DOI:10.28974/idojaras.2024.1.2

IDŐJÁRÁS

Quarterly Journal of the HungaroMet Hungarian Meteorological Service
Vol. 128, No. 1, January – March, 2024, pp. 27–39

Effect of teleconnection patterns on cloudiness in winter in Poland

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(Manuscript received in final form December 5, 2022)

Abstract—The subject of the study was the effect of teleconnection patterns on cloudiness in Poland in the period 1990–2020. The analysis was conducted based on daily cloudiness values from 34 measurement stations of Institute of Meteorology and Water Management - National Research Institute and monthly North Atlantic Oscillation (NAO) and Scandinavia (SCAND) indices from the collection of Climate Prediction Center (CPC). The course of cloudiness values in winter in the multiannual period was analyzed together with its averaged spatial distrubution for the entire winter and for particular winter months. Next, the coefficient of correlation of cloudiness with a given teleconnection pattern index was calculated. The analysis also covered cloudiness in the positive and negative teleconnection phases. The results confirm a variable course and increasing trend of winter cloudiness in Poland. The average cloudiness reached 76% in the studied multiannual period. The correlation coefficient for the North Atlantic Oscillation primarily adopted negative values, and positive for the Scandinavian circulation. The strongest correlation between the teleconnection pattern and cloudiness was observed in February for NAO and in December for SCAND. Cloudiness showed no considerable differences between the positive and negative teleconnection phases.

*Key-words:*cloudiness, teleconnection patterns, climate change, Poland, NAO, SCAND

1. Introduction

Cloudiness is the degree of cover of the sky with clouds. It is determined based on the assessment of the ratio of the area covered by clouds to the space covered by the observation (*Piotrowski,* 2017). Cloudiness depends on the content of water vapor in the air and on condensation conditions, primarily determined by atmospheric teleconnection processes (*Kożuchowski et al.,* 2012). This atmospheric teleconnection processes are spatial patterns in the atmosphere that link weather and climate anomalies over large scale across the globe (*Feldstein* and *Franzke*, 2017). Cloudiness can also be modified due to the effect of local factors such as land relief. Clouds fulfil an important function in the global water circulation, providing atmospheric precipitation on Earth. Moreover, they strongly reflect solar radiation and limit losses on radiation emitted by the Earth's surface (*Piotrowski,* 2017).

The issue of cloudiness and teleconnection patterns has been addressed by many studies. The magnitude and general characteristics of cloudiness in Poland have been described by *Filipiak* (2021), *Sypniewska* and *Szyga-Pluta* (2018), and *Filipiak* and *Miętus* (2009). Equally numerous studies regarding cloudiness have been conducted at local and regional scales. These papers particularly include those by *Żmudzka* (2007), *Matuszko* and *Wojkowski* (2007), and *Wibig* (2008). Moreover, the correlation of cloudiness with the optical thickness of aerosol and sometimes insolation has been investigated (*Bartoszek et al*., 2020), as well as the effect of cloudiness on precipitation and air temperature in Poland (*Żmudzka* 2008).

As shown in earlier studies, the most important teleconnection patterns affecting weather and climate in central Europe include the North Atlantic Oscillation (NAO) and Scandinavia (SCAND) patterns (*Tomczyk,* 2014; *Ptak et al.,* 2018). NAO is a bipolar teleconnection pattern resulting from the co-occurrence of the Azores High and Icelandic Low. It is one of the most evident and repeatable teleconnection patterns. It dictates the weather variability from the eastern coast of North America to Siberia (*Hurrell et al.,* 2003). The positive NAO phase is characterized by a gradient of atmospheric pressure higher than average between the baric centers of the Azores High and Icelandic Low. It results in an inflow of humid and warm air masses from the west over the northern part of Europe, including Poland. The negative phase is related to a lower pressure gradient between these baric centers (Icelandic Low – higher than average pressure, Azores High – lower than average pressure). Such a situation generates inflow of dry and cool air masses from the northeast (*Hurrell,* 1995, *Hurrell* and *Deser,* 2010).

SCAND is a teleconnection pattern characterized by the occurrence of a strong high over the Scandinavian Peninsula with a center over Finland. The area of lower than average pressure extends from western Europe to eastern Russia/western Mongolia. The positive SCAND phase is related to higher than average pressure, creating a situation of blockage over Scandinavia and western Russia. The negative phase is related to lower than average pressure over northern Europe (*Bueha* and *Nakamura,* 2007; *Liu et al.,* 2014; *Nojarov,* 2017; *Tomczyk et al.,* 2019). In the positive phase, dry and cool air is transported over central Europe and central Russia (https://www.cpc.ncep.noaa.gov/data/teledoc/scand.shtml).

The effect of teleconnection patterns on climate and weather in Poland has been evidenced among others in papers by *Adamczyk* (2007) regarding the effect of the North Atlantic Oscillation on cloudiness in Poland in the period 1961–1990. The paper evidenced the dependency of total cloudiness on the intensity of the NAO zonal circulation. The author proved that the correlation is not strong over a predominant part of the country, although in the north, the corelations are stronger and statistically significant. The effect of teleconnection patterns on atmospheric conditions in Poland have also been evidenced in papers regarding thermal and nival conditions (*Bednorz,* 2002; *Tomczyk,* 2015; *Szwed et al.,* 2017). Moreover, research conducted in recent years covered the effect of teleconnection patterns on the value and seasonality of outflow in Polish rivers (*Wrzesiński,* 2010), as well as thermal and ice conditions in lakes in northern Poland (*Ptak et al.,* 2018*,* 2019).

The study objective was to investigate the characteristics of cloudiness in Poland in winter in the years 1990/91–2019/20, and the determination of the effect of teleconnection patterns on cloudiness.

2. Study area, source material, and study methods

The study employed data from 34 stations in Poland functioning in the scope of activity of the Institute of Meteorology and Water Management – National Research Institute (*Fig. 1*). The stations were selected based on the completeness of measurement data.

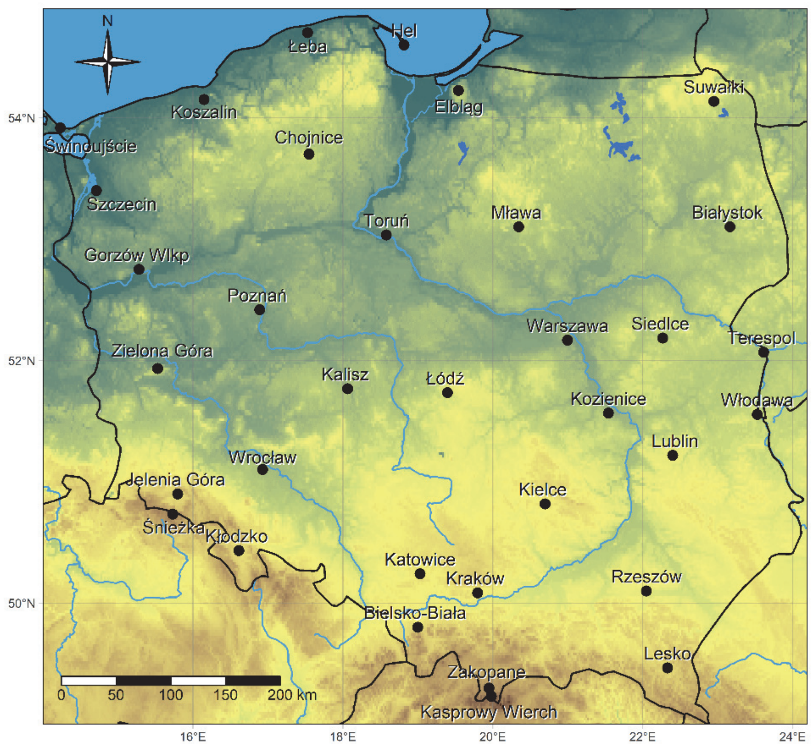

Fig. 1. Location of meteorological stations.

This paper employed mean daily data on cloudiness from 30 winter seasons from 1990/91 to 2019/20. The winter season was defined as the period from December to February. The assessment of cloudiness applies an 8-degree octane scale, where 0/8 means cloudless sky, and 8/8 means complete cloudiness. In the paper, the magnitude of cloudiness was converted from the octane scale to a percent scale. The aforementioned data provided the basis for the determination of the multiannual course of cloudiness in Poland in the winter season and in particular months of the season. Next, the trend and intensity of changes were determined, as well as the statistical significance of the recorded changes.

In the next step, the effect of teleconnection patterns on cloudiness in Poland was analyzed. The source material regarding the North Atlantic Oscillation (NAO) and Scandinavia (SCAND) indices was obtained from the data collection of the Climate Prediction Center (CPC). The teleconnection patterns included in the CPC database were designated by means of principal component analysis based on monthly values of anomalies of height of isobaric surface of 500 hPa (*Barnston* and *Livezey,* 1987). The monthly circulation indices were used for the calculation of the Pearson correlation coefficient between cloudiness and teleconnection patterns. The statistical significance of the correlations was verified by means of a t-student test. Moreover, the strength of correlations was determined according to the classification of correlation scale by Guillford (*Guillford*, 1947). Next, cloudiness was determined at low and high index values (1 and 3 quartiles of the set of index values). All maps and diagrams were prepared based on programming language R.

3. Results

Average cloudiness in winter in Poland in the years 1990/91–2019/20 reached 76%. The spatial distribution of cloudiness in winter and in each winter month showed the highest level in northern Poland, particularly in the central and eastern parts of it (*Fig. 4*). The lowest cloudiness was observed in the northwestern areas of Poland as well as in the south in mountainous areas. In individual stations, the average cloudiness ranged from 67% in Świnoujście to 80% in Suwałki (*Fig. 3*). The winter with the highest average cloudiness was season 2012/13 – 86% (*Fig. 2*). The lowest values were recorded in Świnoujście (76%), and the highest in Gorzów Wielkopolski (90%). In this period, in 85% of stations, the highest value in the analyzed multiannual period was observed. The season with the lowest cloudiness proved to be the season 1992/1993 – 67%. In that period, the lowest cloudiness was recorded in 47% of the stations. The averaged cloudiness for the entire Poland in the multiannual course shows an increasing, statistically significant trend. The analysis of changes in particular stations showed the greatest changes in the western part of the country. In seasons characterized by extreme values of the NAO index, an increase in cloudiness is observed. In the SCAND phase, such a trend is recorded only in the positive phase of the pattern (*Fig. 2*).

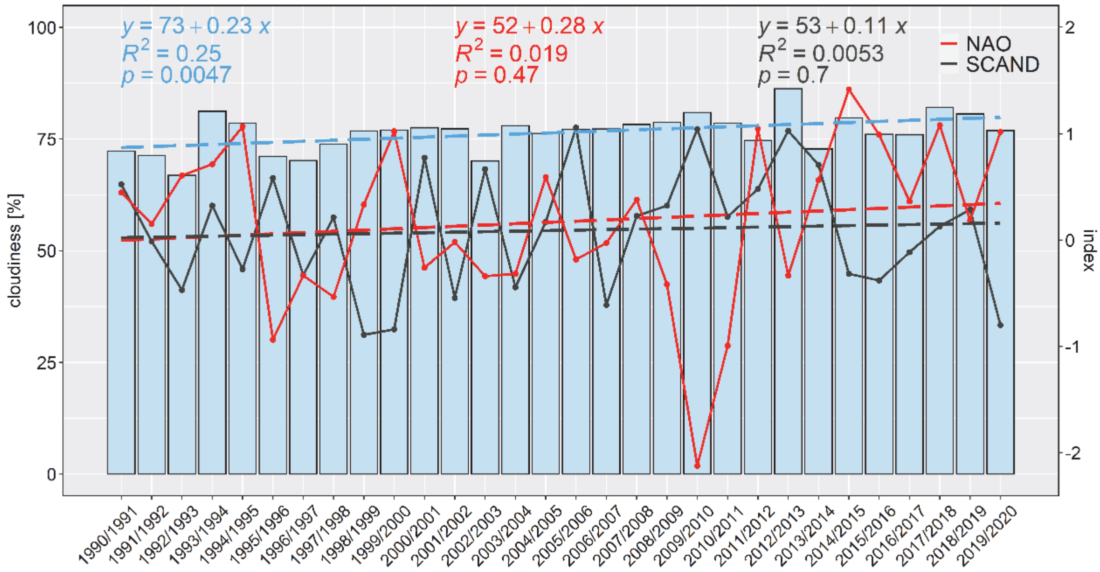

Fig. 2. Course of average cloudiness [%] together with the course of NAO and SCAND indices.

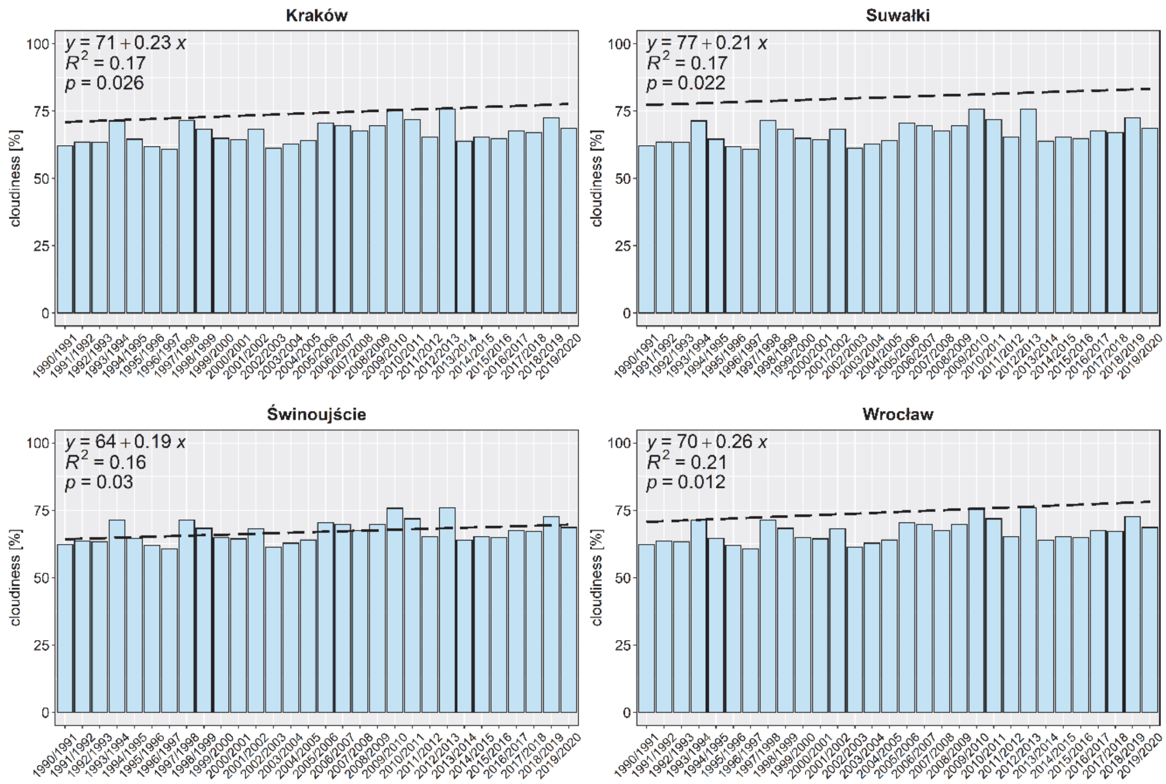

Fig. 3. Course of average seasonal cloudiness [%] in selected stations.

Average cloudiness throughout winter in the multiannual period 1990/91–2019/20 reached 76% (*Fig. 4*). An indentical value of cloudiness was recorded in January. December proved to be a month characterized by the highest cloudiness at the national scale – 78%, and the greatest spatial variability. In February, cloudiness adopted the lowest value of 73%, and showed the highest spatial stability – the variability between extreme cloudiness values was the lowest among all winter months. The maximum monthly cloudiness value was observed in January 2003 – 98%. A minimum was also recorded in January in 1993 – 11%. The level of cloudiness increased towards the north and northeast.

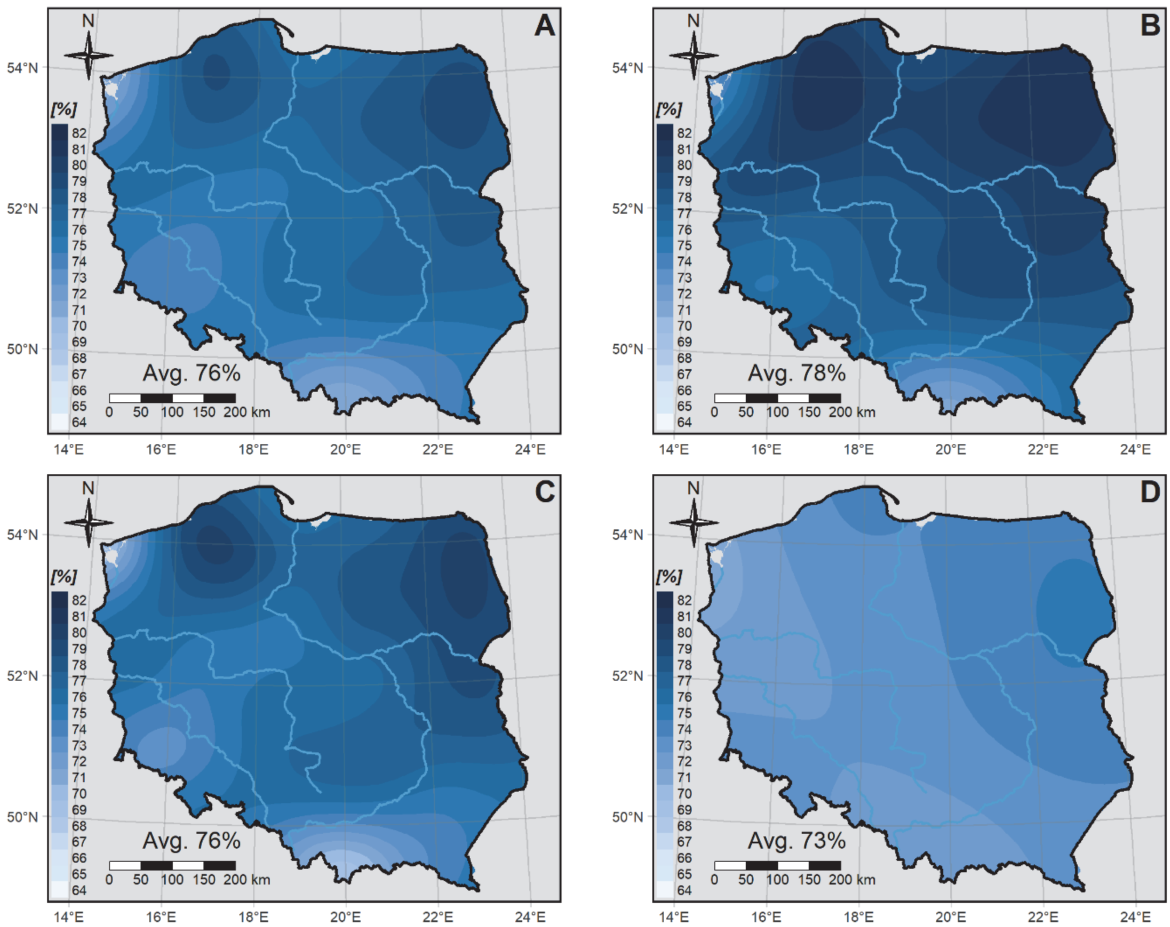

Fig. 4. Spatial distribution of the average cloudiness in winter (A), December (B), January (C), and February (D) in the years 1990/91–2019/20.

The average level of the North Atlantic Oscillation index for winter in the studied multiannual period reached 0.17. The maximum value of the NAO index was recorded in the season 2014/15 (1.41), and the minimum in the season 2009/10 (-2.12). In the studied multiannual period, a slight increase in the NAO index occurred, and it was not statistically significant.

At this stage of the study, the analysis covered the correlation between the cloudiness and the North Atlantic Oscillation index (*Fig. 5*). Over a prevalent area, the correlation was negative, suggesting that in the negative NAO phase, cloudiness increased, and decreased in the positive one. In the spatial distribution of the correlation coefficient for the entire winter period, the strongest correlations are observed in the northwestern part of the country, with a maximum in Świnoujście (-0.35). Positive correlations are determined only in the north-east and in the mountain regions. The average correlation coefficient for the entire Poland reached -0.11. According to the Guillford's correlation scale classification, this suggests weak correlation. In Świnoujście, the correlation was average. In December in the studied multiannual period, the weakest correlation between cloudiness and NAO was recorded. The average correlation coefficient reached only -0.08. The entire northern Poland showed minimum positive values or those approximate to zero. The strongest negative correlations in that month were observed in the southeastern part of the country. Almost an identical situation concerns the spatial distribution of the correlation coefficient in January. Negative values are observed in southern and central Poland, and positive values in northeastern part of Poland with a maximum in Suwałki (0.26). The month most divergent from the average from the entire winter period was February. In that month, the average correlation coefficient for the entire Poland reached -0.42. The strongest correlation was observed in the northern part of the country, particularly in seaside stations such as: Hel (-0.58), Świnoujście (-0.55), or Łeba (-0.54). The only station showing statistical significance for the entire winter was Hel, and in February such significance is shown by as many as 73% of the analyzed stations.

In winter seasons with positive NAO index values (3 quartiles of the set of index values), the average cloudiness was 78%. It was 2% higher than in the negative phase (1 quartile of the set of index values) (*Fig. 6*). In the positive phase, the highest average cloudiness was observed in the north and northeastern parts of the country, as well as in the high mountain station on the Śnieżka Mountain – 83%. A similar situation is observed in the negative phase – the highest cloudiness occured near Koszalin, Łeba, and Suwałki. The exception are mountain areas, where the degree of cloudiness is considerably lower in the negative phase than in the positive one. The lowest cloudiness value was recorded in the northwestern part of Poland with a minimum in Świnoujście both in the positive (66%) and negative phases (68%).

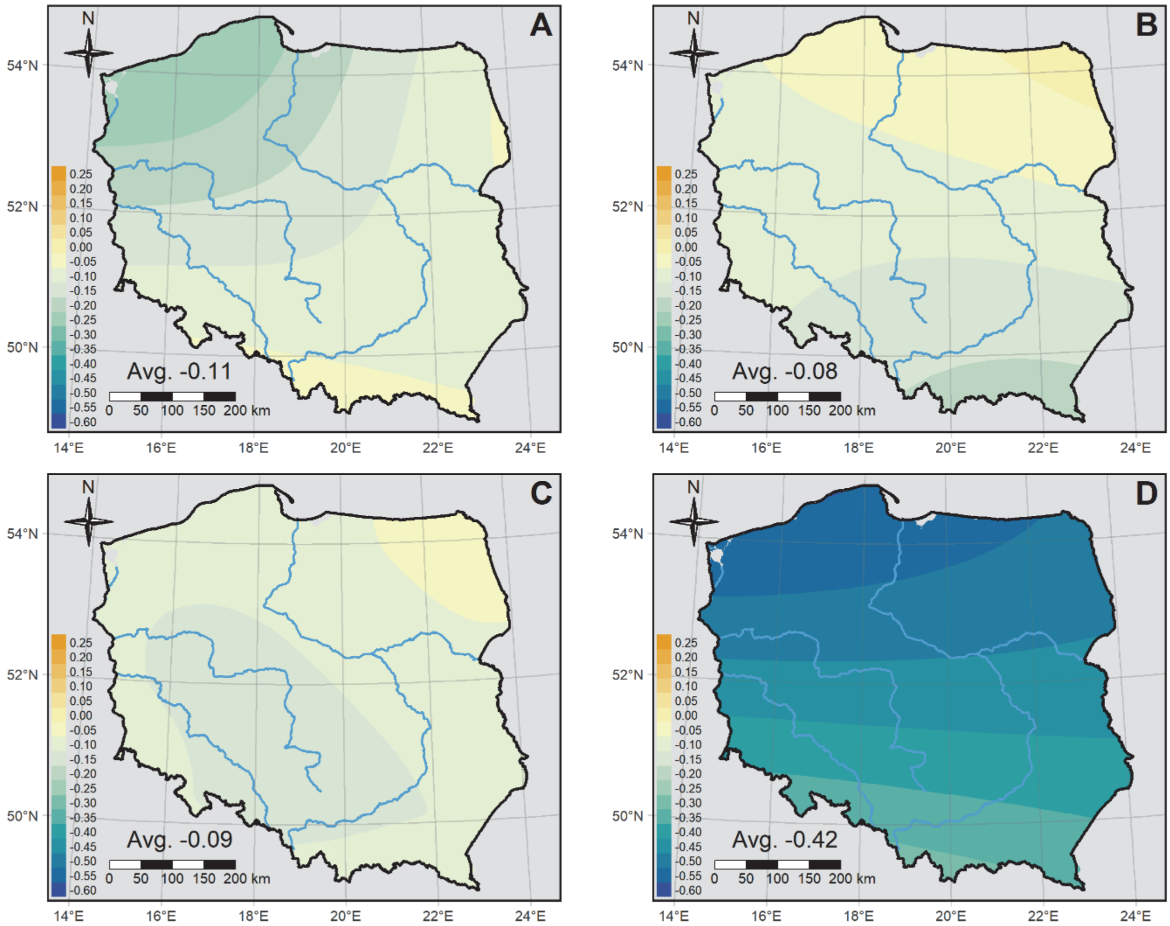

Fig. 5. Pearson correlation coefficient between the NAO index and the cloudiness in winter (A), December (B), January (C), and February (D) in the period 1990/91–2019/20

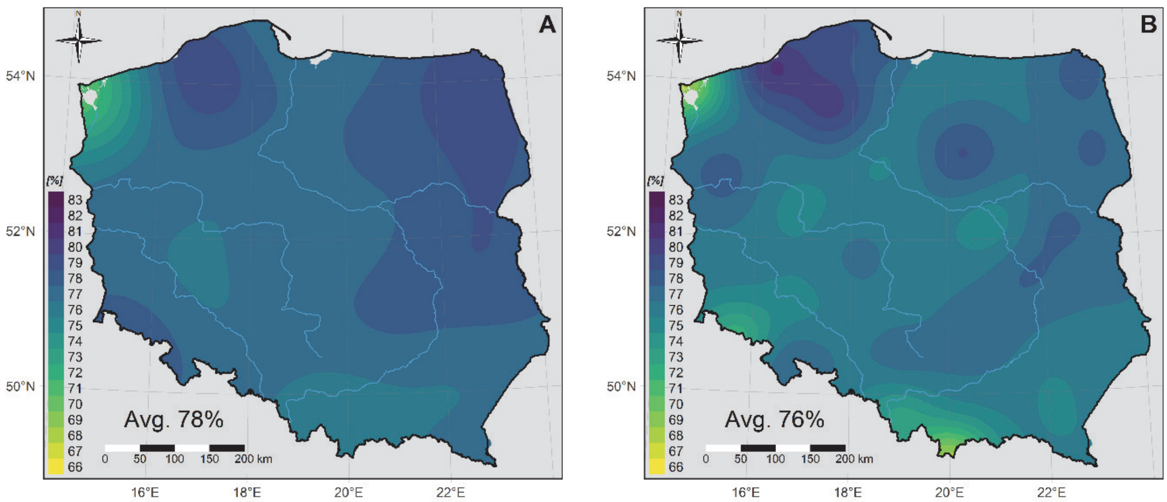

Fig. 6. Average cloudiness [%] in winter periods in which the NAO index was ≥75th percentile (A) and NAO≤ 25th percentile (B) in the years 1990/91–2019/20.

The average value of the Scandinavia index for winter reached 0.10. The highest SCAND index value was observed in season 2005/06 – 1.05. Equally high indices were recorded in seasons 2009/10 – 1.04 and 2012/13 – 1.02, and the lowest index value was observed in season 1998/99 (-0.89). In the studied multiannual period, a minimum increase in the SCAND index was determined. It was not statistically significant.

The Pearson correlation coefficient values between the SCAND index and the cloudiness primarily showed positive values, with the exception of January, when they adopted values below zero (-0.10) (*Fig. 7*). Positive values of the correlation coefficient suggest that the level of cloudiness increased with an increase in the circulation index. The average coefficient for the entire winter in the studied multiannual period reached 0.17, in February -0.06, and the highest correlation was recorded in December -0.39. The strongest correlation for the entire winter period was recorded in southwestern Poland, with a maximum in Wrocław and Kłodzko – 0.31. The only stations showing a negative correlation were high-mountain stations on Kasprowy Wierch and Śnieżka. The month with the strongest dependency between the teleconnection pattern and cloudiness was December. In 6 stations, a correlation higher than 0.50 was recorded. They were primarily stations in the eastern part of the country: Lublin, Terespol, Włodawa, and in the north: Świnoujście, Hel, Chojnice. January and February showed the lowest variability. Their average correlation coefficient values for the entire country were approximately zero. A positive correlation was observed in the west of the country in January and in the east of the country in February. In the multiannual course of winter periods, Hel was statistically significant, and in December as many as 59% of stations were significant.

The average cloudiness at extreme SCAND index values, both in the positive (3 quartiles of the set of index values) and negative phases (3 quartiles of the set of index values) reached equally 76% (*Fig. 8*). The spatial distribution of cloudiness is very similar in both phases. The highest cloudiness in the studied multiannual period was recorded in the north and northeastern part of the country in Koszalin in the negative phase – 80%, and in Chojnice in the positive phase – 80%. The lowest cloudiness values were observed in the northwestern part of the country and in the mountain areas. Minimum values were recorded in Świnoujście – 66% in the negative and 67% in the positive phase.

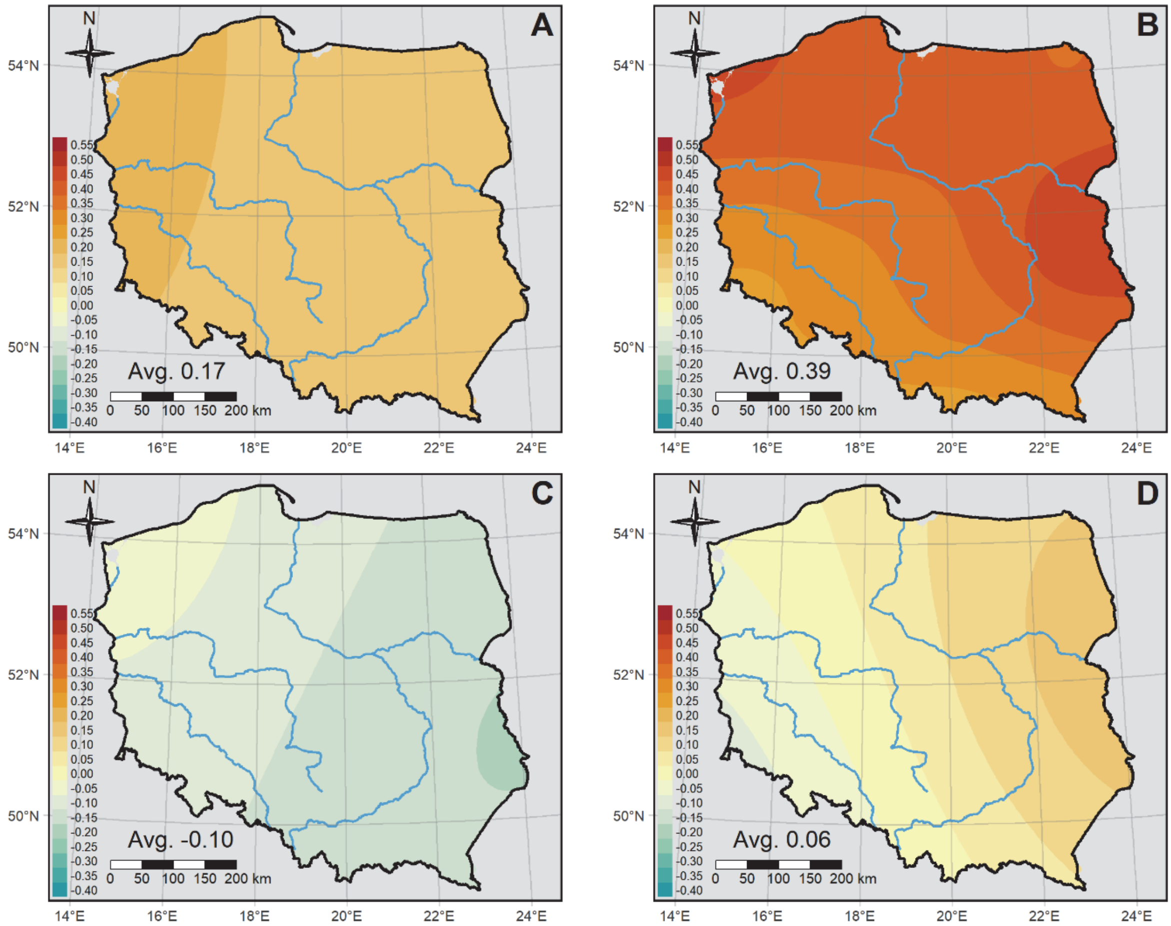

Fig. 7. Pearson correlation coefficient between the SCAND index and cloudiness in winter (A), December (B), January (C), and February (D) in the years 1990/91–2019/20.

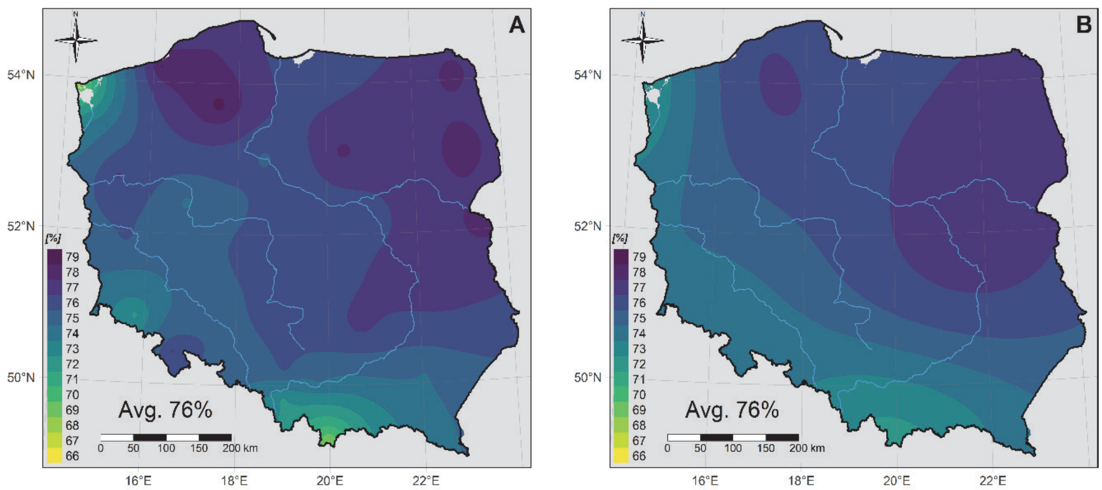

Fig. 8. Average cloudiness [%] in winter periods when the SCAND index was ≥ 75th percentile (A) and SCAND ≤ 25th percentile (B) in the years 1990/91–2019/20.

4. Summary and discussion

The paper shows the variable course of cloudiness in the studied multiannual period. Maximum cloudiness in winter for the entire Poland was recorded in the season 2012/13 – 86%, and the minimum in the season 1992/93 – 67%. The average cloudiness in the years 1990/91–2019/20 was 76%. The month with the highest cloudiness in winter was December – 78%. The increasing trend of cloudiness in Poland is statistically significant. The highest cloudiness in the spatial distribution of the country is observed in the north and northeastern parts of Poland, and stations that stand out including Koszalin, Suwałki, and Chojnice. The lowest cloudiness in the winter period was recorded in the northwest with a minimum in Świnoujście and in mountain areas. Approximate results were obtained in the papers by *Sypniewska* and *Szyga-Pluta* (2018) and *Okoniewska* (2016). Such a spatial distribution in Poland was largely determined by among others: vicinity of the Baltic Sea, more frequent occurrence of lows in northern Poland in winter, and inflow of polar-marine air from the northwest (*Okołowicz,* 1964; *Matuszko* and *Wojkowski,* 2007).

The obtained results confirm the dependency between cloudiness and teleconnection patterns. Averaged correlations in winter and in each individual winter month for the entire Poland are not high however, and in some regions of the country, the correlations are considerably stronger. Similar conclusions were drawn by *Adamczyk* (2007) in the paper regarding the dependency between the North Atlantic Oscillation and the cloudiness in Poland. Higher correlation coefficient values were obtained by among others *Bednorz* (2006) regarding snow cover in northwestern Poland, as well as *Ptak et al.* (2019) investigating ice conditions in Polish lakes. This paper primarily evidences a negative correlation in the dependency of NAO and cloudiness, and positive with SCAND. A negative correlation coefficient suggests that in the negative NAO phase, the level of cloudiness increases, and decreases in the positive phase. A positive correlation, respectively, presents the opposite dependency. The strongest correlation was recorded in the northwestern part of the country for the NAO pattern with a maximum in December, and for SCAND in the northeast with the strongest dependency in February. The correlation coefficient showed statistical significance only in Hel, both between cloudiness and NAO index and SCAND. Correlation coefficients were significant only in months characterized by a strong correlation, in a higher number of stations. Positive and negative teleconnection pattern phases show no particular variability of the average cloudiness for the entire country.

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