sciendo

Bulletin of Geography. Physical Geography Series, No. 18 (2020): 61–71
http://dx.doi.org/10.2478/bgeo-2020-0005

Selected meteorological phenomena posing a hazard to aviation: a case study on Bydgoszcz airport, central Poland

ISSN 2080-7686

OPEN ACCESS

Andrzej Araźny* [1, 2a], **Edward Łaszyca**[3]

[1] Nicolaus Copernicus University, Faculty of Earth Sciences and Spatial Management, Toruń, Poland
[2] Nicolaus Copernicus University, Centre for Climate Change Research, Toruń, Poland
[3] Institute of Meteorology and Water Management - National Research Institute (IMGW-PIB), Poland

Correspondence: Nicolaus Copernicus University in Toruń, Poland. E-mail: andy@umk.pl

[a] https://orcid.org/0000-0002-4277-9599

Abstract. The article describes the occurrence of selected weather phenomena that are hazardous to aviation (thunderstorms, hail, fog and glaze) in Bydgoszcz. The work employs 1971–2010 data from the Bydgoszcz-Airport meteorological station. The hazardous atmospheric phenomena selected for analysis hinder or sometimes even prevent aviation. Of the analysed weather phenomena in Bydgoszcz, those most hazardous to aviation are fog and thunderstorms. The average annual numbers of days featuring them exceed 71 and 14, respectively. The analysis shows that statistically significant threats to aviation have decreased, e.g. number of days with fog (by 4.76 days/10 yrs) and days with thunderstorms (by 1.68 days/10 yrs). However, no clear trends can be seen for the number of days with hail (decrease of 0.14 days/10 yrs) and days with glaze (an increase of 0.16 days/10 yrs).

Key words:
weather phenomena,
applied climatology,
long-term variability,
Bydgoszcz,
Poland

Introduction

Aerial transport is developing rapidly. The number of new connections has increased, and flight routes and durations are getting longer. In the 21st century, air transport has become the safest and fastest mode of transport, with passenger numbers growing rapidly. The International Air Transport Association revealed that present trends in air transport suggest passenger numbers could double to 8.2 billion by 2037 (https://www.iata.org/en/pressroom/pr/2018-10-24-02/). There is also a rapid growth in interest in atmospheric phenomena accompanying air travel and negatively affecting airline transportation e.g. flight delays, cancelled flights, and various accidents (Borsky and Unterberger 2019; Gultepe et al. 2019).

Most of Poland's passenger traffic is accounted for by the airports of Warsaw, Kraków and Gdańsk. Bydgoszcz's number of passengers (425,000 per year) places it further down in the ranking of Polish airports (https://plb.pl/statystyki). Bydgoszcz airport has been growing rapidly in recent years. In terms of growth in passenger numbers in Poland, Bydgoszcz ranked second (behind Poznań) with a 2018 increase of 25% over 2017).

Information on weather conditions in the Bydgoszcz region is spread across many publications and based on data from various multi-annual periods and measurement stations. The present study focuses primarily on weather phenomena around the turn of the 21st century, although the region's climate was also studied in the 1920s and 1930s. The climate of the Bydgoszcz region has been well described, with many works published, e.g. on air temperature (e.g. Hohendorf 1967; Roguski et al. 1996; Bąk 2003; Dudek et al. 2008, 2010; Żarski et al. 2010; Łaszyca and Kuśmierek-Tomaszewska

2013; Kasperska-Wołowicz and Bolewski 2015; Łaszyca 2018) and on atmospheric precipitation (e.g. Hohendorf 1967; Roguski et al. 1996; Łabędzki and Adamski 2010; Żarski et al. 2014). In Poland, issues of aviation meteorology have been presented in monographic studies (e.g. Parczewski 1953; Holec and Tymański 1973; Schmidt 1982; Kaczanowski 1987; Ostrowski 1999; Stopa-Boryczka et al. 2013; Szewczak 2014) and in works relating to the planning of the construction of the airport, and its operation (e.g. Wiążewski and Bąkowski 2007; Błażejczyk and Solon 2009; Szot 2013; Skrzyńska 2019).

Within Poland, Bydgoszcz is located in the "central" bioclimatic region, and its bioclimatic conditions are typical for the country (Błażejczyk and Kunert 2011). Central Poland has favourable biometeorological conditions for air transport staff and passengers. This is due to, among other things, the unobstructed atmospheric circulation and the flat terrain, which help even out differences in thermal and humidity conditions – that is, which alleviate stimuli (Araźny and Smukała 2011).

The aim of the study is to examine the variability of selected weather phenomena that are hazardous to aviation (thunderstorms, hail, fog and glaze) in central Poland, on the example of Bydgoszcz airport in the period 1971–2010.

Methods and materials

Bydgoszcz is a city in north-central Poland, on the Brda and Vistula rivers (Fig. 1). The work uses 1971–2010 meteorological data from the Bydgoszcz-Airport meteorological station. In the years 1951–82 the station operated under the auspices of the Institute of Meteorology and Water Management (IMGW) according to the International Civil Aviation Organisation (ICAO). In the years 1951–65, the station conducted basic measurements of meteorological parameters such as: air temperature, dew point temperature, amount and type of cloud cover, relative humidity, wind direction and speed, and visibility. Since 1966, meteorological observations have been extended to include the following measurements: height of cloud base, atmospheric pressure at sea and station level, water vapour pressure, atmospheric phenomena, type of precipitation, ground condition. In 1983–2010 meteorological measurements were continued by military observers and civilian employees of the military at the Military Airport Meteorological Station according to the ICAO. In February 2007, the IMGW station at the Bydgoszcz-Szwederowo airport was reactivated. Station employees measure meteorological parameters: cloud types and amount, lower cloud base, wind direction and speed, air temperature, dew point temperature, relative humidity, atmospheric pressure, atmospheric phenomena, and visibility. The station also conducts meteorological services for civil aviation (*Meteorologiczna Osłona Lotnictwa Cywilnego* [MOLC]). The measuring points are located at about 800 m from each other in a fenced-off, restricted part of the airport, so the data used for the tests were considered homogeneous, meeting the measurement comparability criterion. The stations were located on a plateau at the Bydgoszcz-Szwederowo Airport (φ=53˚05'N, λ=17˚58'E, h=72.0 m a.s.l.), at about 3.5 km from the city centre, with no anthropogenic influence, which guarantees their representativeness for the Bydgoszcz Airport (Figs 2 and 3).

All data have been carefully checked and homogenised using the Standard Normal Homogeneity Test (Alexandersson 1986) modified by Štěpánek (2008). The data series was determined to be homogeneous. The study examined the variability of selected hazardous weather phenomena (thunderstorms, hail, fog and glaze) in terms of monthly, seasonal and annual values of meteorological elements in the period 1971–2010. Regression analysis was carried out and the direction and trends of changes in the examined elements over time were determined based on a linear function.

According to the definition used at IMGW-PIB meteorological stations, a thunderstorm is considered to have occurred when a thunderclap is heard less than 10 seconds after seeing the lightning, while for distant thunderstorms, thunder will be heard more than 10 seconds after lightning is observed, or thunder may be heard with no observable preceding lighting (Derek et al. 2015). Thunderstorms are always associated with the occurrence of cumulonimbus (Cb) clouds. The occurrence of thunderstorms is associated with a strong increase in cumulus clouds, caused by thermal ground factors or the

 Citation: Bulletin of Geography. Physical Geography Series 2020, 18, http://dx.doi.org/10.2478/bgeo-2020-0005

Fig. 1. Location of the study area

Fig. 2. Military meteorological garden at the Bydgoszcz-Szwederowo Airport in the 1990s. (photo: J. Czop)

Fig. 3. Bydgoszcz-Szwederowo Airport meteorological garden of the Institute of Meteorology and Water Management - National Research Institute in the 21st century (photo: E. Łaszyca)

movement of atmospheric fronts. Thunderstorms are often associated with heavy precipitation (Woś 1999) and are a local phenomenon. During a flight in a thunderstorm zone, there is a high probability of heavy turbulence, lightning, hail, icing, and wind shear as downbursts or microbursts (Domicz and Szutowski 1998; Szot 2013; Szewczak 2014). In Bydgoszcz, which is located in lowland central Poland, general atmospheric circulation and related inflowing air masses play a major role in the formation

of thunderstorms (Bielec-Bąkowska 2002; Kolendowicz 2005).

Research on the occurrence of thunderstorms in Bydgoszcz is supplemented by an analysis of the occurrence of hail as potentially the most dangerous thunderstorm precipitation. "Hail" is the term for the precipitation of ice pellets usually of diameter 5–50 mm (Niedźwiedź 2003). In addition to limiting visibility, hail may cause mechanical damage to an aircraft, thus reducing its aerodynamic properties. In addition, hailstones falling on the airport apron and runways also affect the airport's operational condition, usually temporarily restricting traffic.

The first condition that must obtain when starting a flight is sufficient visibility. The aviation parameter that determines the minimum permissible visibility for aircraft take-off is minimum atmospheric conditions. These comprise fog and cloud base height. Fog is a suspension of small droplets of water or ice crystals in the ground layer of the air reducing horizontal visibility to below 1 km (Niedźwiedź 2003). Fog is an atmospheric phenomenon that negatively affects many areas of human activity, including impeding air traffic and complicating its organisation. The greatest impediment to aviation is thick fog. Visibility of less than 300 m results in air transport being suspended at most airports around the world. Fog also contributes to the persistence of particulate and gas contaminants in the air, decreasing the influx of solar radiation and reducing visibility, while also deteriorating human well-being and exacerbating many diseases (Błażejczyk and Kunert 2011).

Glaze (or "clear ice") is a coating of ice that results from supercooled droplets of drizzle or rain freezing to surfaces with a temperature lower or slightly higher than 0°C (Niedźwiedź 2003). Glaze may also form as a result of unchilled drizzle droplets or rain freezing immediately upon contact with a surface below 0°C (Woś 1999). Glaze presents a particular hazard to aviation activities. Its occurrence prevents any manoeuvres being conducted on runways and the apron, thus preventing the airport from serving air traffic.

Results

Number of thunderstorm days

Analysis of the annual course shows that the thunderstorm maximum in Bydgoszcz occurred in July (an average of 4.0 days with a thunderstorm), followed by June, August and May (Fig. 4A). The greatest number of days with a thunderstorm in a single month (13) occurred in July 1973. In the analysed 40-year period, July and August were the only months in which thunderstorms always occurred. Thunderstorm incidence was 95% in May and June, 45% in September, and 25% in April. The minimum occurred in November, when there was no thunderstorm in the study period.

In Bydgoszcz, the annual average number of days with a thunderstorm was 14.3 in 1971–2010. There were a total of 570 days with a thunderstorm in the 40-year study period. Because thunderstorms predominantly have convective origins, they predominate in the summer. In the warm half-year (April–September) there were 556 thunderstorms, and in the cool half-year (October–March) only 14. In the winter months there were only 4 days with thunderstorms, while none occurred in November. Thunderstorms were most numerous in 1973 and 1997 both across the year as a whole (29) and in the warm half-year (28). By contrast, the least (6) occurred in 2003 (Fig. 4B).

In Bydgoszcz, the number of thunderstorms decreased in the years 1971–2010. The decrease was statistically significant, both for the summer half-year and over the year (by 1.62 days and 1.68 days/10 yrs, respectively). The number of days with a thunderstorm in the winter half-year shows a weak downward trend that is not statistically significant (0.06 days/10 yrs).

Number of days with hail

In Bydgoszcz in the annual course over 1971–2010, the hail maximum occurred in May and June (an average of 0.2 days with hail). Hail was most frequent (2 days) in December 1978 and January 2010.

Citation: Bulletin of Geography. Physical Geography Series 2020, 18, http://dx.doi.org/10.2478/bgeo-2020-0005

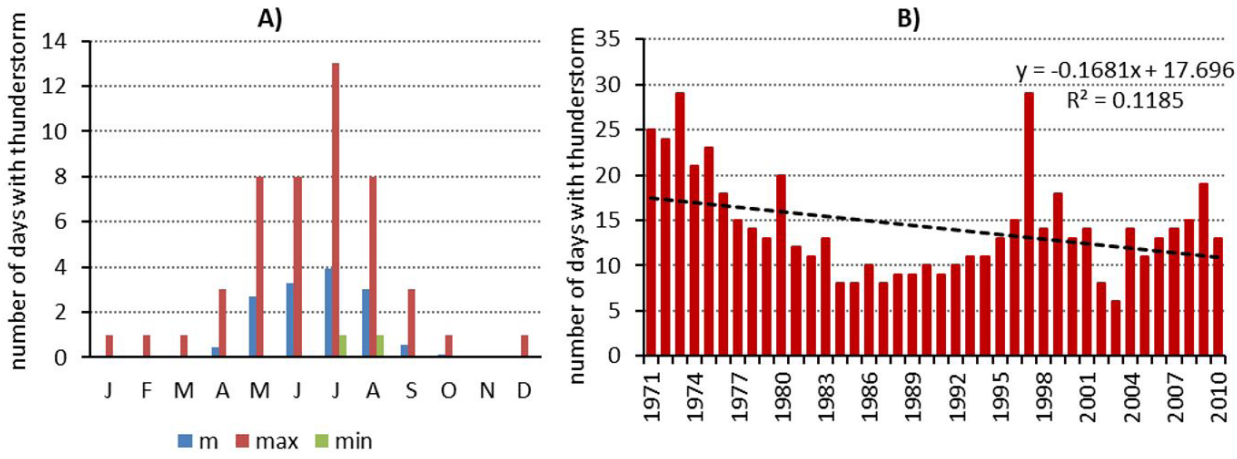

Fig. 4. A) Annual course of mean (m), maximum (max) and minimum (min) number of days with a thunderstorm; and B) Number of days with a thunderstorm by year in Bydgoszcz in the period 1971–2010

In Bydgoszcz, there was no hail in November during the study period (Fig. 5A).

Precipitation of hail was extremely rare in the Bydgoszcz-Airport area (about 1 day/yr). Over the 40 years, there were 25 such days in the warm half of the year, and 14 in the cool half-year. The total seasonal hailfall was highest in spring (13), and lowest in autumn (5). Analysis of the frequency of this dangerous weather phenomenon shows that hail occurred in 26 of the 40 analysed years (frequency 65.0%), in 55% of warm half-years, and in 27.5% of cool half-years. The year 1975 was record-breaking in terms of the number of days with hail, with as many as 4 such days – all in the warm half-year (Fig. 5B).

Trend analysis of the annual sum of number of days with hail did not show an increase in aviation hazards over the years 1971–2010. There was a falling tendency in the number of days with hail (0.14 days/10 yrs) and in the temporal variability of the phenomenon.

Number of days with fog

In Bydgoszcz, over the course of the average year, fog was most often recorded in December (10.7 days) and November (10.1 days). Conversely, it was least frequent in June and July (on average 2.2 and 2.4 days, respectively) (Fig. 6A). During the study period the most days with fog (18) occurred in October 1977.

Fog is a relatively common phenomenon in Bydgoszcz, being recorded about 71 days a year. The annual total number of days with fog ranged from 41 (in 2009) to 100 (in 1997) (Fig. 6B). In the re-

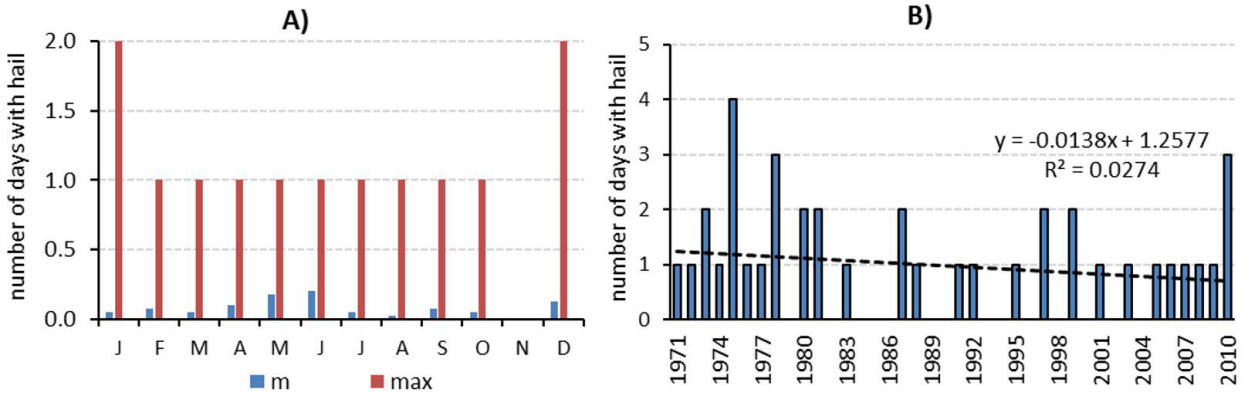

Fig. 5. A) Annual course of mean (m) and maximum (max) number of days with hail; and B) Number of days with hail by year in Bydgoszcz in the period 1971–2010

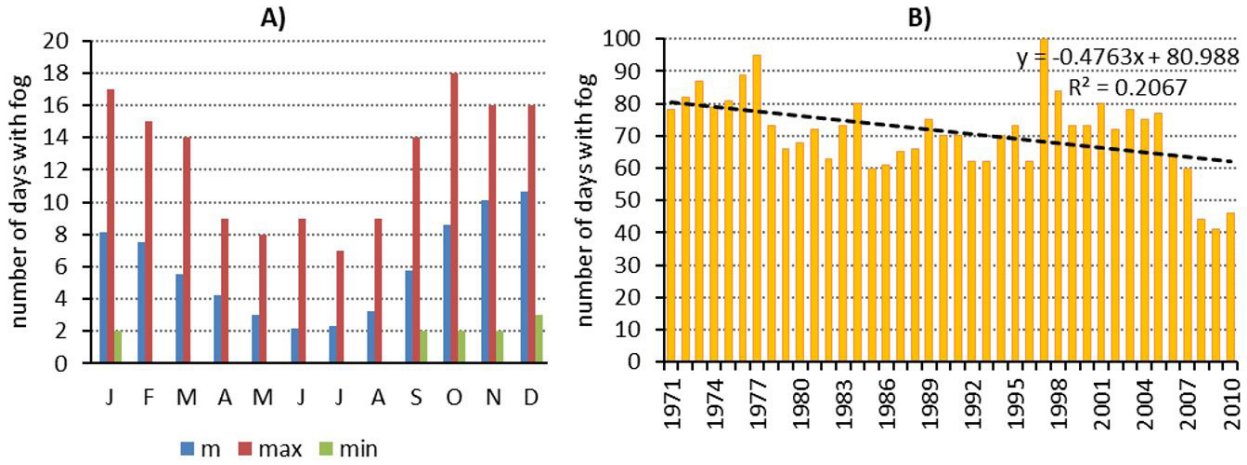

Fig. 6. A) Annual course of mean (m), maximum (max) and minimum (min) number of days with fog; and B) Number of days with fog in Bydgoszcz by year in the period 1971–2010

cord year (1997) the most days with fog occurred in December (15), in February (14) and in January (13). Fogs have always occurred, every year, from September to January in the study period. In Bydgoszcz there were a total of 2,849 days with fog in the years 1971–2010. In the cool and warm half-years, there were 2,021 and 828 days, respectively.

In Bydgoszcz in the 40-year study period the number of days with fog during the year was found to have decreased (by 4.76 days/10 yrs), which is statistically significant at the level of 0.05. The decrease in number of days with fog is greater in the cool half-year (3.64 days/10 yrs) than in the summer half-year (1.11 days/10 yrs). Of the individual seasons, the number of fogs decreased most in autumn (1.77 days/10 yrs) – a statistically significant decrease.

Number of days with glaze

In Bydgoszcz in the annual course, the highest average number of days with glaze occurred in December (1.9 days) and January (1.2 days). This phenomenon occurs sporadically outside the winter period. In the 40 years, this phenomenon did not occur in Bydgoszcz between March and October (Fig. 7A).

In Bydgoszcz in the years 1971–2010, the average number of days with glaze was 4.5. According to observations, there were a total of 181 days with this phenomenon in the study period. There were 142 days with glaze in the winter months (December–February) and 39 days in November. Analysis of the incidence of this hazardous weather phenomenon shows that glaze occurred in 37 of the 40 years

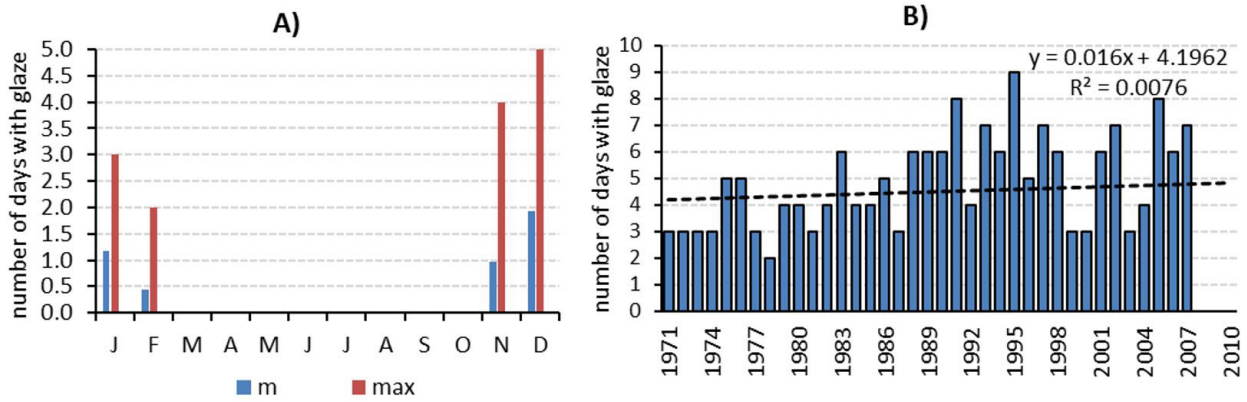

Fig. 7. A) Annual course of the mean (m) and maximum (max) number of days with glaze; and B) Number of days with glaze in Bydgoszcz by year in the period 1971–2010

Citation: Bulletin of Geography. Physical Geography Series 2020, 18, http://dx.doi.org/10.2478/bgeo-2020-0005

(all except 2008–2010) (92.5%). The record year in terms of number of days with glaze (9 days) was 1995 (Fig. 7B).

Analysis of the trends in the number of days with glaze showed a slight increase in 1971–2010. These days increase in number each year, including in winter (0.16 and 0.04 days/10 yrs, respectively). These changes are not statistically significant.

Discussion

In Europe, thunderstorms are the most frequent during summertime, from May to September (Taszarek et al. 2020), while during wintertime convective activity shifts to the Mediterranean area (Galanaki et al. 2015, 2018; Enno et al. 2019; Taszarek et al. 2019, 2020). According to Proud (2015) in the period from March 2014 to February 2015, 2.4% of aircraft in Europe reported their position to be within 40 km of a thunderstorm, most frequently during summer.

In Poland Bielec-Bąkowska (2002) analysed the occurrence of thunderstorms from 56 meteorological stations in the period 1949–98. A spatial analysis of the number of days with thunderstorms in Poland done by Bielec-Bąkowska (2002) showed that, even though there are 24 such days on average in Poland per year, the numbers varies from 15 in the north-west of the country to 33 in the south-east. A similar distribution is given by other authors, e.g. Grabowska (2001) and Lorenc (2005). No trend was found in the multi-annual course of mean yearly number of days with thunderstorms in Poland (Bielec-Bąkowska 2002, 2013). In this study in Bydgoszcz, the number of days with thunderstorms decreased (by about 2 days/10 years).

Across the vast majority of Europe, the hail season starts in April/May and lasts until August/September – e.g. in Germany (Mohr and Kunz 2013) or France (Dessens 1986). By contrast, hail is reported to be a year-round phenomenon near the coasts, where the climate is strongly influenced by the Atlantic Ocean or the Mediterranean (Punge and Kunz 2016).

In Poland, Bielec-Bąkowska (2010) identified on average about 17 hail days per year by analysing observational data from 23 weather stations (in the period 1966–2006). Number of days with thunderstorms increases from northwestern Poland (15,4 days at Świnoujście station) to southeastern part of Poland (34,4 days at Lesko station) (Bielec-Bąkowska 2002). The author also analyzed hail days at 23 stations and found similarity in spatial distribution of hail days and days with storm (Bielec-Bąkowska 2013). Suwala (2010) also analysed station data, for the whole year (in the period 1973–2009), and obtained the highest hail activity at a station on the Baltic coast (up to 10 hail days per year). In another study, only for the warm half year, Suwala and Bednorz (2013) report an average point hail frequency of 1.12, which is close to the estimation of Bielec-Bąkowska (2010). No trend was found in the multi-annual course of mean yearly number of days with hail in Poland (Bielec-Bąkowska 2013). Similar results were obtained for the airport in Bydgoszcz in this work.

In European countries, according to Vautard et al. (2009) frequency of low-visibility conditions such as fog, mist and haze has declined over the past 30 years, for all seasons and all visibility ranges between 0 and 8 km. This decline is spatially and temporally correlated with trends in sulphur dioxide emissions, suggesting a significant contribution of air-quality improvements (Vautard et al. 2009). This is confirmed by studies of fog and low stratus (FLS) conducted by Cermak et al. (2009) and Egli et al. (2017). Winter shows the highest FLS occurrence, but with a general decrease over the most recent period. Spring, summer and autumn show less pronounced trends and lower average FLS frequencies.

In Poland, numbers of days with fog are highest in mountainous areas. Clouds that reach mountain peaks (the Tatras, the Sudetes) are often treated as fogs. Therefore, the average annual number of days with fog is 310 days on Śnieżka, and 290 on Kasprowy Wierch (Lorenc 2005). Meanwhile, the number of days with fog in the lowland part of the country ranges from fewer than 40 on parts of the Baltic coast and in eastern central Poland, through about 50 in the middle of the country, to over 90 in the Chojnice area of the Pomeranian Lake District and over 80 in the middle Odra river basin (Lorenc 2005). Fogs are more common at stations located in topographical depressions. As Lorenc and Myszura (2012) stated for the period 1971–2005, the de-

crease in number of fog days in Poland, e.g. in Kraków or Opole, may be significantly caused by an anthropogenic factor, such as falling concentrations of suspended particulate matter. This study found a statistically significant reduction in threat to aviation in Bydgoszcz – the number of days with fog fell (5 days/10 yrs). Similar results were obtained by Łupikasza and Niedźwiedź (2013) for Kraków-Balice (for the period 1966–2015).

The Polish lowlands of Central Europe experienced from fewer than 2 days with glaze to more than 10 in the period 1971–2000 (Lorenc 2005). The fewest days with glaze (below 2) occur on the western Baltic coast, in the north of the Kraków–Częstochowa Upland up to the Opole Plain, and in the middle Dunajec basin. The number of days with glaze is highest in the Siedlce Upland (over 10). In the mountains, the number of days with glaze is higher, reaching 13 on Kasprowy Wierch and 26 on Śnieżka (Lorenc 2005). In the years 2001–05 there was an upward trend in this phenomenon at most stations in Poland. In Siedlce, where glaze incidence is very high, it increased from 10 days/yr (1971–2005) to about 15 days/yr (2001–05) (Dołęga and Lorenc 2012). In the present study of Bydgoszcz, the same 5-year period brought an average of only 2 days/yr with glaze.

Summary

The analysis of weather phenomena hazardous to aviation in Bydgoszcz in 1971–2010 allows several conclusions to be drawn:

- The average annual number of thunderstorm days was around 14. During the study period, the number of thunderstorm days fell statistically significantly (by 1.68 days/10 yrs).
- There were few days with hail (around 1 per year). A falling trend in aviation threats was found in the form of a decrease in the number of days with hail (0.14 days/10 yrs).
- The annual average number of fog days was 71. A statistically significant decrease in number of fog days (of 4.76 days/10 yrs) was found during the study period.
- There were an average of around 4.5 days with glaze in Bydgoszcz. In the surveyed years, the number of such days increased slightly (0.16 days/10 yrs).

Each phenomenon examined in the study (thunderstorms, hailstorms, fog and glaze) is hazardous to aircraft in flight, or performing take-off or landing manoeuvres. Each is dangerous to a differing degree and at different times of the day and year. Weather phenomena are most dangerous when their actions coincide with one another. The study revealed that no months are entirely devoid of days with weather conditions adverse for aviation activities. It was found that the greatest threat to air traffic in Bydgoszcz is from November to February.

Summing up the distribution of phenomena unfavourable to aviation activities, relative to Poland as a whole, (Lorenc 2005; Woś 2010) Bydgoszcz has specific local climate properties: less frequent thunderstorms, hail and glaze, but more days with fog.

Disclosure statement

No potential conflict of interest was reported by the authors.

Author contributions

Study design AA, EŁ; data collection EŁ; statistical analysis EŁ, AA; result interpretation AA, EŁ; manuscript preparation AA, EŁ; literature review: EŁ, AA.

Acknowledgements

We thank the anonymous reviewers for their careful reading of our manuscript and their many insightful comments and suggestions.

References

ALEXANDERSSON H, 1986, A homogeneity test applied to precipitation data. *Journal of Climatology* 6: 661-675.

ARAŹNY A and SMUKAŁA K, 2011, Ocena bodźcowości warunków termiczno-wilgotnościowych w Polsce w przekroju południkowym w okresie 1976-2005. *Annales UMCS sectio B* LXVI (2): 77-90. DOI: https://doi.org/10.2478/v10066-011-0014-z

BĄK B, 2003, Warunki klimatyczne Wielkopolski i Kujaw. *Woda-Środowisko-Obszary Wiejskie* 3(9): 11-38.

BIELEC-BĄKOWSKA Z, 2002, *Zróżnicowanie przestrzenne i zmienność wieloletnia występowania burz w Polsce. Wydawnictwo Uniwersytetu Śląskiego*, Katowice.

BIELEC-BĄKOWSKA Z, 2010, Występowanie gradu w Polsce w świetle cyrkulacji atmosfery w latach 1966 – 2006. In: Ciupa T and Suligowski R (eds), *Woda w badaniach geograficznych,* Instytut Geografii, Uniwersytet Jana Kochanowskiego, Kielce, 367-382.

BIELEC-BĄKOWSKA Z, 2013, Burze i grady w Polsce, *Prace Geograficzne* 132, 99-132.

BŁAŻEJCZYK K and KUNERT A, 2011, *Bioklimatyczne uwarunkowania rekreacji i turystyki w Polsce*. Monografie 13, PAN IGiPZ, Warszawa.

BŁAŻEJCZYK K and SOLON J, 2009, Uwarunkowania środowiskowe, Studia nad lokalizacją regionalnych portów lotniczych na Mazowszu. *Prace Geograficzne* 220: 59-80.

BORSKY S and UNTERBERGER C, 2019, Bad weather and flight delays: the impact of sudden and slow onset weather events. *Economics of Transportation* 18: 10–26. DOI: https://doi.org/10.1016/j.ecotra.2019.02.002

CERMAK J, EASTMAN R.M, BENDIX J and WARREN S.G, 2009, European climatology of fog and low stratus based on geostationary satellite observations. *Quarterly Journal of the Royal Meteorological Society* 135: 2125-2130, DOI: https://doi.org/10.1002/qj.503

DEREK P, GÓRKA A, GRZELAK-AGACIAK E, JURCZAK K, KAMIŃSKA M, KIELOCH B, LECH H, LETACHOWICZ J, RAGIN G, RÓŻDŻYŃSKI K, STEPKO W, SUCHECKI S, TRZEBUNIA J and WOŹNIAK Ł, 2015, *Instrukcja dla stacji meteorologicznych*. Instytut Meteorologii i Gospodarki Wodnej - Państwowy Instytut Badawczy, Warszawa.

DESSENS J, 1986, Hail in southwestern France. I: Hailfall characteristics and hailstrom environment. *Journal of Applied Meteorology and Climatology* 25: 35–47.

DOŁĘGA E and LORENC H, 2012, Ryzyko występowania gołoledzi w Polsce. In: Lorenc H (ed.), *Klęski żywiołowe a bezpieczeństwo wewnętrzne kraju,* IMGW-PIB, Warszawa: 98-119.

DOMICZ J and SZUTOWSKI L, 2004, *Podręcznik pilota samolotowego*. Poznań.

DUDEK S, KUŚMIEREK R and ŻARSKI J, 2008, Porównanie warunków termicznych Bydgoszczy i okolicy. In: Kłysik et al. (eds), *Klimat i bioklimat miast*. Wydawnictwo Uniwersytetu Łódzkiego, Łódź: 157–164.

DUDEK S, KUŚMIEREK-TOMASZEWSKA R and ŻARSKI J, 2010, Charakterystyka miejskiej wyspy ciepła na przykładzie Bydgoszczy. *Ekologia i Technika* XVIII(4): 180-185.

EGLI S, THIES B, DRÖNNER J, CERMAK J and BENDIX J, 2017, A 10 year fog and low stratus climatology for Europe based on meteosat second generation data. *Quarterly Journal of the Royal Meteorological Society* 143(702): 530–541, DOI: https://doi.org/10.1002/qj.2941

ENNO S.E, SUGIER J, ALBER R and SELTZER M, 2019, Lightning flash density in Europe based on 10 years of ATDnet data. *Atmospheric Research* 235, 104769, DOI: https://doi.org/10.1016/j.atmosres.2019.104769

GALANAKI E, KOTORNI V, LAGOUVARDOS K and ARGIRIOU A, 2015, A ten-year analysis of cloud-to-ground lightning activity over the Eastern Mediterranean region. *Atmospheric Research* 166: 213-222, DOI: https://doi.org/10.1016/j.atmosres.2015.07.008

GALANAKI E, LAGOUVARDOS K, KOTORNI V, FLAOUNAS E and ARGIRIOU A, 2018, Thunderstorm climatology in the Mediterranean using cloud-to-ground lightning observations. *Atmospheric Research* 207: 136-144, DOI: https://doi.org/10.1016/j.atmosres.2018.03.004

GRABOWSKA K, 2001, Zmienność aktywności burzowej w niektórych regionach geograficznych Polski, *Prace i Studia Geograficzne UW* 29: 181 - 190.

GULTEPE I, SHARMAN R, WILLIAMS P.D, ZHOU B, ELLROD G, MINNIS P, TRIER S, GRIFFIN S, YUM S.S, GHARABAGHI B and FELTZ W, 2019, A review of high impact weather for aviation meteorology. *Pure and Applied Geophysics* 176, 1869–1921. DOI: https://doi.org/10.1007/s00024-019-02168-6

HOHENDORF E, 1967, Klimat. In: Swinarski A (ed.) *Województwo bydgoskie. Krajobraz dzieje kultura gospodarka*. Bydgoszcz, 28-34.

HOLEC M. and TYMAŃSKI P, 1973, *Podstawy meteorologii i nawigacji meteorologicznej*. Wydawnictwo Morskie, Gdańsk.

KACZANOWSKI L, 1987, *Analiza i prognoza pogody dla lotnictwa*. Dowództwo Wojsk Obrony Powietrznej Kraju, Warszawa.

KASPERSKA-WOŁOWICZ W and BOLEWSKI T, 2015, Zmienność temperatury powietrza w Bydgoszczy w latach 1931-2013. *Woda-Środowisko-Obszary Wiejskie* 15(3): 25-43.

KOLENDOWICZ L, 2005, *Wpływ cyrkulacji atmosferycznej oraz temperatury i wilgotności powietrza na występowanie dni z burzą na obszarze Polski*. Wydawnictwo Naukowe UAM, Poznań.

LORENC H (ed.), 2005, *Atlas klimatu Polski*. IMGW Warszawa.

LORENC H and MYSZURA A, 2012, Ryzyko występowania mgieł w Polsce. In: Lorenc H (ed.), *Klęski żywiołowe a bezpieczeństwo wewnętrzne kraju*, IMGW-PIB, Warszawa.

ŁABĘDZKI L and ADAMSKI P, 2010, Związek między opadami uprzednimi a uwilgotnieniem gleby w uprawie buraków cukrowych na Kujawach. *Woda-Środowisko-Obszary Wiejskie* 10(3): 165-174.

ŁASZYCA E, 2018, *Ocena zasobów i zagrożeń meteorologicznych w rejonie Bydgoszczy w latach 1971-2010*. Rozprawa doktorska. Uniwersytet Technologiczno-Przyrodniczy im. Jana i Jędrzeja Śniadeckich, Bydgoszcz.

ŁASZYCA E and KUŚMIEREK-TOMASZEWSKA R, 2013, Ocena warunków termicznych w rejonie Bydgoszczy na przykładzie stacji Lotnisko Bydgoszcz-Szwederowo. *Infrastruktura i Ekologia Terenów Wiejskich* 1/II: 73-87.

ŁUPIKASZA E and NIEDŹWIEDŹ T, 2016, Synoptic climatology of fog in selected locations of southern Poland (1966-2015). *Bulletin of Geography. Physical Geography Series* 11: 5-15, DOI: https://doi.org/10.1515/bgeo-2016-0010

MOHR S and KUNZ M, 2013, Recent trends and variabilities of convective parameters relevant for hail events in Germany and Europe. *Atmospheric Research* 123: 211–228.

NIEDŹWIEDŹ T (ed.), 2003, *Słownik meteorologiczny*. Instytut Meteorologii i Gospodarki Wodnej, Warszawa.

OSTROWSKI M, 1999, *Meteorologia dla lotnictwa sportowego*. Aeroklub Polski, Warszawa.

PARCZEWSKI W, 1953, *Meteorologia szybowcowa*. Wydawnictwo Ligi Lotniczej, Warszawa.

PROUD SR, 2015, Analysis of aircraft flights near convective weather over Europe. *Weather* 70: 292-296, DOI: https://doi.org/10.1002/wea.2569

PUNGE H.J and KUNZ M, 2016, Hail Observations and Hailstorm Characteristics in Europe: A review. *Atmospheric Research* 176-177, 159-184, DOI: 10.1016/j.atmosres.2016.02.012

ROGUSKI W, KASPERSKA W and ŁABĘDZKI L, 1996, Warunki termiczne i opadowe w Bydgoszczy w latach 1945–1994 na tle lat 1848–1930. *Wiadomości IMUZ*, 19(1): 7–20.

SCHMIDT M, 1982, *Meteorologia dla potrzeb szybownictwa*. Wydawnictwa Łączności i Komunikacji, Warszawa.

SKRZYŃSKA M, 2019, Występowanie mgły na wybranych lotniskach w Południowej Polsce i jego uwarunkowania cyrkulacyjne. *Prace Geograficzne* 158: 27-44. DOI: https://doi.org/10.4467/20833113PG.19.014.10918

SZEWCZAK P, 2014, *Meteorologia dla pilota samolotowego*. AVIA-TEST, Poznań.

SZOT S, 2013, Synoptyczne uwarunkowania zjawisk niebezpiecznych dla lotnictwa. *Zeszyty Naukowe Towarzystwa Doktorantów UJ Nauki Ścisłe* 7: 25-38.

STOPA-BORYCZKA M, BORYCZKA J, WAWER J, DOBROWOLSKA M, OSOWIEC M, BŁAŻEK E, SKRZYPCZUK J and GRZĘDA M, 2013, *Ocena klimatu na potrzeby lotnictwa w Warszawie i innych miastach Polski. XXIX Atlas współzależności parametrów meteorologicznych i geograficznych w Polsce*. Uniwersytet Warszawski, Warszawa.

SUWALA K, 2010, Hail occurrence in Poland. *Quaestiones Geographicae* 30 (3): 115–126.

SUWALA K and BEDNORZ E, 2013. Climatology of hail in Central Europe. *Quaestiones Geographicae* 32: 99–110.

ŠTĚPÁNEK P, 2008, *AnClim - software for time series analysis*. Fac. of Natural Sciences, Masaryk University, Brno.

TASZAREK M, ALLEN J, PÚČIK T, GROENEMEIJER P, CZERNECKI B, KOLENDOWICZ L, LAGOUVARDOS K, KOTRONI V and SCHULZ W, 2019, A climatology of thunderstorms across Europe from a synthesis of multiple data sources. *Journal of Climate* 32: 1813-1837, DOI: https://doi.org/10.1175/JCLI-D-18-0372.1

TASZAREK M, KENDZIERSKI S and PILGUJ N, 2020, Hazardous weather affecting European airports: Climatological estimates of situations with limited visibility, thunderstorm, low-level wind shear and snowfall from ERA5. *Weather and Climate Extremes* 28, 100243. DOI: https://doi.org/10.1016/j.wace.2020.100243

VAUTARD R, YIOU P and VAN OLDENBORGH G. J, 2009, Decline of fog, mist and haze in Europe over the past 30 years, *Nature Geoscience* 2: 115–119, DOI: https://doi.org/10.1038/NGEO414

WIĄŻEWSKI W and BĄKOWSKI R, 2007, Sytuacje synoptyczne sprzyjające występowaniu mgieł na lotnisku Kraków-Balice. In: Piotrowicz K and Twardosz R (eds), *Wahania klimatu w różnych skalach przestrzennych i czasowych*, Kraków, 337-345.

WOŚ A, 1999, *Klimat Polski*. Wydawnictwo Naukowe PWN, Warszawa.

WOŚ A, 2010, *Klimat Polski w drugiej połowie XX wieku*. Wydawnictwo Naukowe UAM, Poznań.

ŻARSKI J, DUDEK S and KUŚMIEREK-TOMASZEWSKA R, 2010, Tendencje zmian temperatury powietrza w okolicy Bydgoszczy. *Infrastruktura i Ekologia Obszarów Wiejskich* 2: 131-141.

ŻARSKI J, DUDEK S, KUŚMIEREK-TOMASZEWSKA R, BOJAR W, KNOPIK L and ŻARSKI W, 2014, Agroklimatologiczna ocena opadów atmosferycznych okresu wegetacyjnego w rejonie Bydgoszczy. *Infrastruktura i Ekologia Terenów Wiejskich* II/3: 643-656.

Received 6 March 2020
Accepted 29 May 2020