1994). The potential solar radiation resources of the Lower Silesia (SW Poland) as a source of the so-called clean energy was analyzed by Bryś (2006). The climatic and meteorological conditions necessary for the use of solar energy in Poland were presented by Podogrocki (1989, 2007).

Over the past few decades, many studies have pointed out the change of global solar trends, together with an alternation of radiation periods. Since the 1980s, the so-called period of "dimming", characteristic for earlier decades of the twentieth century, has been displaced by a new "brightening" radiation period (Alpert et al. 2005; Norris, Wild 2007; Ohrvil et al. 2009; Sanchez-Lorenzo et al. 2007, 2017; Stanhill 2005, 2007; Stanhill, Cohen 2001, 2005; Stjern et al. 2009; Streets et al. 2006; Wild 2009; Wild et al. 2005, 2007, 2009). The research performed in Estonia (Russak 1987, 1990; Tooming 2002) and Russia (Abakumova et al. 1996; Abakumova, Bondarenko 2008) and prove that the changes are related both with long-term trends of cloudiness (Kleniewska et al. 2016; Matuszko 2009, 2012; Ohrvill et al. 2009; Stjern et al. 2009; Warren et al. 2007; Wibig 2003, 2004; Żmudzka 2007) and changes in air transparency (Ohrvil et al. 2009; Ruckstuhl, Norris 2009; Sun, Groisman 2000; Uscka-Kowalkowska 2008a, b, 2009, 2013). A great number of research papers point to the anthropogenic genesis of these changes (Ahrens 2008; IPCC 2013; Wibig 2009), yet many other accentuate the importance of natural source factors (Bryś 2005; Bryś, Bryś 2003; Jaworowski 2003, 2007; Kondratyev, Galindo 1997; Marsz 2005, 2010; Marsz, Styszyńska 2002, 2006, 2009; Ohrvil et al. 2009; Pisek, Brazdil 2006; Soon et al 1996). In this context, the key aim of this paper is the presentation of the multi-annual variability of global solar radiation in the agricultural area of Lower Silesia on a broad spatial background, in order to provide new arguments to the discussion on the observed long-term radiation changes in Europe and the North Hemisphere.

2. Materials and methods

The Agro- and Hydrometeorology Wrocław-Swojec Observatory (51°07'φN, 17°10'λE, 121 m a.s.l.) is located in the eastern peripheral, agricultural part of Wrocław (formerly: Breslau). The observatory is located on the side of watershed area, under the hydrological influence of floodwaters from the Odra and Widawa rivers. Such a location facilitates the neutralization of the urban heat island (UHI) and accentuates the frequency of winds from the WNW-NW sector (Bryś 2007a, b). Due to its location and the features of the active area, which is characteristic for agricultural land in the Silesian Lowlands, the results of actinometrical measurements conducted in this area are representative for the eastern part of Wrocław-Magdeburg Ustromtal.

Since 1961, measurements of sunshine duration (S) and global radiation ($K\downarrow$) have been collected at the height of 1.5 m above ground level, over the lawn of the observatory. Detailed characteristics in terms of the instrumental and methodological approaches used here can be found in previous papers of the authors (Bryś 2006, 2007, 2013, 2015, 2017; Bryś, Bryś 2002, 2003, 2007), which point to circulation conditions and the influence of the cyclical magnetic activity of the sun (Wolf number) on the analyzed actinometrical data.

The research is based on the revised, continuous and homogenous 56-year long measurement series (1961-2016) of global radiation (Bryś 2017). The paper presents average and extreme (monthly, annual) values and variability of the analyzed radiation fluxon a seasonal and yearly basis, as such dynamic aspects play an important role in climatological analysis. The paper also includes a comparative approach to respective data from Warsaw (1961-2015), as a relatively representative area for the central part of Poland[1] (Bogdańska, Podogrocki 2000; Podogrocki 2007), and Potsdam (1950-2016), as representative area for the eastern part of Germany[2].

3. Measurement results and discussion

The course of global radiation $K\downarrow$ in the period of 1961-2016 (Fig. 1) is marked by a strong positive trend, with the wave-like variability of the moving sums of 12- and 60-month periods. It only partly corresponds to a solar cyclicity of approximately 11-12 years of length, as the influence of the multiannual variability of circulation is prevalent. It is important to contrast the cloudy and rainy period of the 1970s and 1980s, when annual sums of $K\downarrow$ reached only the average level of approximately 3 700 MJ·m^{-2} compared to later years with smaller annual precipitation levels (Bryś, Bryś 2002; Bryś 2017), when the adequate radiation sums amount to 3 900-4 000 MJ·m^{-2}. It is indicative that annual sums for sunshine duration in the first period reached the average level of 1 300 hrs, followed 1600-1700 hrs in the next period (Bryś 2015, 2017).

The extreme annual values of $K\downarrow$ were recorded 8 or 12 years later than the respective values obtained for sunshine

[1] ttp://wrdc.mgo.rssi.ru
[2] http://www.klima-potsdam.de/

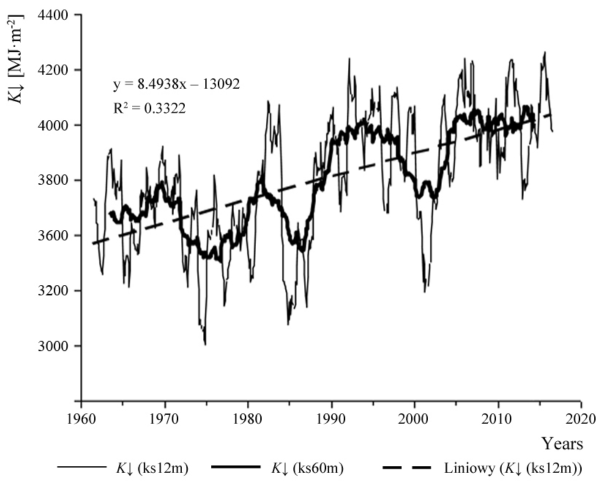

Fig. 1. The runs of 12- and 60-month (mean yearly values) moving sums (ks12m and ks60m) of global radiation *K*↓ in Wrocław-Swojec in the years of 1961-2016 (Liniowy = Linear trend)

duration (Bryś 2015, 2017), which indicates the effect of circulation conditions on these differences, as well as a considerable independence of direct radiation from the global radiation. A minimum *K*↓ (3 257.3 MJ·m^{-2}, that is 904.8 kWh·m^{-2}) was recorded in 1974 (8 years later than the minimum *S*). The first maximum (4 246.7 MJ·m^{-2}, i.e. 1 179.6 kWh·m^{-2}) was observed in 2015 (12 years later than the maximum *S*), and the second maximum in magnitude (4 227.1 MJ·m^{-2}, i.e. 1 174.2 kWh·m^{-2}) in 2011 (8 years later than the maximum *S*). The mean annual sum for the period (1971-2000) amounted to 3 751.6 MJ·m^{-2} (i.e. 1 042.1 kWh·m^{-2}), while for the 50- and 56-year long periods, the sums were calculated as 3 773.6 MJ·m^{-2} and 3 802.9 MJ·m^{-2} (i.e. 1 048.2 and 1 056.4 kWh·m^{-2}), respectively.

For the purpose of determining the climate change influence on global radiation and solar energy resources in the Silesian Lowlands, it is important to consider the dynamics of radiation variability. The linear trend of global radiation in Wrocław-Swojec in the years of 1961-2016 (Fig. 1) shows a growth of annual *K*↓ sums by 407,8 MJ·m^{-2} (i.e. 113.3 kWh·m^{-2}) within 50 years and by 457,7 MJ·m^{-2} (i.e. 127.1 kWh·m^{-2}) within 56 years.

For all seasons (Fig. 2), a significant positive trend of the 3-month sums of global radiation *K*↓ can be observed. The strongest trend (a = 3.808, R^2 = 0.347) is recorded in spring (March-May). A weaker trend is observed in summer (a = 2.991, R^2 = 0.137), as the highest values of *K*↓ for this season were already recorded in the first part of the 1990s. The weakest seasonal trend is characteristic for winter (a = 0.469, R^2 = 0.077), so but the changes are jointed with the time when the values of *K*↓ are the lowest in the year.

The very significant positive trend of the *K*↓ sums of the warm half-year (April-September) (Bryś 2017) is also reached (Fig. 3). In these sums, which are of crucial importance to the values for the *K*↓ yearly sums (of which they constitute on average 77.8%), as well as in the appropriate annual (Jan.-Dec.) sums, a significant increase (Bryś 2017) in values is recorded (approx. 250 MJ·m^{-2} for the half-year sums) between the two circulation periods (early and advanced) of the NAO (North Atlantic Circulation) positive phase. For the target time periods of the *K*↓ yearly and half-year sums (distinctly visible in the runs of the 60-month moving sums), a boundary can be seen at year 1987, between the earlier period (1961-1987) with relatively low values of these sums and the later period (1988-2016), with relatively high values of these sums. Such a division of the study period of 1961-2016 is not only induced by an evident radiation turning point, which appears in the research of actinometrical series (Bryś 2013, 2017), but also occurs in similar series of air temperature *Tp*, saturation deficit *d* and precipitation *P* in Wrocław (Bryś 2017). There are significant macro-circulation reasons behind this, and therefore, such a division appears also in the mean NAO indexes for the warm half-year and summer (Bryś 2017), that is, in the periods when the maximum yearly *K*↓, *Tp*, *d*, *P* values in Wrocław are observed.

The first period includes the advanced and last stages of the negative phase of the NAO (1955-1973, or up until 1978), and the juvenile stage of the positive phase of the NAO (1974-1987, or 1979-1987). The 1974-1978 years include a turning point, and therefore it is very difficult to fix a precise time boundary between these phases (Hurrel 2017; Marsz, Styszyńska 2002, 2006). For the years of 1979-1987, an abrupt transition to recurring positive phases of the NAO is observed, occurring during the 1979/80 winter. In addition, a substantial negative phase of the pattern appeared twice, in the winters of 1984/85 and 1985/86[3]. The second analyzed period (1988-2016) includes the advanced stage of the positive phase of the NAO. However, the period of November 1995 to February 1996 was characterized by a return to the strong negative phase of the NAO, with later years dominated by evident positive values of the wintertime NAO.

The precise distinction of these phases and stages is not an easy task and is still the subject of research and discussion (Bryś, Bryś 2002; Marsz, Styszyńska 2002, 2006; Wibig 2000, 2001)[4]. Most often, the relationship between changes of the NAO and European climate are considered as teleconnections of different NAO winter patterns with continental temperature and precipitation (Hurrell 1995;

[3] http://www.cpc.ncep.noaa.gov/data/teledoc/nao.shtml
[4] see also: http://www.cpc.ncep.noaa.gov/data/teledoc/nao.shtml 2017; https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based

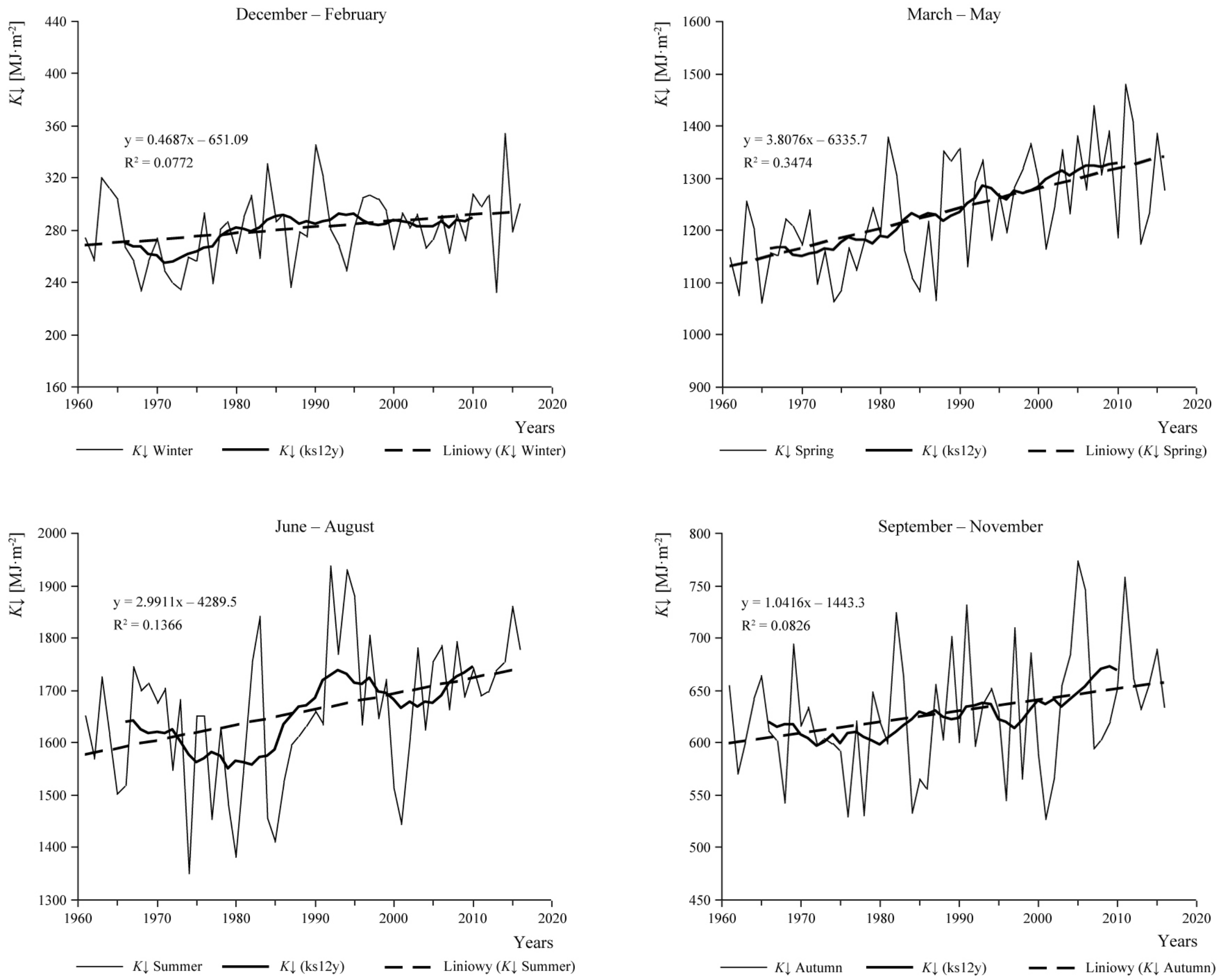

Fig. 2. The courses of seasonal (winter XII-II, spring III-V, summer VI-VIII, autumn IX-XI) sums of global radiation $K\downarrow$ and their 12-year (ks12y) moving averages in Wrocław-Swojec in the years of 1961-2016 (Liniowy = Linear trend)

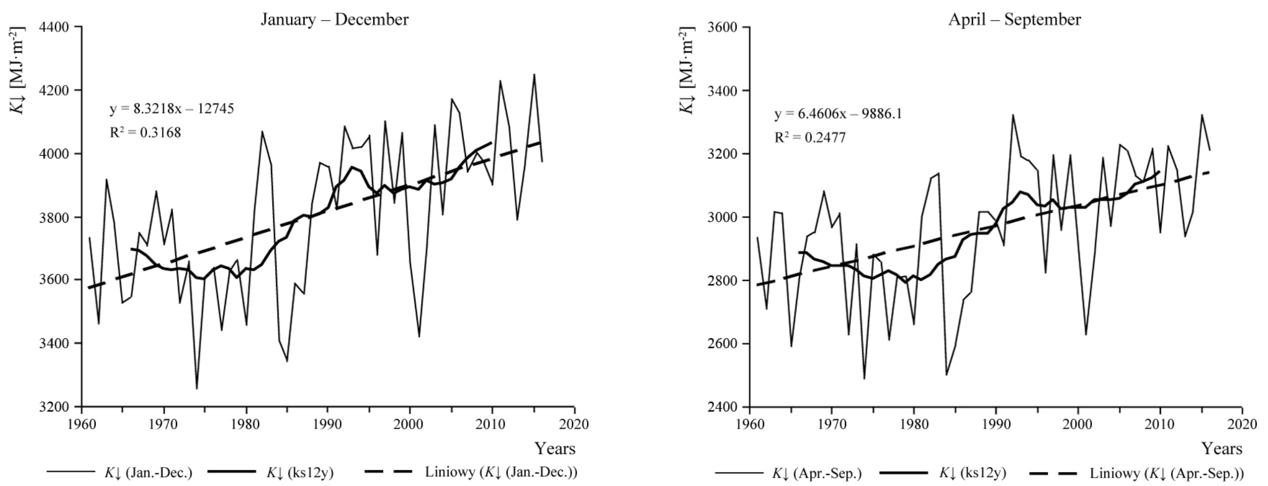

Fig. 3. The runs of annual (Jan.-Dec.) and half-year (Apr.-Sep.) sums of $K\downarrow$ and their 12-year (ks12y) moving averages in Wrocław-Swojec in the years of 1961-2016 (Liniowy = Linear trend)

Marsz 2005; Marsz, Styszyńska 2002, 2006). The problem of teleconnections between NAO and monthly sums of $K\downarrow$ in Wrocław is only considered in the earlier studies of the authors (Bryś, Bryś 2002; Bryś 2017). There exists a lack of similar studies for other areas in Poland and Central Europe, thus the current study also takes into consideration Potsdam and Warsaw.

The courses of monthly mean values of global radiation intensity $K\downarrow$ in Wrocław-Swojec between the years 1961-2016 (Fig. 4) show that the most important trends in the spring and summer growth of $K\downarrow$ are found in April (a = 0.549, R^2 = 0.207), May (a = 0.619, R^2 = 0.137), and August (a = 0.467, R^2 = 0.147). Also significant is the positive trend for March (a = 0.272, R^2 = 0.105), and the increasing trend for July (a = 0.446, R^2 = 0.064) (with a significance of p = 0.062 for Spearman's test and p = 0.075 for tau-Kendall's test). For the autumn period, there is a significant, positive trend for November (a = 0.119, R^2 = 0.123), whereas for winter an increasing trend for February (a = 0.131, R^2 = 0.055) is observed, which is not, however, significant (p = 0.115 of Spearman's test, p = 0,116 of tau-Kendall's test).

In many monthly courses, the interesting phenomenon, particularly in February, July, August and October, of a strong wave characterizing the 12-year (ks12y) moving averages is observed (Fig. 4). The top of the wave in February coincides with the second part of the 1980s, while July and October it is observed in first part of the1990s, and in August, in the mid-1990s and the first years of second part of the 1990s. The similar top of the wave for the whole summer season is observed in the first part of the 1990s (Fig. 2), as with the whole year and warm half-year (Fig. 3). Most likely, for these last cases (Fig. 3), a new wave is current forming, or will form in the close future (around 2020). Such phenomena are an important radiation feature of natural climatic fluctuations over many years.

Similar trends and variations of $K\downarrow$ annual sums between the two compared circulation periods were reached in Potsdam (Fig. 5 and Fig. 6) and Warsaw (Fig. 6). As in Wrocław, for these stations, a boundary is noted around year 1987, between the first period (1961-1987) with low values of these sums and the later period (1988-2015, or 2016), with relatively high values of these sums. A comparison of trends for Potsdam, Wrocław and Warsaw proves that the strongest positive trend of $K\downarrow$ annual sums is observed in Warsaw (Fig 6), closely followed by Wrocław (Fig. 3 and Fig. 7), and the weakest in Potsdam (Fig. 5 and Fig. 6).

In the period of 1961-2015, the highest annual sum of $K\downarrow$ was noted in Wrocław (4 246.7 MJ·m^{-2} in 2015), 2.1% lower in Potsdam (4 158.6 MJ·m^{-2} in 2003), and 5.0% lower than the Wrocław maximum in Warsaw (4 033.2 MJ·m^{-2} in 2012). The lowest minimum annual sums of $K\downarrow$ were registered in Potsdam (3 195.2 MJ·m^{-2} in 1984), followed by Warsaw (3 217.2 MJ·m^{-2} in 1980, 0.7% larger than in Potsdam), and in Wrocław (3 257.4 MJ·m^{-2} in 1974, 1.9% larger than in Potsdam). The highest annual average sum in the 55-year research period appears in Wrocław (3 799.9 MJ·m^{-2}), which is 2.8% higher than in Potsdam (3 694.9 MJ·m^{-2}), and 3.5% higher than that in Warsaw (3 671.6 MJ·m^{-2}). The coefficient of variability for the annual sums of $K\downarrow$ averages is 5.6% for Potsdam, and 6.4% for both Warsaw and Wrocław. The relatively low annual sums of $K\downarrow$ for Warsaw in comparison to Belsk, Puławy, and other suburban areas in the radius of approximately 100 km from Warsaw, proves that the radiation values registered in Warsaw were reduced due to the influence of a greater amount of cloudiness generated by a very intensive UHI (Urban Heat Island) and local strong atmospheric pollution (Bogdańska, Podogrocki 2000; Górski, Górska 2000; Podogrocki 1984; Podogrocki, Słomka 1993). However, the radiation data from station Warsaw-Bielany is included in the longest actinometrical series in Poland, thus they have a relatively representative character for the central part of Poland, which is the main aim of the current analysis.

The relationship between $K\downarrow$ and macro-circulation conditions are very complicated and are linked to oceanic influences based on the solar features of the climate in Central Europe, which varies in time. This influence is a natural derivative of source impact of sun activity on the Earth's climate (Soon et al. 1996) and of the important role of the contrast between the land and the ocean, as two different active global surfaces. They form, together with the influence of the Earth's rotary and circumsolar movement and other astronomical and geophysical conditions (particularly volcanic activity), the main features of a heat, moisture and momentum transfer and climatic diversification, on different spatial and temporal scales. The natural implication of these conditions is the oceanic circulation and layout, the thermal features of oceanic streams in the North Atlantic, and the interaction between the ocean and atmosphere in the formation of the main atmospheric mass flow over the European synoptic area (Marsz, Styszyńska 2002, 2006; Paszyński, Niedźwiedź 1991; Wibig 2000, 2001; Woś 1999, 2010; Żmudzka 2007). The transformation of these atmospheric masses over land, in addition to the duration and direction of advection, depends on many different features of land morphology and types of land cover and their physical properties. The variability of cloudiness over Poland depends not only on source areas and the path of atmospheric mass, but also on circulation epochs (Kożuchowski et al. 2000; Żmudzka 2007).

Based on these conclusions from the above citied papers s, the current analysis confirms the conclusions of the earlier studies of the authors (Bryś, Bryś 2002; Bryś 2017), in that the teleconnections between the NAO and $K\downarrow$ in Central Europe have a very complicated and asynchronous character. Taking the example of August, Figure 8 shows some differences of this asynchronous character between the years 1959-1987 and 1988-2016, which are visible both in Wrocław and Potsdam, and demand a wider, more detailed analysis. The relations have a larger, climatological context jointed with long-term variations of circulation

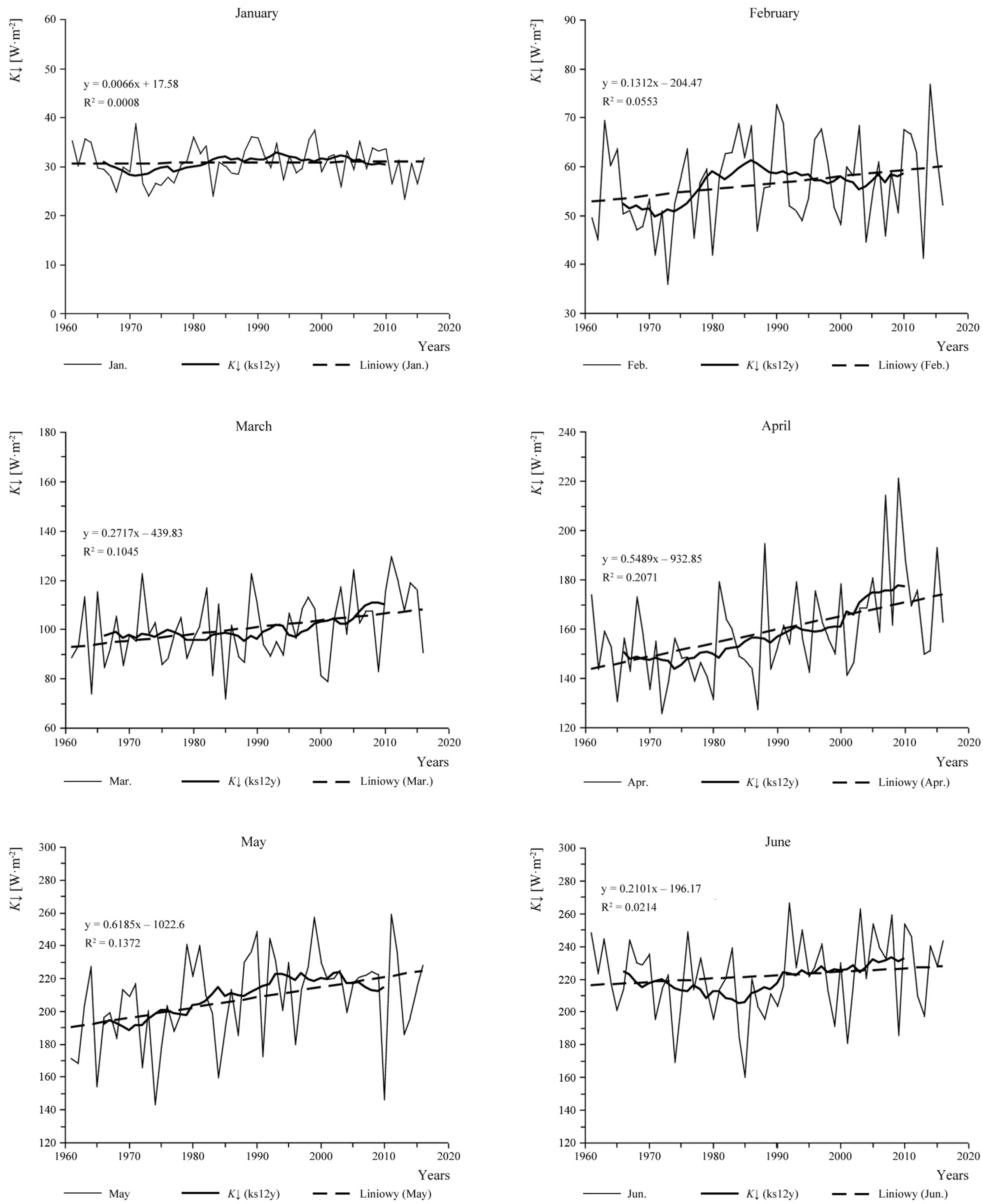

Fig. 4. The courses of average monthly values of global radiation intensity $K\downarrow$ and their 12-year (ks12y) moving averages in Wrocław-Swojec in the years of 1961-2016 (Liniowy = Linear trend) – Part A

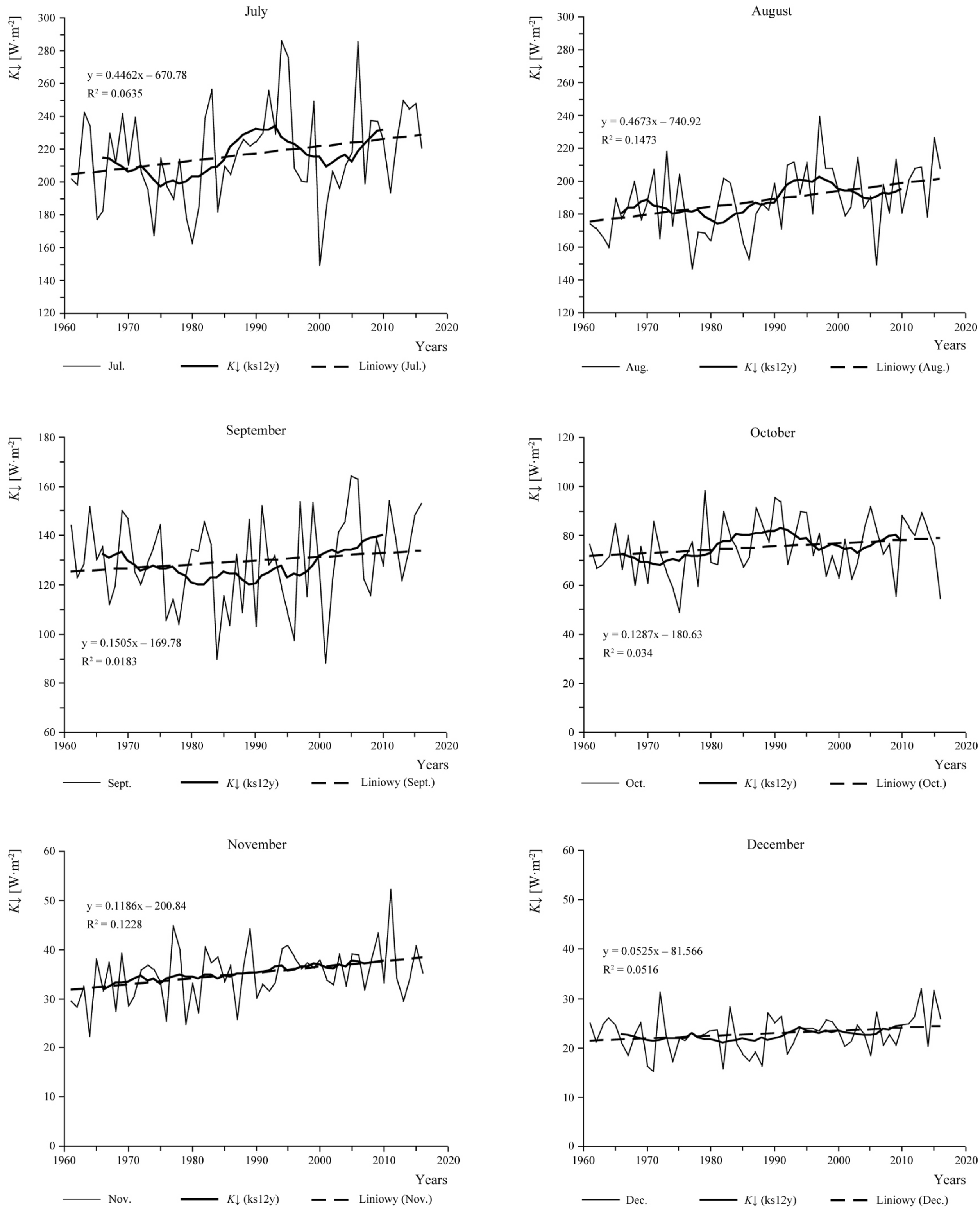

Fig. 4b. The courses of average monthly values of global radiation intensity $K\downarrow$ and their 12-year (ks12y) moving averages in Wrocław-Swojec in the years of 1961-2016 (Liniowy = Linear trend) – Part B

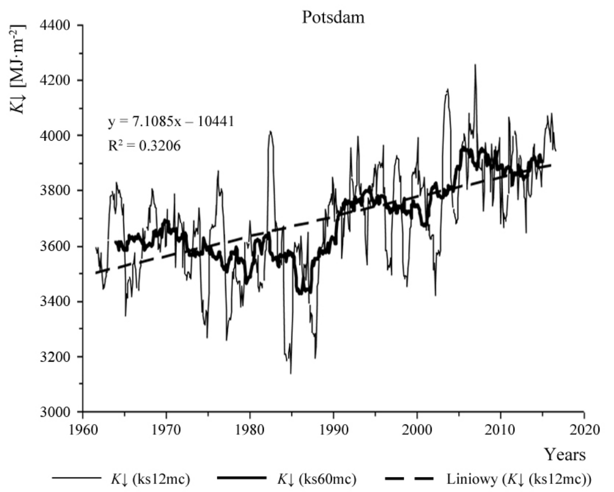

Fig. 5. The runs of 12- and 60-month (mean yearly values) moving sums (ks12m and ks60m) of global radiation *K*↓ in Potsdam in the years of 1961-2016 (Liniowy = Linear trend)

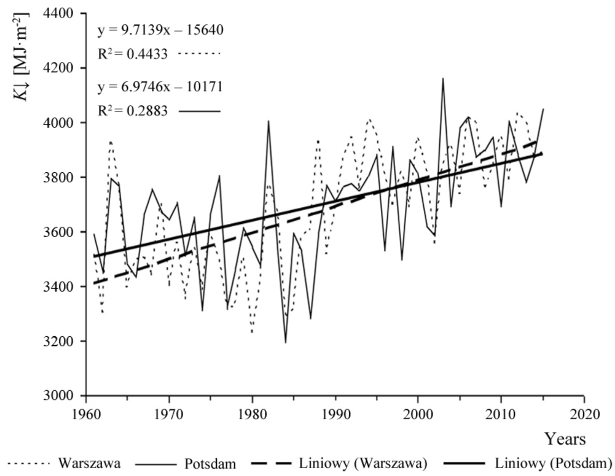

Fig. 6. The comparison of runs of annual (Jan.-Dec.) sums of *K*↓ and their trends in Potsdam and Warsaw (Warszawa) in the years of 1961-2015 (Liniowy = Linear trend)

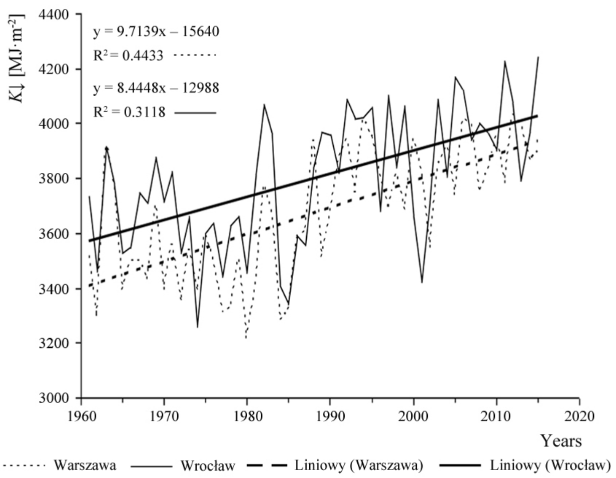

Fig. 7. The comparison of runs of annual (Jan.-Dec.) sums of *K*↓ and their trends in Wrocław and Warsaw (Warszawa) in the years of 1961-2015 (Liniowy = Linear trend)

patterns in the synoptic broad scale not only over Europe and the North Atlantic, but also over the Middle East, the west part of Siberia and the north peripheries of Africa.

Strong positive phases of the NAO tend to be associated with above-average temperatures in northern Europe, and below-average temperatures across southern Europe and the Middle East. They are also associated with above-average precipitation over northern Europe and Scandinavia in winter, and below-average precipitation over southern and central Europe. Opposite patterns of temperature and precipitation anomalies are typically observed during strong negative phases of the NAO[5]. Such spatial teleconnections of the winter NAO are likely to impact future barometric patterns over the European Synoptic Area (Marsz, Styszyńska 2006; Marsz 2010) and the directions and features of atmospheric advection in Central Europe during the summer.

A detailed analysis of these teleconnections demands a different study. In addition to the NAO, such analysis needs to also explore the topic of climatological influences of other circulation patterns on the main radiation climatic features in Poland and Central Europe.

4. Summary

The observed positive trends show significant increasing values of the investigated global radiation sums for Lower Silesia, Central Poland and the east part of Germany. The growth of the *K*↓ sums is linked to the macro-regional circulation changes, particularly with the basic stages of the NAO positive phase and their influence on the weather in Central Europe. The first, juvenile stage of the phase (the 1970s and 1980s), when annual sums of *K*↓ in Wrocław-Swojec only reached the average level of approximately 3 700 MJ·m^{-2} and the warm half-year approximately 2 800 MJ·m^{-2}, was cloudy and rainy. This period was distinctly different compared to the advanced stage (the 1990s and later years), with a longer sunshine duration and smaller annual precipitation, with adequate radiation sums amounting to 3 900-4 000 MJ·m^{-2} and 3 000-3 100 MJ·m^{-2}, respectively. Similar variations were reached in Warsaw and Potsdam. The noted trends and periods of solar change are linked to similar variations in cloudiness and sunshine duration, which are typically observed in Poland (Bryś 2015; Dubicka, Pyka 2001; Koźmiński, Michalska 2005; Matuszko 2009; Morawska-Horawska 1985, 2002; Podstawczyńska 2003, 2007) and Central Europe (Bryś 2013, Ohrvil et al. 2009). The paper confirms the conclusions of previous studies made by the authors (Bryś 2013, 2015, 2017;

[5] http://www.cpc.ncep.noaa.gov/data/teledoc/nao.shtml

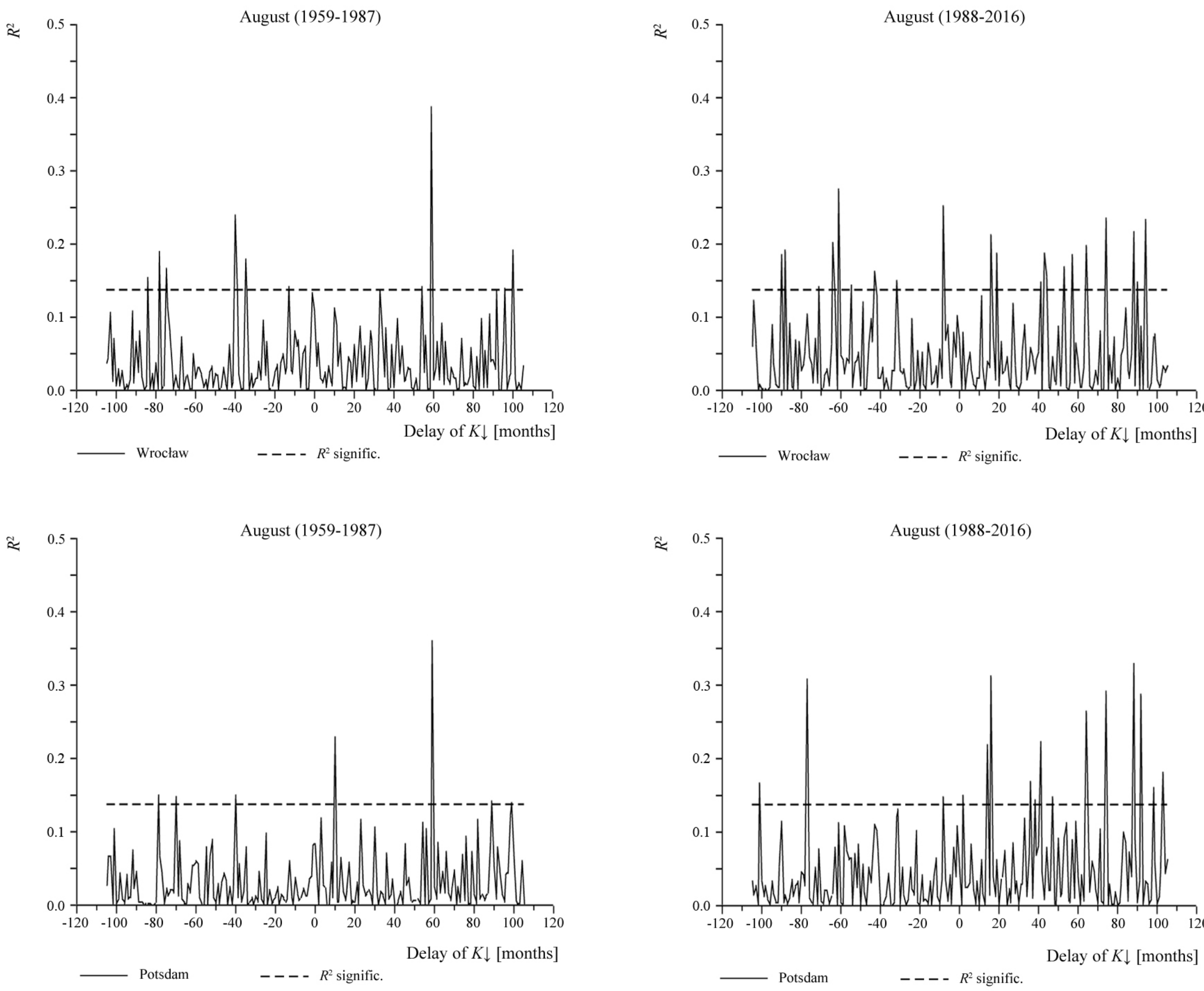

Fig. 8. The comparison of runs of the asynchronous coefficient of determination (R^2) for the correlations between monthly indices of the NAO and monthly sums of $K\downarrow$ in Wrocław and Potsdam in the years 1959-1987 and 1988-2016 for the month of August. Explanation: delay of $K\downarrow$ from –105 to 105 months, 0 – the synchronous correlation, $R2$ significant. – the lower boundary of a value for the coefficient of determination (R^2), which is statistical significant

Bryś, Bryś 2002, 2003, 2007), on the main role of naturally observed radiation trends. The derived results point out that radiation trends are strongly connected to natural long-term macro-circulation changes (Marsz 2005, Marsz, Styszyńska 2002, 2006, 2009; Ohrvil et al. 2009; Pisek, Brazdil 2006) in the Northern Hemisphere. In addition to influences of other north hemispheric barometric patterns (Marsz, Styszyńska 2006), they are relatively strongly related to the phases and sub-phases of the North Atlantic Oscillation. These atmospheric changes are connected with long-term changes in oceanic circulation, particularly with wind-driven circulation or the meridional overturning circulation (MOC) and the behaviors and features of oceanic surface currents (Marsz, Styszyńska 2009; Olbers et al. 2012). Teleconnections most often have an asynchronous character and perform quasi-periodically, with several year long waves of radiation changes as an important phenomenon for many years of climatic fluctuations. Further studies should involve a detailed analysis of atmospheric pollution emissions and their influence on global radiation. Such studies can determine whether the macro-circulation, natural genesis of the radiation changes is more important than the influence of anthropogenic aerosols on climate, as suggested by Ahrens (2008), Wibig (2009) and other researchers that support the main theses of the IPCC Report (2013).

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