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Long-term variability of *Altocumulus lenticularis* clouds in Katowice and atmospheric circulation conditions

Patryk Sikora **Małgorzata Falarz**

University of Silesia in Katowice
Faculty of Natural Sciences
ul. Będzińska 60, 41-200 Sosnowiec
patryk.sikora@o365.us.edu.pl • malgorzata.falarz@us.edu.pl (corresponding author)

Abstract. The aim of this paper is to analyse the annual and long-term variability in the occurrence of these clouds in the Silesian Upland (on the example of Katowice) as well as to indicate its causes related to atmospheric circulation. The source material comes from the IMGW-PIB. The paper uses data on mid-level cloud cover in Katowice in the years 1971-2020. *Altocumulus lenticularis* (*Ac len*) clouds, coded $C_M = 4$, were analysed for eight time points a day (every 3 hours) during the study period. The study also used data on air masses, weather fronts, and types of atmospheric circulation based on the *Calendar of atmospheric circulation types for southern Poland* compiled by Niedźwiedź (2024). Most occurrences of *Ac len* were observed in autumn, and least in summer. The highest average number of days and number of cases of *Ac len* were recorded in October and November, while the lowest in April. In terms of the diurnal distribution, these clouds occurred most frequently between 6:00 and 15:00 UTC. Based on a 50-year dataset, a statistically significant decreasing trends for both number of cases and number of days were found for this type of cloud cover (-2.7 days per 10 years). The maximum number of occurrences was found in 1975, and the minimum in 2016. The highest conditional probability of occurrence of a lenticular cloud in Upper Silesia was found for advection of air masses from the south and southwest in cyclonic pressure systems (>25%) and for advection of a warm polar maritime air mass over southern Poland (20%).

Keywords: cloudiness, *Altocumulus lenticularis*, atmospheric circulation, Silesian Upland.

Introduction

Altocumulus lenticularis (*Ac len*) is one of the species of *Altocumulus* clouds. It is mid-level cloud, typically occurring between 2 km and 7 km above the ground surface. These clouds have a distinctive lens- or almond-shaped appearance, often significantly elongated, with well-defined contours (WMO, 2017) (Fig. 1). They can occur both as single clouds or consist of several smaller components, often occurring at different levels (the *duplicatus* variety). A characteristic feature of *Ac len* clouds is their rapidly changing shape and size. It is largely dependent on the wind speed and direction at the altitude where this type of cloud cover occurs. A change in wind speed and direction causes frequent and relatively rapid changes in the appearance of these clouds, which distinguishes them from the other *Altocumulus* cloud species. According to the cloud coding system developed by the World Meteorological Organisation (WMO, 2017), *Ac len* clouds are coded as $C_M = 4$. This code is assigned exclusively to this cloud species, which confirms its uniqueness and distinctive appearance compared with other *Altocumulus* clouds.

Compared with other cloud species, *Ac len* are relatively rare. In Poland they are mostly observed in the southern part of the country, mainly in the mountains and foothill areas. In central and northern Poland this cloud species occurs very sporadically, with no more than several occurrences observed annually. This is related to the specificity of the formation of lenticular clouds. These are clouds strongly associated with foehn winds, formed when the advection of the wind is relatively perpendicular to the alignment of the mountain ranges. They form on the leeward side of an orographic barrier when the air descends and undulating air movement occurs. The foehn effect was investigated by Ustrnul (1992a, 1992b) who considered the occurrence of *Ac len* clouds as one of the components forming the basis for determining days with *halny* (a foehn wind) in southern Poland.

The long-term variability in various aspects of the cloudiness in Poland was studied by, among others, the team of Matuszko et al. Their analyses mainly focused on cloud cover over Kraków, using observational data dating back to 1896 (Marsz et al., 2024). These studies considered the individual types of clouds, their variability in occurrence over the years, and the impact of the atmospheric circulation conditions (Matuszko, 2003; Matuszko & Węglarczyk, 2018; Matuszko et al., 2022). Some studies covered the whole area of Poland, using data from IMGW meteorological stations located throughout country (Filipiak & Miętus, 2009; Filipiak, 2021; Matuszko et al., 2022; Miś, 2024), while others focused solely on selected Polish cities, such as Kraków and Poznań (Szyga-Pluta, 2022). In recent years, however, satellite data have been increasingly used in studies of cloud cover (Łapeta et al., 2006; Kotarba, 2010; Nowak & Czarnecki, 2023; Wojciechowska et al., 2023). Many papers also refer to the relation between cloud cover and other climate elements (Bartoszek et al., 2020). There have also been studies on cloud cover of larger areas, including those covering the whole of Europe (Koch, 1971; Henderson-Sellers et al., 1987; Bartok et al., 2012). Their studies used data on cloudiness from synoptic stations as well as satellite data. Among other aspects, these studies investigated the effect of maritime and continental climate features on cloud cover in Europe (Koch, 1971). Many of them relied on satellite data for comparison with observations from synoptic stations (Henderson-Sellers et al., 1987; Bartok et al., 2012).

Although some studies have focused on individual types of clouds (Matuszko, 2003; Matuszko & Węglarczyk, 2018; Matuszko et al., 2022; Szyga-Pluta, 2022; Marsz et al.,

Fig. 1. The *Altocumulus lenticularis* clouds over Katowice (view towards the east); 31 July 2024 13:41 (local time). Photo: Patryk Sikora

2024), the papers based on these studies generally lack a detailed breakdown by cloud species, indicating a gap in research on the long-term variability of *Altocumulus lenticularis*. Only some interesting images of these clouds were published (Clark, 2019) apart from a brief description of meteorological conditions during observations of these clouds (Scholbrock, 2011).

The aim of this study is to determine the annual and long-term variability in the occurrence of *Altocumulus lenticularis* cloud in the Silesian Upland (on the example of Katowice) as well as to indicate its causes related to atmospheric circulation.

Data and methods

The study used data from the meteorological station of the Institute of Meteorology and Water Management – the National Research Institute (IMGW-PIB, 2024) located in Katowice-Muchowiec. The station is situated in southern Poland, in the Katowice Upland, which forms a part of the Silesian Upland (Solon et al., 2018), within the city of Katowice (50°14'26''N 19°01'58''E). The station is located at an altitude of 278 m asl. The location of the station did not change significantly during the study period. The only change occurred in 2007 when the station was moved about 100 metres to the east. This did not affect the visual observations of cloudiness.

For this study, mid-level cloud cover data, coded as $C_M = 4$, for the years 1971-2020 were used for each day at eight time points a day (0:00, 3:00, 6:00, 9:00, 12:00, 15:00, 18:00, and 21:00 UTC). In total, more than 146,000 time-point values were analysed. The data series acquired are complete and do not contain deficiencies. The analysis was necessarily ended in 2020, because the following year, the station in Katowice switched to a daytime observation mode. In some cases *Ac len* cloud can also be coded as $C_M = 5\text{-}9$. However, it was not possible to isolate these cases from other species also coded as $C_M = 5\text{-}9$, because in the IMGW-PIB database verbal records of cloud species have been available only since 2011. In the period of 10 years 2011-2020, only 13 cases of *Ac len* cloud encoded differently than $C_M = 4$ were found in the verbal descriptions of clouds, with 324 cases coded as $C_M = 4$ (in eight terms per day). The actual number of days and occurrences of *Ac len* may also be underestimate due to the sky being obscured by low-level clouds.

The study used the Calendar of atmospheric circulation types for southern Poland (Niedźwiedź, 1981, 1988, 2024; Niedźwiedź et al., 2009) which contains information on the types of circulation, air masses and weather fronts on each day between 1971 and 2020. The types of circulation, air masses and fronts along with their total frequency in the analysed period are presented in Table 1.

Based on the acquired data, calculations and graphs were compiled and analysed. The number of days and the number of *Ac len* cases during the study period were calculated. An analysis was carried out of the distribution of these values throughout the day (for the eight measurement time points) and the month as well as in a breakdown by the season. Furthermore, sequences of occurrences of these clouds of at least 3 days were analysed. The long-term variability and trends in the annual number of days and the annual number of *Ac len* cases between 1971 and 2020 were examined. The regression coefficient was calculated, and the statistical significance of the trends (at the 0.05 level) was tested using the *t*-test. All calculations were performed using Excel and Statistica software. The con-

ditional probability of *Ac len* occurrences under different air masses, weather fronts, and types of atmospheric circulation was calculated using the method applied by Twardosz & Niedźwiedź (2001). It was determined as a quotient (expressed as a percentage) of the number of days with an *Ac len* cloud occurrence in a particular air mass/front/type of circulation, divided by the total number of days with the occurrence of particular air mass, front or type of circulation during the entire study period. In selected cases, the frequency of *Ac len* occurrences was also determined for different types of atmospheric circulation. The frequency was calculated as the quotient (expressed as a percentage) of the number of occurrences of a particular type of circulation on days with an *Ac len* divided by the total number of days with *Ac len* occurrence.

Results

The number of days with an *Ac len* occurrence recorded in Katowice throughout the study period was 1,685, which represents 9.2% of the total number of days. The average annual number of days with *Ac len* occurrence was 34. During the fifty-year period from 1971 to 2020, there was a noticeable variation in the occurrence of *Ac len* clouds in the Silesian Upland during the year. On the monthly basis, the average number of days with this cloud type varied from 2.1 days in April to 3.9 days in October (Fig. 2a). The highest number of days was recorded on average in October and November (3.9 days). A high average was also observed in May (3.2 days). In most months, the occurrence of *Ac len* was close to the overall monthly average. Significantly lower than the average was the number of days in February, April, July and August; it was slightly above two days.

During the study period 1971-2020, the maximum number of days with an *Ac len* occurrence according to the month varied from 6 days in July (1993) to 11 days in November (i.e. 37% of the days per month; in 1977 and 2000; Fig. 2b). Notably, in 1975, the monthly maxima of *Ac len* occurrence were in line with the maxima for the whole long-term period in as many as three months, i.e. in March, April and June (8-9 days). Over the fifty-year period, there were situations when no occurrences of *Ac len* were observed in a given month. The highest number of such cases was recorded in August (absence in 13 years), while the lowest was in October (only 1 year, 1985).

Similar features of the annual distribution of *Ac len* occurrence were found by analysing the number of cases of this cloud (*Ac len* could be observed more than once a day). The average annual number of *Ac len* cases in the study period 1971-2020 in the Silesian Highlands was 46. In the individual months of the year, the average number of *Ac len* cases varied from 2.7 in July to 5.9 in November (Fig. 3a). By far the greatest number of *Ac len* cases was observed on average in October and November (5.9 cases), which corresponds to the highest monthly average number of days with the occurrence of these clouds. For most of the months, the average number of *Ac len* occurrences was similar to the overall monthly average. However, in February, April and July, the average number of occurrences was significantly below this average, not exceeding three observations per month. These months were characterised by both the lowest average number of cases and the fewest days, which confirms the significant links between these two characteristics.

In the fifty-year study period (1971-2020), the maximum numbers of *Ac len* cases per month ranged from 8 in February (1974, 1988, and 1995) to 22 in November (1977; 9%

Table 1. General frequency of the occurrence of circulation types, air masses and atmospheric fronts in southern Poland in 1971-2020 based on Calendar of circulation types (Niedźwiedź, 2024)

Types of circulation						Air masses			Atmospheric fronts		
Abbreviation	Explanation	General frequency [%]	Abbreviation	Explanation	General frequency [%]	Abbreviation	Explanation	General frequency [%]	Abbreviation	Explanation	General frequency [%]
Na	north anticyclonic	3.1	Nc	north cyclonic	2.7	PA	Arctic Air	8.3	-	days without fronts	60.2
NEa	northeast anticyclonic	3.4	NEc	northeast cyclonic	2.4	PPm	Polar martime	16.3	c	warm front	8.2
Ea	east anticyclonic	4.4	Ec	east cyclonic	2.3	PPms	Polar maritime old	31.2	z	cold front	16.5
SEa	southeast anticyclonic	4.7	SEc	southeast cyclonic	2.6	PPmc	Polar maritime warm	9.5	o	occluded front (occlusion)	4.8
Sa	south anticyclonic	3.2	Sc	south cyclonic	2.9	PPk	Polar continental	19.6	st	stationary front	3.2
SWa	southwest anticyclonic	4.5	SWc	southwest cyclonic	5.6	PZ	Tropical Air	2.5	rfr	a few different fronts during a day	7.1
Wa	west anticyclonic	8.6	Wc	west cyclonic	9.3	rmp	different air masses	12.6			
NWa	northwest anticyclonic	5.4	NWc	northwest cyclonic	5.4						
Ca	high-pressure centre over southern Poland	2.7	Cc	low-pressure centre over southern Poland	0.8						
Ka	high-pressure ridge	12.5	Bc	cyclonic trough	11.3						
			X	unspecified synoptic situations or a col	2.0						

of all the time points in the month; Fig. 3b). In 1975, the monthly maxima of *Ac len* cases were consistent with the maxima for the entire period for as many as five months, i.e. January, March, April, June and July (9-15 observations).

An analysis of the number of days and occurrences of lenticular clouds by season also reveals seasonal variation in their frequency (Fig. 4). By far, the season with the highest number of days and cases was autumn (September – November), with an average of 10.5 days, and 15.4 cases during the study period. In contrast, the lowest average number of days and cases was observed in summer (June – August), with 7.2 days and 9.2 cases. Comparable values were found for winter (December – February) and spring (March – May). On average, slightly more days with *Ac len* occurrences were recorded in spring – 8.2 days (winter – 7.9 days) while slightly more *Ac len* cases were recorded in winter – 10.9 occurrences (spring – 10.5 occurrences).

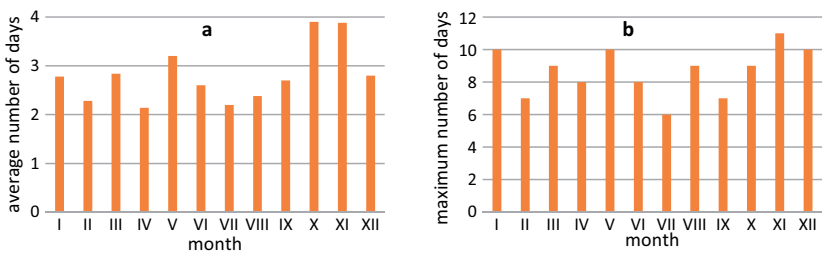

Fig. 2. Number of days with *Ac len* occurrences: a) monthly average, b) monthly maximum in Katowice (1971-2020)

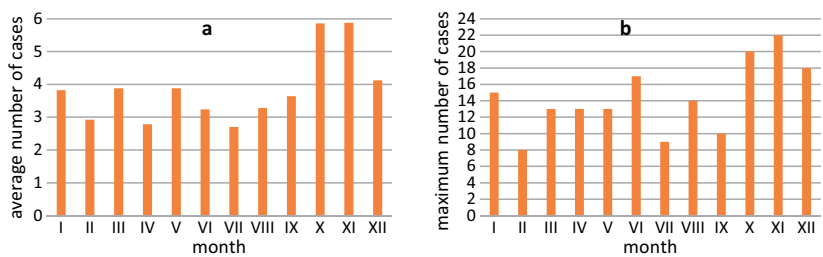

Fig. 3. Number of *Ac len* cases: a) monthly average, b) monthly maximum in Katowice (1971-2020)

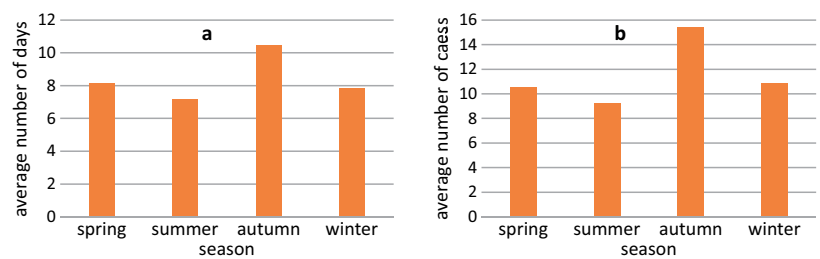

Fig. 4. Average number of days (a) and the number of *Ac len* cases (b) in Katowice in each season (1971-2020)

There is a clearly noticeable diurnal variation in the occurrence of *Ac len* in the Silesian Upland during the study period 1971-2020 (Fig. 5). These clouds were most often observed between 6:00 and 15:00 UTC, with a maximum at noon (10.3 cases on average). On the other hand, they were rarely observed between 18:00 and 3:00 UTC, with a minimum at midnight (0.8 cases on average). The time interval from 6:00 UTC to 15:00 UTC recorded the vast majority of all *Ac len* cases in the fifty-year period (84% of all cases). In the remaining hours of the day, lenticular clouds were rarely observed. During the study period, there was not a single day on which *Ac len* occurred at all the 8 observation time points. The longest-lasting occurrence of a lenticular cloud during a single day was recorded on 18th October 1980. On that day, an *Ac len* was observed at five observation time points, from 9:00 UTC to 21:00 UTC inclusive.

In the fifty-year study period (1971-2020), a total of 58 sequences of at least three days with *Ac len* occurrences were observed in Katowice (Fig. 6). This corresponds to an average of just over one sequence per year. The vast majority of these were three--day sequences (41 sequences) accounting for 71% of the total number. There were also 13 four-day sequences and four five-day sequences observed (13th – 17th January 1975, 2nd – 6th April 1975, 9th – 13th May 1997 and 19th – 23rd October 2006). Longer sequences were not observed. The common features of the longest sequences observed were the occurrences of advection from the south, southwest and west, mainly in cyclonic conditions, and the presence of a polar maritime air mass (warm or transformed) for most of the duration of the sequence. The largest number of sequences of at least 3 days with the occurrence of lenticular clouds was recorded in 1975 (8). No such sequences were observed after 2013.

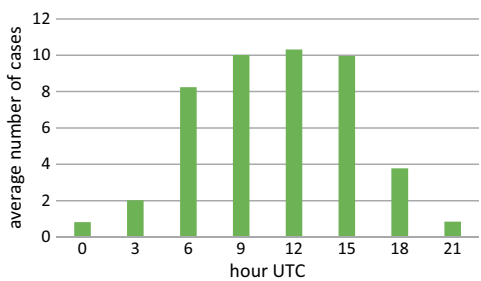

Fig. 5. Average number *Ac len* cases at the individual observation time points (every 3 hours) in Katowice (1971-2020)

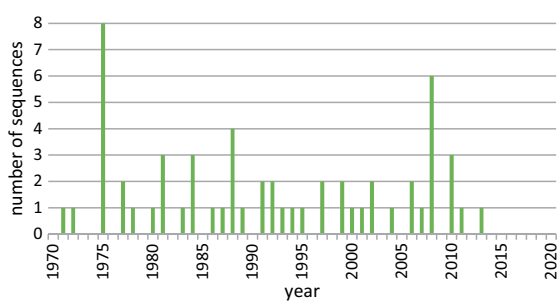

Fig. 6. Number of sequences of at least 3 days with *Ac len* occurrences in Katowice (1971-2020)

The variability in the occurrence of lenticular clouds in the Silesian Upland in the years 1971-2020 is presented in the long-term course of the number of days and number of cases of this cloud species (Fig. 7a). Both the number of days and the number of *Ac len* cases showed decreasing trends, statistically significant at the significance level of 0.05. The value of the slope coefficient for the number of days is -0.27, which means an average decrease in the number of days with *Ac len* occurrences by 2.7 per 10 years. The downward trend is not uniform and the study period is characterised by alternating periods of increase and decrease in the number of days with *Ac len* occurrences. An analysis of the five-year moving average makes it possible to define four periods of relatively low values of the number of recorded days with *Ac len* occurrences, 1976-1978, 1986-1991, 2001-2003, and 2008-2017, and three periods of fairly high values, 1978-1986, 1991-2001, and 2003-2008. However, this is too short a period of time to establish the cyclical nature of the phenomenon. There are significant variability in the number of days with *Ac len* occurrences between the years. The highest number of days with *Ac len* occurrences was recorded in 1975 – 71 days (19% of all the days in the year) and in 2008 – 65 days (18% of all the days in the year). These values depart significantly from the five-year moving average values for these years. In contrast, the lowest number of days with *Ac len* occurrences were recorded in 2016 – 17 days (5% of all the days in the year); in 1991, 1998 and 2018 – 20 days (5% of all the days in the year), and in 2019 – 21 days (6% of all the days in the year).

Similar conclusions arise from an analysis of the long-term course of the number of *Ac len* cases (Fig. 7b). In the long-term distribution a statistically significant downward trend was also found. The value of the slope is -0.41, which translates into an average decrease in the number of *Ac len* occurrences by 4.1 per 10 years. An analysis of the five-year moving average also shows alternating periods of increase and decrease in the number of *Ac len* cases over the study period. These periods are the same as for the number of days with *Ac len* occurrences, i.e. reduced number of events in 1976-1978, 1986-1991, 2001-2003 and 2008-2017 and an increase in the number of cases in 1978-1986, 1991-2001 and 2003-2008. The highest number of *Ac len* cases was recorded in 1975 – 106 events (at 4% of all possible time points) and in 2008 – 90 events (at 3% of all possible time points). These values depart significantly from the five-year moving average values for these years. In contrast, the lowest number of *Ac len* cases were recorded in 2016 – 22 events (at 1% of all possible time points). A small number of *Ac len* occurrences were also observed in 1998 – 25 events and 2018 – 24 events.

The figure showing the temporal distribution of the *Ac len* occurrences (Fig. 8) for particular months and years in Katowice illustrates the significant variations in the occurrence of these clouds, thereby reflecting the features depicted in Fig. 6a and Fig. 6b. There are visible the months characterised by the highest number of days and *Ac len* cases observed (October and November). Based on the diagram, it is possible to distinguish two periods with significantly reduced numbers of the days and occurrences of these clouds observed, i.e. the 1990s and the period after 2011. Lenticular clouds were particularly rare in the last five years of the study period. The situation in which the clouds under study occurred at least once in each month of the year occurred in 10 years of the fifty-year period (1975, 1983, 1987, 1997, 1999-2000, 2005, 2007-2008, and 2012).

The frequency of occurrence of days with lenticular clouds in the study period 1971-2020 in Katowice was 54.4% under cyclonic conditions and 44.3% under anticyclonic conditions. The remaining 1.3% of days with lenticular clouds were recorded under

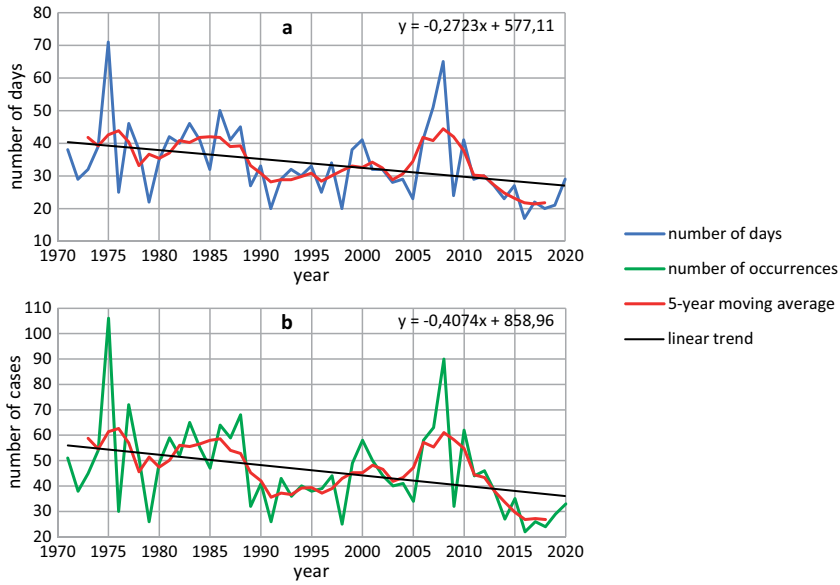

Fig. 7. Long-term trend of the number of days (a) and of the number of *Ac len* cases (b) in Katowice (1971-2020)

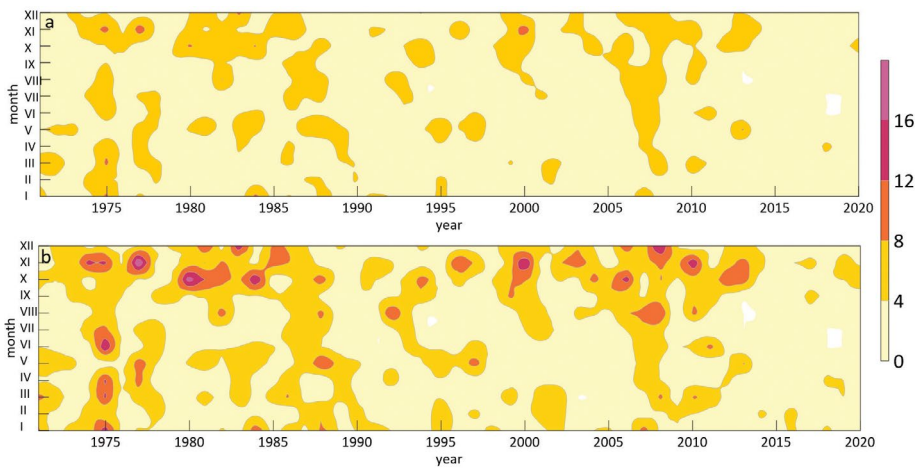

Fig. 8. Number of days (a) and number of *Ac len* cases (b) for months and years in Katowice (1971-2020)

unclassified conditions or col. The frequency of air advection from the south, southwest and west on days with *Ac len* occurrence was as high as 67.9% in total. In contrast, the frequency of advection from the other directions (north, northeast, east, southeast and northwest) considered jointly for days with *Ac len* occurrence was only 16.3%.

An analysis of the conditional probability of an occurrence of a lenticular cloud under different atmospheric circulation conditions was performed for the fifty-year study period 1971-2020. The factors taken into account were types of atmospheric circulation air

masses and weather fronts. The conditional probability for circulation types is presented in Fig. 9a. The highest conditional probability of *Ac len* occurrence was found for cyclonic advection from the southwest (SWc), which was 29.7%, while the lowest was found for cyclonic advection from the northeast (NEc) and east (Ec) and low-pressure centres (Cc), which was 1.4%. A probability of *Ac len* occurrence over 10% was found for six types of circulation. These were days with cyclonic conditions and advection from the southwest (SWc), from the south (Sc) – 25.7% and from the west (Wc) – 15.0%, and with anticyclonic conditions and advection from the southwest (SWa) – 19.4%, from the south (Sa) – 14.7% and from the west (Wa) – 12.7%. For the other types of circulation, the lenticular clouds occurred much less frequently in the fifty-year study period, and the probability of their occurrence depending on the types of circulation did not exceed 7%. Based on the calculated values, it was found that the conditional probability of *Ac len* occurrence was higher under cyclonic conditions at 11.1%. Under anticyclonic conditions, this probability was 7.8%. Another important factor was the direction of advection. Under both cyclonic and anticyclonic conditions, the prevailing directions were south, southwest and west. The conditional probability of *Ac len* occurrence for these three advection directions taken together was 18.3%, being higher under cyclonic (21.4%) than anticyclonic (15.0%) conditions. For the northerly, northeasterly, easterly, southeasterly and northwesterly wind directions, the conditional probability of *Ac len* occurrence was only 4.1%. It was higher under anticyclonic (4.9%) than cyclonic (3.1%) conditions in contrast to the prevailing advection directions. A higher conditional probability of *Ac len* occurrence was also observed for high-pressure centres (3.0%) than for low-pressure centres (1.4%).

Based on the analysis of the air masses, the probability of the occurrence of lenticular clouds was found to be higher for some of them. Depending on the air mass, this probabi-

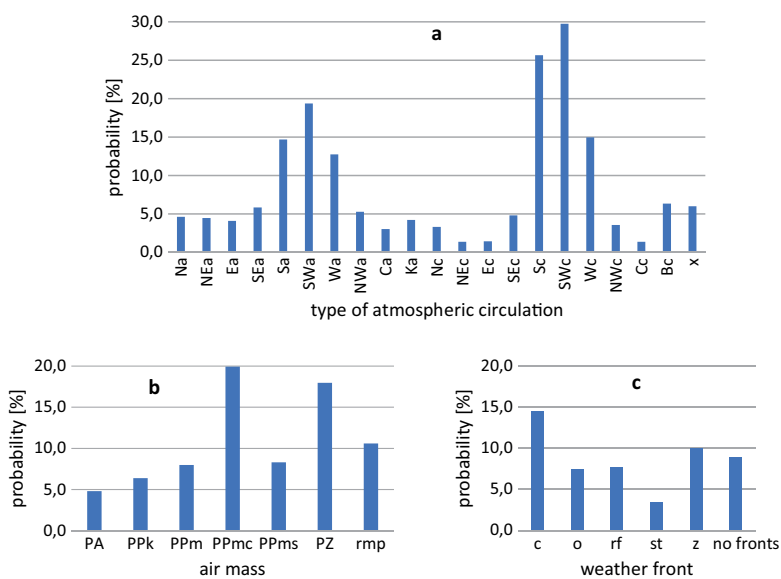

Fig. 9. Conditional probability of *Ac len* occurrence with: a) types of atmospheric circulation; b) different air masses; c) weather fronts in Katowice (1971-2020)

lity ranged from 4.8% to 19.9% (Fig. 9b). The highest probability (19.9%) of the occurrence of these clouds was found on days when a warm polar maritime (PPmc) air mass passed over southern Poland. Definitely high was also the probability of an occurrence of a lenticular cloud for the tropical air mass (PZ) – 18.0%. The probability in the case of various air masses (rmp) that occurred during a single day was 10.6%. For the other air masses, the probability of an occurrence of a lenticular cloud was below 10%: transformed (old) polar maritime air (PPms) – 8.3%, polar maritime air (PPm) – 8.0%, polar continental air (PPk) – 6.4%. By far the lowest probability of *Ac len* occurrence, was recorded on days with the occurrence of arctic air mass (PA); this probability was 4.8%.

Throughout the study period lenticular clouds show less dependence on the occurrence of various weather fronts over southern Poland. Depending on the type of weather front, the conditional probability ranged from 3.4% to 14.5% (Fig. 9c). The highest probability of *Ac len* occurrence was associated with the occurrence of a warm weather front (c) and was 14.5%. The probability of *Ac len* occurrence for days with a cold weather front (z) was lower than that for a warm front by almost 5 percentage points and was 10.0%. For the occurrence of other weather fronts, the probability of *Ac len* occurrence was very low: various fronts on the same day (rf) – 7.6%, occluded front (o) – 7.5% and stationary front (st) – 3.4% (the lowest probability among all the types of weather fronts). For the days when no weather fronts occurred, the conditional probability of *Ac len* occurrence was 8.9%.

Discussion

The long-term variability in the occurrence as well as the impact of atmospheric circulation conditions on the formation of lenticular clouds has been poorly studied. The lack of sufficient literature and similar analyses on this particular cloud species makes it impossible to compare these conclusions with other studies. Many authors of studies on cloudiness focus on analyses related to the cloud cover levels or rely solely on cloud types without more detailed analyses on cloud species. It should be borne in mind that cloud types and species are determined by visual observations without the use of measuring instruments. This implies a risk of some subjectivity in the assessment and even errors in cloud observations and coding. This may affect the results obtained. Moreover, observations conducted during the night increase the difficulty of identifying cloudiness. The latter may be the reason for the less frequent observations of the *Ac len* cloud between 18 and 3 UTC, as found in this paper.

However, the meteorological station in Katowice belongs to the group of first-order stations with 24-hour observations throughout the whole study period. This minimises the likelihood of erroneous observations. Analyses related to the type of cloudiness indicate a positive trend in the occurrence of *Altocumulus* clouds in recent decades (Matuszko, 2003; Filipiak, 2021). Nevertheless, a decreasing trend in the occurrence of lenticular clouds was found. This may be related to an increase in the occurrence of other species of this cloud. However, no results are available for these species (*stratiformis*, *castellanus*, *floccus* and *volutus*). On the basis of analyses of the meridional circulation index, it can be noted that this type of circulation is most frequent in autumn and winter, with maximum values in October and November, while it is least frequent

in summer (Niedźwiedź & Ustrnul, 2021), which coincides with the periods when *Ac len* were most frequent (autumn) and least frequent (summer) in Upper Silesia. In 1975, when the maximum number of days and cases of *Ac len* occurrence were observed, the meridional circulation index had a rather high value (above 20%; Niedźwiedź & Ustrnul, 2021). The long-term trend of the type of atmospheric circulation with advection from the south (S) is positive, statistically significant in summer and autumn. In contrast, the SE circulation type for the whole year and in winter in the period 1874-2020 shows a negative, statistically significant trend. The type describing advection from the west (W), for which the probability of *Ac len* occurrence is also quite significant, is characterised by a strong negative trend from spring to autumn (Bielec-Bąkowska, 2022). This trend is consistent with the trend of *Ac len* occurrence. Marsz et al. (2024) further found no statistically significant correlation coefficients between zonal sea surface temperature gradients on the Atlantic Ocean and the annual frequency of *Ac* cloud over the southern Poland. Due to the small number of studies on lenticular clouds to date, there are many areas for future research on this cloud species in Poland. The statistically significant negative trend of *Ac len* occurrence may be related to global climate change (IPCC, 2021, 2023), which also affects the atmospheric circulation conditions. To confirm this, studies on a larger area covering e.g. the entire area of the Carpathian foreland are needed. Also worthy of attention are more detailed analyses to better understand the mechanism of the formation and behaviour of lenticular clouds. This paper merely distinguishes the basic and most important features of these clouds and their formation and occurrence as well as the impact of the atmospheric circulation conditions on these phenomena in a general way, without in-depth analyses. It also presents the long-term changes in *Ac len* cloud that occurred during the fifty-year period 1971-2020.

Conclusions

The analysis of the long-term variability in the occurrence of *Altocumulus lenticularis* clouds in the Silesian Uplands (on the example of Katowice) in the period 1971-2020, together with the impact of the atmospheric circulation conditions, enabled some basic conclusions to be drawn:

- despite the distance of approx. 85 km from the main ridge of the Carpathian Mountains to the north, lenticular clouds occur in Katowice on an average of 34 days annually; an average of 46 cases of *Ac len* occurrence were observed annually at the designated time points (every 3 hours);
- there is a clearly visible statistically significant downward trend in the number of observed days and cases over the fifty-year study period; between 1971 and 2020 there was an average decrease in the number of days with *Ac len* occurrence by 2.7 days per 10 years and 4.1 cases per 10 years;
- the highest number of days and cases of *Ac len* occurrence were observed in 1975 while the lowest numbers were observed in 2016. Despite the downward trend, alternating periods of lower and higher numbers of recorded days and events of *Ac len* occurrence are noticeable;
- the highest number of days of *Ac len* occurrence were observed in autumn (with a maximum in November) while the lowest – in summer (with a minimum in July);

- lenticular clouds were mainly observed during the day, between 6:00 and 15:00 UTC (83.8% of all events) with a maximum at 12:00 UTC and a minimum at 0:00 UTC;
- the highest conditional probability of *Ac len* occurrence in Upper Silesia was found for air advection from the south and southwest under cyclonic pressure systems (26% and 30%, respectively) and for the advection of warm polar maritime air mass over southern Poland (20%).

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