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Synoptic climatology of fog in selected locations of southern Poland (1966–2015)

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Abstract. This paper investigates fog frequency in southern Poland in relation to various topography (concave and convex forms) and atmospheric circulation types. It also discusses long-term variability in the annual and seasonal number of days with fog. Daily information on fog occurrence was taken from three high quality synoptic stations representing various landforms: Kraków-Balice (bottom of the hollow), Katowice-Muchowiec (Silesian Upland) and Bielsko-Aleksandrowice (summit of Carpathian Foothill). In the central part of southern Poland during the last 50 years (1966–2015) fog occurred on average during 53–67 days a year. The annual number of foggy days in Kraków (67 days) located in a structural basin was by 14–15 days higher than in Bielsko (53 days) situated in the Silesian Foothills. In the annual course, high fog occurrence (above 6 days per month) was observed from September to January, with the maximum in Kraków (10 days in October). At every station the monthly minimum of fog occurrence fell in July (2 days). In summer and spring the highest probability of fog occurrence was found on days with anticyclonic types and air advection from the northeastern (Na, NEa) and eastern (Ea, SEa) sectors. In autumn, a high probability was also found for the anticyclonic types with advection of air mass from the eastern and southern sectors. In the Carpathian Foothills (Bielsko) the probability of fog occurrence in winter was significantly enhanced only for the cyclonic types with air advection from the eastern sector (NEc, Ec, SEc) and nonadvective types Cc (cyclone centre) and Bc (cyclonic trough). Trends in the fog frequency were mostly insignificant. The only significant decreasing trend was found in Kraków on the annual scale and in summer when fog frequency was low.

Key words:
fog frequency,
fog day trends,
circulation types,
southern Poland

Introduction

Fog is counted among the most dangerous meteorological phenomena, manifesting itself in reduced visibility which causes delays in transportation and, in some cases, serious accidents. Fog is considered to be exceptionally dangerous for airplanes during take-off and landing. Therefore information on this weather phenomenon is included into both SYNOP and METAR synoptic messages.

Fog consists of water droplets or ice crystals suspended in the atmosphere in the vicinity the earth's surface which reduces horizontal visibility below 1 km. The critical value of relative humidity beyond which condensation is initiated and fog forms can be achieved in four ways (Day 2008): (1) addition of water vapour to the volume of space in question, (2) cooling of the volume by contact with a colder surface, (3) cooling by infrared radiation from the volume itself, (4) expansion cooling due to ascent of the air mass. Fog may form within homogeneous air-masses (advection fog, radiation fog) and at the boundaries between different air masses (frontal fog).

Spatial distribution of the annual number of days with fog in Poland is highly variable and strongly depends on local factors, particularly on terrain forms, altitude and location of water reservoirs (sea, lakes). The highest fog frequency is observed in the mountains (Carpathian Mountains and Sudetes) in southern Poland. Average annual number of days with fog changes with altitude. In the Western Carpathians the frequency increases significantly from about 100 days at 1,000 m a.s.l. to more than 250–290 days on the Tatra ridges that are higher than 2,000 m a.s.l. (Błaś and Sobik 2004; Lorenc 2005; Ustrnul and Czekierda 2009; Woś 2010; Ustrnul et al. 2014). The mountain fogs are of the advection and orographic types and usually occur when the mountain slopes and ridges are shrouded in clouds. In the majority of Polish lowlands the average annual number of days with fog varies from 40 to 60 days (Piwkowski 1976; Woś 2010; IMGW-PIB 2012). Only in the Pomeranian lake region in Northern Poland and a few concave landforms does fog frequency exceed 70 days. The aim of this paper is to recognize the differentiation in fog frequency in southern Poland depending on different topography (concave and convex forms) and in relation to atmospheric circulation types. The second purpose is to determine the long-term variability in the annual and seasonal numbers of days with fog.

The influence of topography on fog occurrence has rarely been discussed in the literature. Valuable research on that problem was performed by Golding (1993). His investigations of fog formation and numerical simulation performed for Western Australia indicate fog development's strong dependence on terrain. Radiation fog occurring during clear and calm nights usually forms in concave landforms (river valleys, small hollows and intermountain basins).

Data and methods

Daily information on fog occurrence was taken from three high quality airport stations operated by the Institute of Meteorology and Water Management, National Research Institute (IMGW-PIB) and located in central southern Poland (Table 1). The stations represent different topography. The Kraków-Balice station (International airport) represents the bottom of a hollow (237 m a.s.l.) surrounded by hills of an altitude of 330–365 m a.s.l. The basin is approximately 6 km wide. The airport is located behind a densely built up city area. Katowice-Muchowiec (local airport), located about 58 km WNW from Kraków, represents the Silesian Upland with an altitude of 47 m higher than the Cholerzyn Basin. From the north the station is surrounded by the industrial and urban areas of the Upper Silesia Industrial Region, but there is forest to the south of the station. The third station, Bielsko-Aleksandrowice (small sport airport), is located 48 km to the south of Katowice and 64 km WSW of Kraków. The station represents a typical flat summit of the Carpathian Foothill ahead of the slopes of Silesian Beskid Mountains with low-density housing. Its altitude is 47 m higher than Katowice and by 161 m higher than Kraków-Balice airport (Fig. 1).

Chronological series of fog occurrence covering the last 50-year period of 1966–2015 were taken from meteorological yearbooks and from the Archive of IMGW-PIB (for the period 1966–1999) and from SYNOP messages available online from the OGIMET database (Valor and López 2016) with a 3-hour resolution (for the period 2000–2015). Data are of a very good quality since the methods of observations and location of the stations did not change during the analysed period. The synoptic data with a time resolution of eight observations per day (00–21 UTC) were used to create a daily database, where days with fog were denoted by 1 and days without fog were denoted by 0. The day was considered as a foggy day if fog occurred in at least one observation term or between terms. Chronological series of monthly, seasonal and annual numbers of fog days were calculated on the base of the daily database and then characterized with the following descriptive statistics: arithmetical average, standard

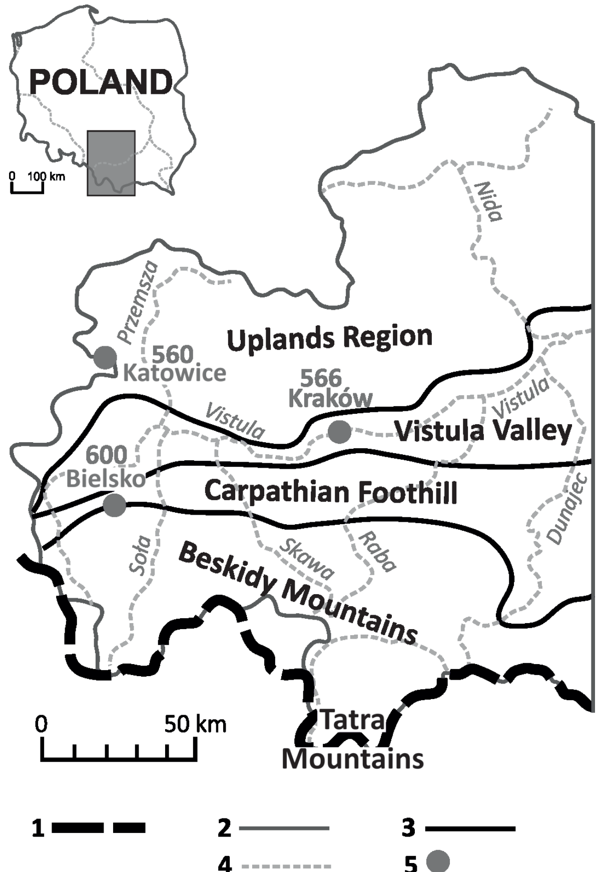

Fig. 1 Research area and location of the meteorological stations. Borders: 1 – cross-country borders, 2 – the Upper Vistula Basin, 3 – geographical regions; 4 – rivers, 5 – main meteorological stations with WMO numbers

error of the average, maximum and minimum values and range of variability.

We used the catalogue of circulation types created for the upper Vistula Basin (Niedźwiedź 1981, 2000, 2016; Niedźwiedź and Łupikasza 2016) to perform synoptic analysis of fog frequency. The catalogue consists of 21 circulation types denoted by direction of air advection (e.g. N – northern, SE – south-eastern, etc.) and the type of pressure system (a – anticyclonic, c – cyclonic). Sixteen of the 21 types are advection types, whereas the further four are non-advection types (Ca – central anticyclonic, centre over or very near southern Poland, Ka – anticyclonic wedge, ridge, Cc – centre of cyclone above or very near southern Poland, Bc – cyclonic trough). Days with fuzzy or complicated sea level pressure (SLP) pattern or with col were marked "x". The classification of advection types is methodologically similar to the well-known Lamb (1972) classification for the British Isles with the only difference that transitional types were not included into the presented classification.

The conditional probability of fog occurrence in every circulation type was calculated from the seasonal perspective (DJF – winter, MAM – spring, JJA – summer, SON – autumn). Circulation types favouring fog occurrence were selected. A circulation type (TC) was recognized as favouring fog occurrence in i season if its conditional probability (CP_{TCi}) was higher than the enlarged (or threshold) probability of $P_i+0.25*P_i$, where Pi is probability of fog occurrence in i season (regardless of circulation type) (see formula 1).

$$CP_{TCi}-(P_i+0.25*P_i) > 0 \rightarrow \text{favouring TC} \qquad (1)$$

Trends in fog frequency were calculated with the least-square linear regression method and t-test and were expressed as a change in days per 10 years. The threshold of 0.05 was adopted for statistically significant trends ($\alpha<0.05$).

Annual course of fog occurrence

In central southern Poland fog occurred on average during 53–67 days a year. The annual number of foggy days in Kraków (67 days) located in a structural basin was by 14–15 days higher than in Bielsko (53 days) situated in the Silesian Foothills. The frequency of fog changed distinctively throughout the year reaching no more than 10 days in summer and slightly more in spring (Table 2).

Table 1. Meteorological stations of IMGW-PIB used to research fog frequency in central southern Poland

WMO number	Station name	Latitude	Longitude	Altitude m a.s.l.	Landform
12600	Bielsko-Aleksandrowice	49°48'N	19°00'E	398	Carpathian Foothill summit
12560	Katowice-Muchowiec	50°14'N	19°02'7E	284	Silesian Upland
12566	Kraków-Balice	50°05'N	19°48'E	237	Cholerzyn Basin

IMGW-PIB – Institute of Meteorology and Water Management, National Research Institute

The monthly minimum of fog occurrence (2 days) fell in July (Fig. 2). Autumn was the foggiest season in Kraków (10 days in October) and Katowice (8 days in October) while in Bielsko-Aleksandrowice the maximum fog occurrence was observed in November (7 days) and winter months, when advection fog prevailed or fog formed by the reduced base of Stratus clouds. Regional variability in the fog frequency in autumn was much bigger than in any other season, particularly in October and September when the difference in monthly fog frequency between Kraków and Bielsko Biała reached 5 and 4 days respectively (Fig. 2). The range of annual variability in the fog frequency, calculated as the difference between the average monthly maximum and minimum frequencies, equalled 8 days in Kraków and 6 days in Katowice and Bielsko-Aleksandrowice. There was a gradual decrease in fog frequency between October or November and July and then quite a rapid increase during the subsequent 3 months until October or November (Fig. 2). The range of the long-term variability in the monthly fog frequency in the cold part of the year was clearly higher than between April and August (15–17 days vs. 8 days on average). The range of variability in seasonal fog frequency (Table 2) peaks in autumn (37 days in Kraków) or in winter (32 days in Bielsko, 28 days in Katowice). In Kraków autumn fog forming in concave relief is usually of the radiation type, while winter fog in the more elevated locations of Katowice and Bielsko is rather of an advection type.

Fog occurrence in relation to circulation types

Fog occurrence depends on, among others, properties of particular air massess; therefore, clear relationships can be assumed between atmospheric circulation in the synoptic scale and fog frequency. Figure 3 shows the conditional probability of fog occurrence in various circulation types denoted by direction of air advection and the kind of baric centre as described in the chapter "Data and Methods". The pattern of the relations changes throughout the year. In summer and spring the highest probability of fog occurrence was found on days with anticyclonic types and air advection from the northeastern (Na, NEa) and eastern (Ea, SEa) sectors. In Katowice and Kraków the probability of fog occurrence in these circulation types in summer was clearly higher than in spring, while at Bielsko-Alek-

Table 2. Selected descriptive statistics for seasonal number of days with fog in Kraków, Katowice and Bielsko-Aleksandrowice (1966–2015)

WMO no	Statistic	MAM	JJA	SON	DJF	YEAR
Kraków (12566)	avg.±SE	10.3 (±0.6)	8.7 (±0.6)	26.5 (±1.1)	21.6 (±1.1)	67.4 (±2.3)
	Max	24 (1985)	19 (1985)	50 (1982)	43 (1982)	116 (1982)
	Min	3 (2002)	2 (1994, 2015)	13 (1992)	10 (2003)	43 (2004)
	VR	21	17	37	33	73
Katowice (12560)	avg±SE	9.0 (±0.6)	6.6 (±0.5)	20.7 (±0.8)	18.3 (±0.9)	54.6 (±1.5)
	Max	27 (1996)	14	35	37 (2006)	91 (1996)
	Min	1 (2015)	0 (2008, 2015)	9 (1966)	9(1)	35(2)
	VR	26	14	26	28	56
Bielsko (12600)	avg±SE	11.2 (±0.8)	6.2 (±0.5)	16.1 (±0.8)	19.2 (±1.0)	52.8 (±2.0)
	Max	28 (1985)	15 (1989)	32 (1989)	36 (1972, 2006)	85(3)
	Min	2 (1992)	0(4)	7(5)	4 (1967)	30 (1992)
	VR	26	15	25	32	55

(1)1984, 1995, 2002; (2)1969, 1983, 2015; (3)1985, 1989, 2010; (4)1971, 1994, 2015; (5)1966, 1980, 1983; WMO no – station number attributed by World Meteorological Organization; avg. – arithmetical average; SE – standard error; VR – range of variability

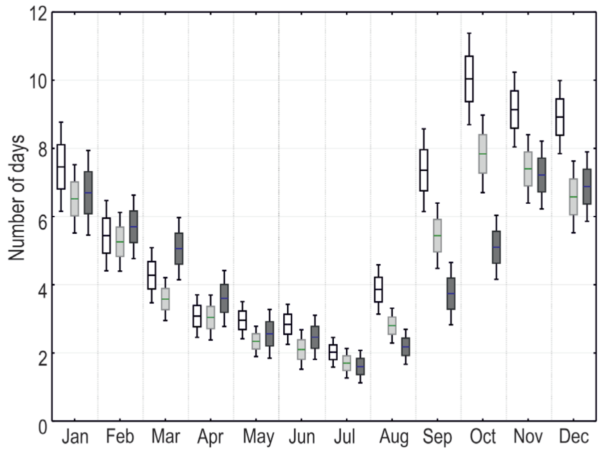

Fig. 2. Average monthly number of foggy days (white bar – Kraków, light grey bar – Katowice, dark grey bar – Bielsko). Box: arithmetical average (midline) ±standard error, whiskers: 95% confidence interval

sandrowice station fog was more probable in spring than in summer. At every station the lowest probability of fog occurrence is related to air advection from the western sector (SW, W, NW) during both cyclonic and anticyclonic conditions.

Spring and summer fogs are usually of a radiation type, since clear or little cloud cover conditions during anticyclonic conditions favours the cooling of the earth surface and thus fog formation. The differences calculated between conditional probabilities of fog occurrence in particular circulation types and the enlarged seasonal probabilities of fog occurrence (Table 3) indicate that in both spring and summer, fog occurrence was significantly enhanced by air advection from the northeastern sector (Na, NEa, Ea) under anticyclonic conditions (positive differences). The high probability of fog occurrence during northerly and northeasterly anticyclonic circulation in Bielsko during spring and summer is due to the upslide of cool air on the slopes of the Silesian Beskid Mountains that leads to water vapour condensation over the Carpathian Foothills. This mainly concerns advection fog. In Katowice and Kraków radiation fog was clearly related to other anticyclonic types including those with air advection from the southeastern sector (Sa, SEa) and nonadvective types Ca and Ka.

At the Bielsko-Aleksandrowice station located in the Silesia Foothills and the most elevated above sea level, fog was also favoured by cyclonic types Nc, NEc and Ec (Table 3, Fig. 3). In the cold part of the year the relations between fog occurrence and atmospheric circulation were quite different from those in warm seasons and more spatially variable. In autumn, fog was most probable on days with nonadvective anticyclonic types, particularly when the centre of the high was located over the research area or on days with Ka type. A high probability was also found for SWa type. This relation applies to Katowice and Kraków, while in Bielsko Biała fog oc-

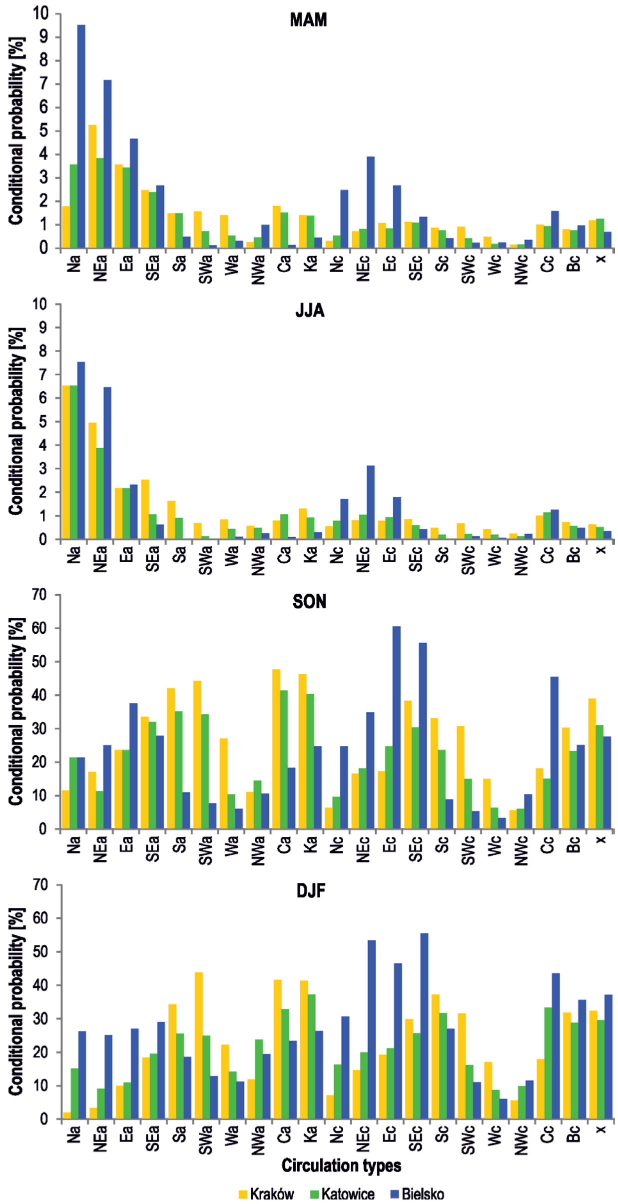

Fig. 3. Conditional probability of fog occurrence in circulation types in spring (MAM), summer (JJA), autumn (SON) and winter (DJF) in Kraków, Katowice and Bielsko in the period 1966–2015

curred most often on days with air advection from the eastern sector when the area was influenced by a low pressure system and on days with nonadvective type Cc. Anticyclonic types favouring fog occurrence include Ea and SEa types (Table 3, Fig. 3). In winter at Katowice and Kraków stations fog usually occurred on days with nonadvective anticyclonic types Ca and Ka (and SWa – Kraków only) or cyclonic types Sc. These relations indicate that the majority of winter fogs at these stations might be related to air pollution from heating during frosty anticyclonic winter weather. In Bielsko the probability of fog occurrence was significantly enhanced only for cyclonic types with air advection from the eastern sector (NEc, Ec, SEc) and the nonadvective types Cc and Bc (Table 3, Fig. 3). The high frequency of fog during cyclonic circulation types in Bielsko-Aleksandrowice was due to the elevation of the station, which is located above the height of the condensation level in this season.

Variability and trends in fog days

Fluctuations dominated in the long-term course of fog frequency. The only significant trend was found in Kraków on the annual scale and in summer when fog frequency was low (Table 4, Fig. 4). In Kraków in every season including those with insignificant trends, a clear drop in the frequency of fog was recognized at the turn of the 1990s. The average annual frequency of fog reached 79 days in the period 1966–1985 and was much lower in the period

Table 3. Differences between conditional probability of fog occurrence in circulation types and threshold probability (enlarged probability of fog occurrence regardless of circulation type). Positive differences indicate circulation types favouring fog occurrence

Season	MAM			JJA			SON			DJF		
WMO number	12566	12560	12600	12 566	12560	12600	12566	12560	12600	12 566	12560	12600
P_i	0.95	0.83	1.05	0.81	0.61	0.58	29.06	22.68	17.58	24.06	20.25	21.39
$P_i+0.25P_i$	**1.4**	**1.2**	**1.6**	**1.2**	**0.9**	**0.9**	**43.6**	**34.0**	**26.4**	**36.1**	**30.4**	**32.1**
P	$CP_{TCi} - (P_i+0,25*P_i)$											
Na	**+0.4**	**+2.3**	**+8.0**	**+5.3**	**+5.6**	**+6.7**	-32.0	-12.6	-4.9	-34.1	-15.2	-5.8
NEa	**+3.8**	**+2.6**	**+5.6**	**+3.7**	**+3.0**	**+5.6**	-26.5	-22.7	-1.4	-32.7	-21.3	-7.1
Ea	**+2.1**	**+2.2**	**+3.1**	**+1.0**	**+1.2**	**+1.5**	-20.0	-10.4	**+11.1**	-26.1	-19.5	-5.1
SEa	**+1.1**	**+1.1**	**+1.1**	**+1.3**	**+0.1**	-0.2	-10.0	-2.0	+1.6	-17.7	-10.8	-3.1
Sa	**+0.1**	**+0.2**	-1.1	**+0.4**	0.0	-0.9	-1.6	**+1.1**	-15.4	-1.8	-4.8	-13.5
SWa	**+0.1**	-0.5	-1.5	-0.5	-0.8	-0.9	**+0.6**	**+0.3**	-18.7	**+7.7**	-5.5	-19.2
Wa	0.0	-0.7	-1.3	-0.4	-0.5	-0.8	-16.5	-23.6	-20.3	-13.9	-16.2	-20.8
NWa	-1.2	-0.8	-0.6	-0.7	-0.4	-0.6	-32.5	-19.6	-15.7	-24.2	-6.7	-12.6
Ca	**+0.4**	**+0.3**	-1.4	-0.4	**+0.1**	-0.8	**+4.0**	**+7.3**	-8.0	**+5.5**	**+2.5**	-8.7
Ka	0.0	**+0.1**	-1.1	**+0.1**	0.0	-0.6	**+2.7**	**+6.3**	-1.7	**+5.3**	**+6.8**	-5.8
Nc	-1.1	-0.7	**+0.9**	-0.7	-0.1	**+0.9**	-37.1	-24.3	-1.6	-28.9	-14.1	-1.5
NEc	-0.7	-0.4	**+2.3**	-0.4	**+0.1**	**+2.3**	-26.9	-15.8	**+8.5**	-21.4	-10.4	**+21.2**
Ec	-0.4	-0.4	**+1.1**	-0.4	0.0	**+0.9**	-26.3	-9.3	**+34.1**	-16.9	-9.2	**+14.4**
SEc	-0.3	-0.2	-0.2	-0.4	-0.3	-0.4	-5.3	-3.6	**+29.3**	-6.2	-4.7	**+23.5**
Sc	-0.5	-0.5	-1.2	-0.7	-0.7	-0.9	-10.5	-10.4	-17.5	**+1.1**	**+1.4**	-5.1
SWc	-0.5	-0.8	-1.3	-0.5	-0.7	-0.7	-12.9	-19.0	-21.0	-4.5	-14.1	-21.0
Wc	-0.9	-1.1	-1.3	-0.8	-0.7	-0.8	-28.6	-27.6	-23.1	-19.0	-21.6	-26.0
NWc	-1.3	-1.1	-1.2	-1.0	-0.8	-0.6	-37.9	-27.9	-15.9	-30.6	-20.5	-20.6
Cc	-0.4	-0.3	0.0	-0.2	**+0.2**	+0.4	-25.4	-18.9	**+19.1**	-18.1	**+3.0**	**+11.5**
Bc	-0.6	-0.5	-0.6	-0.5	-0.4	-0.4	-13.2	-10.7	-1.2	-4.2	-1.5	**+3.5**
x	-0.2	0.0	-0.9	-0.6	-0.4	-0.5	-4.5	-3.0	+1.2	-3.7	-0.9	+5.1

12566 – Kraków, 12560 – Katowice, 12600 – Bielsko, $CP_{TCi} - (P_i+0,25*P_i)$ – Difference between conditional probability of fog occurrence in circulation types TC in “i” season “CPTCi” and probability of fog occurrence in “i” season regardless of CT”P_i” enlarged by 25% of P_i (Pi+0,25*P_i, bolded values – threshold probability used to select circulation types favouring fog occurrence (enlarged probability), bolded and underlined values – circulation types favouring the occurrence of fog

1986–2015, reaching 60 days. Recent years have also been characterized by a lower range of variability in fog frequency in both Kraków and the other two stations. A significant decrease was also detected in Bielsko in summer (Fig. 4). The strong decreasing trend in the annual number of days with fog in Kraków was due to the exceptionally high frequency in the period 1971–1985, which exceeded by 20–30 days the frequency of the event at other stations. Such a high difference can only be explained by the high concentration of air pollution in those times in Kraków, which favoured fog occurrence. Located at higher altitudes, Katowice and Bielsko stations observed lower number of days with fog, due to lower concentrations of pollution and better venting conditions which were unfavourable for fog occurrence. In the subsequent years the differences in the fog frequency between Kraków and other stations were smaller.

The only season in which the long-term patterns of fog frequencies were hardly differentiated between the stations was spring. In that season advection fog dominated, characterised by a wide spatial extent. The high frequency of fog in the industrial period was clearly seen in summer and autumn when radiation fog usually occurred just as in the concave terrain of Kraków Balice, where the air was strongly polluted before1990. After that period the regional variability diminished. After 1996 a decreasing tendency was found at every station and could be related to increasing trends in air temperature.

Discussion

Morawska (1966) analysed fog frequency in the Kraków city centre using data from the climatological station of the Jagiellonian University (maintained by the Department of Climatology in the Institute of Geography and Spatial Management, and earlier by the Astronomical Observatory) and reported 60 days with fog on the annual scale in the 100-year period of 1861–1960. In the next 40-year period (1961–2000) this number declined to 55 days (Wypych 2003). The extremely high fog frequency (81–130 days) reported in the period 1957–1968 was probably related to high concentrations of air pollution in Kraków. In the period 1966–1971 the annual number of days with fog in rural areas was 20 days lower than in the city centre. After 1971 this situation changed and during 1972–2000 the number of foggy days was 36 days greater at Kraków-Balice airport than in the urban area. This was probably due to a decrease in air pollution concentration, increased warming in the urbanized area and the intensification of the urban heat island, preventing fog formation.

In Katowice and Kraków fog was clearly related to anticyclonic types with air advection from the southeastern sector (Sa, SEa) and nonadvective types Ca and Ka, while in Latvia (Avotniece et al. 2015) the most favourable conditions for fog formation exist during anticyclonic situations with air advection from S, SW and W. Anticyclonic conditions also favoured fog occurrence in Oxford in the winter season (Gomez and Smith 1984). Moreover, the long-term variability of fog frequency in Latvia in the 52-year-long period of 1960–2012 was similar to that in Kraków (Avotniece et al. 2015). The average number of days with fog calculated from 14 stations decreased from 54 days in 1960 to about 20–40 days in the period 1990–2012. This tendency of fog frequency was linked to improvements in air quality and an increase in air temperature in urbanized areas. Klemm and Lin (2016) found that a change of ten percent in aerosol concentration had about the same effect on fog occurence as a change of 0.1°C in air temperature. Reduction in fog frequency over the last 30 years has been reported for more than 300 stations in Europe (Vautard et al. 2009) and other localities (Gomez and Smith 1984; Sachweh and Koepke 1995, 1997; Kokkola et al. 2003; Shi et al. 2008; Witi and La Dochy 2008; van Oldenborgh et al. 2010; Sugimoto et al. 2013; Fu et al. 2014). An increase in the frequency of fog events due to growing industrial activity and rising atmospheric pollution concentration is observed in India (Singh and Dey 2012; Shrivastava et al. 2016) and other parts of South Asia (Syed et al. 2012).

Conclusions

In the central part of southern Poland during the last 50 years (1966–2015) fog occurred on average

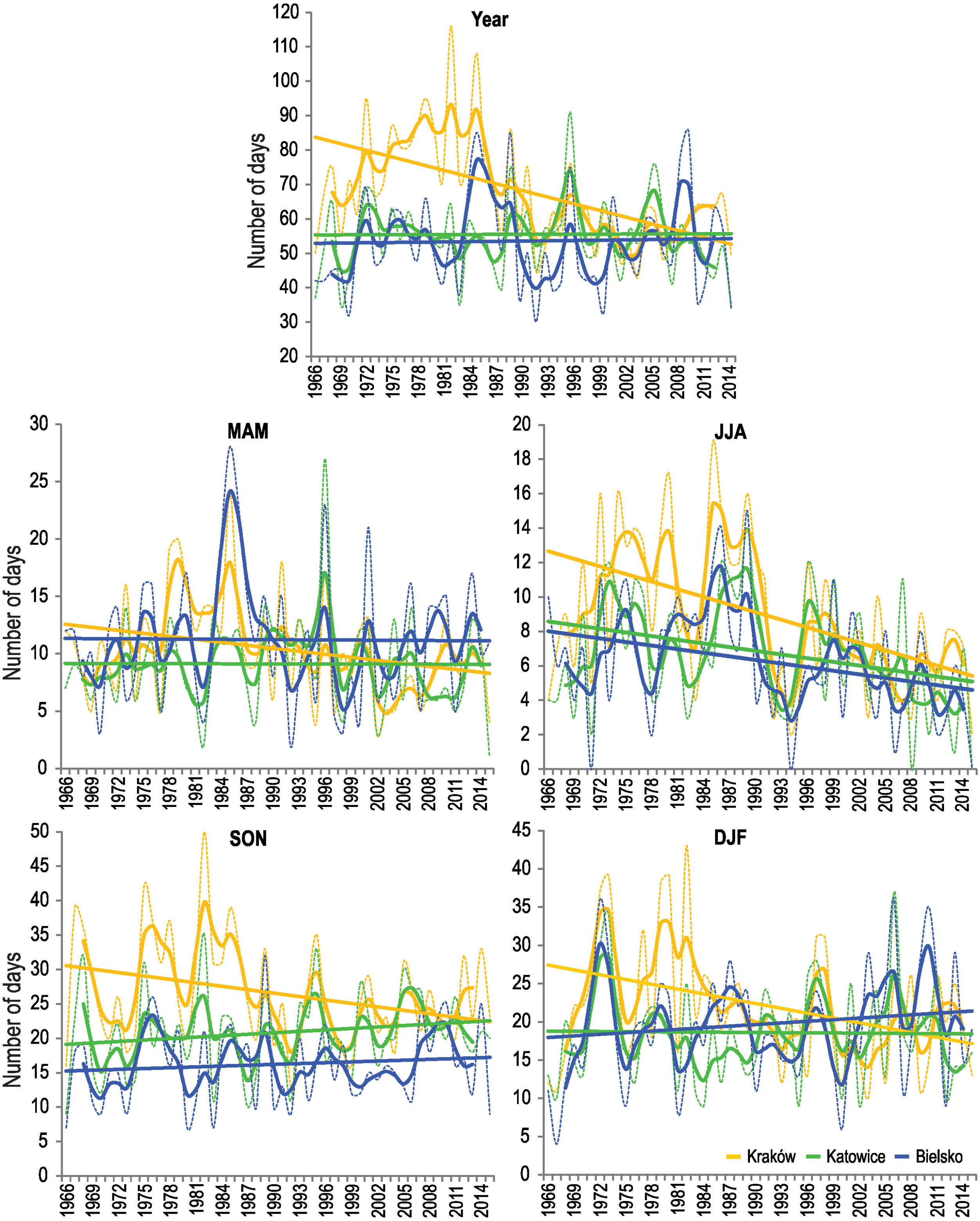

Fig. 4. Long-term course of the number of days with fog in Kraków (12566, dark yellow line), Katowice (12560, green line) and Bielsko (12600, blue line) in the period 1966–2015. Thin lines – raw values; thick lines – values smoothed with a 5-year Gauss Filter, straight lines – linear trend

Table 4. Trends in the seasonal fog frequency in the period 1966–2015

Station		MAM	JJA	SON	DJF	Year
12566	Trend/10y	-0.9	**-1.2****	-1.3	-1.5	**-5.0*****
	p	0.052	**0.003**	0.080	0.062	**0.0007**
12560	Trend/10y	-0.1	-0.6	+0.7	+0.1	0.0
	P	0.846	0.080	0.247	0.838	0.925
12600	Trend/10y	-0.1	**-0.8***	+0.4	+1.1	+0.4
	p	0.919	**0.018**	0.428	0.142	0.786

p – statistical significance ,* <0.05, **<0.01, ***<0.001

during 53–67 days a year. The annual number of foggy days in Kraków (67 days) located in a structural basin was 14–15 days higher than in Bielsko (53 days) situated in the Silesian Foothills.

In Kraków, as an example, the annual number of foggy days in urbanized areas was 36 days lower than at the airport, located in concave relief, and in the rural areas. Hollows favour the occurrence of fog by radiative cooling during clear and calm nights.

In the annual course, a high frequency of foggy days (above 6 days per month) was observed from September to January in Kraków (10 days in October). The period of high fog frequency is shorter (October–January) on the Silesian Upland (Katowice) and even shorter (November–January) on the summit of the Carpathian Foothills (Bielsko-Aleksandrowice). The monthly minimum of fog occurrence fell in July (2 days) at every station.

The occurrence of fog significantly depended on direction of air advection. These relations varied both throughout the year and regionally. In summer and spring the highest probability of fog occurrence was found on days with anticyclonic types and air advection from the northeastern (Na, NEa) and eastern (Ea, SEa) sector.

In autumn and winter in Kraków and Katowice fog was most probable on days with nonadvective anticyclonic types, particularly when the centre of the high or anticyclonic ridge was located over the research area. In autumn, a high probability of the phenomena was also found for days with anticyclonic types and air mass advection from the eastern and southern sectors. In the Carpathian Foothills (Bielsko) the probability of fog occurrence in winter was significantly enhanced only for cyclonic types with air advection from the eastern sector (NEc, Ec, SEc) and nonadvective types Cc (cyclone center) and Bc (cyclonic trough).

Fluctuations dominated in the long-term course of fog frequency. Significant decreasing trend was found in Kraków on the annual scale and in summer. The highest number of fog days in the urbanized area of Kraków was observed during the period with the highest air pollution. Diminishing air pollution caused decreasing trends in fog frequency. Currently, the lowest number of fog events is observed in the city centre of Kraków due to the warming and formation of an urban heat island.

On the Silesian Upland (Katowice) and Carpathian Foothills (Bielsko) the long-term course of fog frequency did not show clear trends. A significant decrease in fog frequency was detected only in Bielsko in summer.

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