PRACE GEOGRAFICZNE, zeszyt 112

Instytut Geografii i Gospodarki Przestrzennej UJ
Kraków 2003

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AIR HUMIDITY AND FOGS IN CRACOW IN THE PERIOD 1961-2000 IN RELATION TO SYNOPTIC SITUATIONS

Abstract: Based on the data from the Climatological Station of the Department of Climatology, Institute of Geography and Spatial Management, Jagiellonian University, the variability of air humidity was described and the number of days with fog in Cracow was determined for the period 1961-2000. An analysis of the frequency of fog occurrence in relation to synoptic situations and specific parameters of air humidity was conducted based on the catalogue of synoptic situations in the upper Vistula river basin.

Key words: air humidity, fog, synoptic situations

1. Introduction

The influence of a city on particular elements of climate is an issue often discussed. The research results obtained hitherto indicate that air temperature is higher within a city than in the suburban areas. They also show changes in other factors such as the structure and intensity of cloud cover and increasing precipitation trend (especially in the case of intensive precipitation). At the same time, research on the multi-annual changes of air humidity parameters and on the effects of a city on these parameters is very limited.

The objective of this project is twofold: first, to describe the course of air humidity in Cracow in the last 40 years of the 20th century; second, to determine the probability of fog occurrence in relation to particular humidity parameters and to a specific synoptic situation. The analysis was based on data from daily measurements (morning, noon and evening) obtained from the Research Station of the Department of Climatology, Institute of Geography and Spatial Management, Jagiellonian University, and the catalogue of synoptic situations in the upper Vistula river basin by T. Niedźwiedź.

2. Characteristics of humidity conditions in Cracow in the years 1961-2000

A non-ventilated psychrometer, placed in a standard Stevenson's shelter attached to the NNW wall of the station's building, 12 meters above the ground, was used to collect the data. The multi-annual changes of air humidity parameters and their annual variability were characterised based on these data. To ensure homogeneity of the analysed data, the same calculation method chosen from psychrometric and hygrometric tables was employed for the whole period. The analysis was done for the average daily, monthly and annual values.

2.1. Multi-annual variability of air humidity parameters

The courses of air humidity parameters showed significant year-to-year variations (Fig. 1a, b and c). It is possible to describe their tendencies during the aforementioned period.

Water vapour pressure (e) has the least variable multi-annual course of average yearly values (Fig. 1a). The standard deviation of the multi-annual average (e_{av}=9.7 hPa) was just 0.38 hPa. The lowest value in the examined period was 9.1 hPa (in 1976 and 1980) and the highest value was 10.6 hPa (in 1989). The variability range of average monthly values did not exceed 5.0 hPa. The highest variability was recorded in July (in 1979 – 13.1, and in 1972 – 18.0 hPa). Water vapour pressure shows a very slightly increasing trend, just 0.3 hPa during the considered period. Interestingly, a decrease of values was observed in autumn months (September and November by 0.3 and 0.5 hPa, respectively).

The average multi-annual value of relative air humidity (f) for the examined period was 78%. The highest annual averages (f_{av}>80%) were recorded in the 1960s (f_{av}= 82% in 1962, 1966 and 1968), and the lowest in the early 1990s (f_{av}=74% in 1992 and 1993). Therefore, a decreasing trend was evident (Fig. 1b). The mean annual value of relative air humidity in Cracow decreased by 6% over the last 40 years. Mostly the multi-annual courses of mean monthly relative air humidity in May and February (a decline by 10 and 9% respectively) were responsible for that. The values of monthly means were differentiated most in May and least in December (standard deviation s=±5 and ±3% respectively).

There was insignificant variability in the multi-annual saturation deficit (d), (Fig. 1c). The variability coefficient for the examined period was 14.2%. The variability range was 2.4 hPa with the lowest and highest mean annual value of saturation deficit d=3.1 hPa and 5.5 hPa in 1965 and 1992, respectively. The multi-annual average (d_{av}) was 4.1 hPa. The periods 1981-1983 and 1990-1994 were especially interesting in the multi-annual course of saturation deficit. During these periods the annual averages exceeded 4.5 hPa (with the highest values at 5.2 hPa in 1983 and 5.5 hPa in 1992). Those two periods, similarly as another increase in the annual average of saturation deficit since 1998, had significant effect on the positive value of the trend line equation (Fig. 1c). The increase in the value of saturation deficit of air humidity was 1.3 hPa in the 40-year examined period. The highest increase of this value in the above period occurred in August and in May (3.1 and 3.0 hPa, respectively). Summer months had also

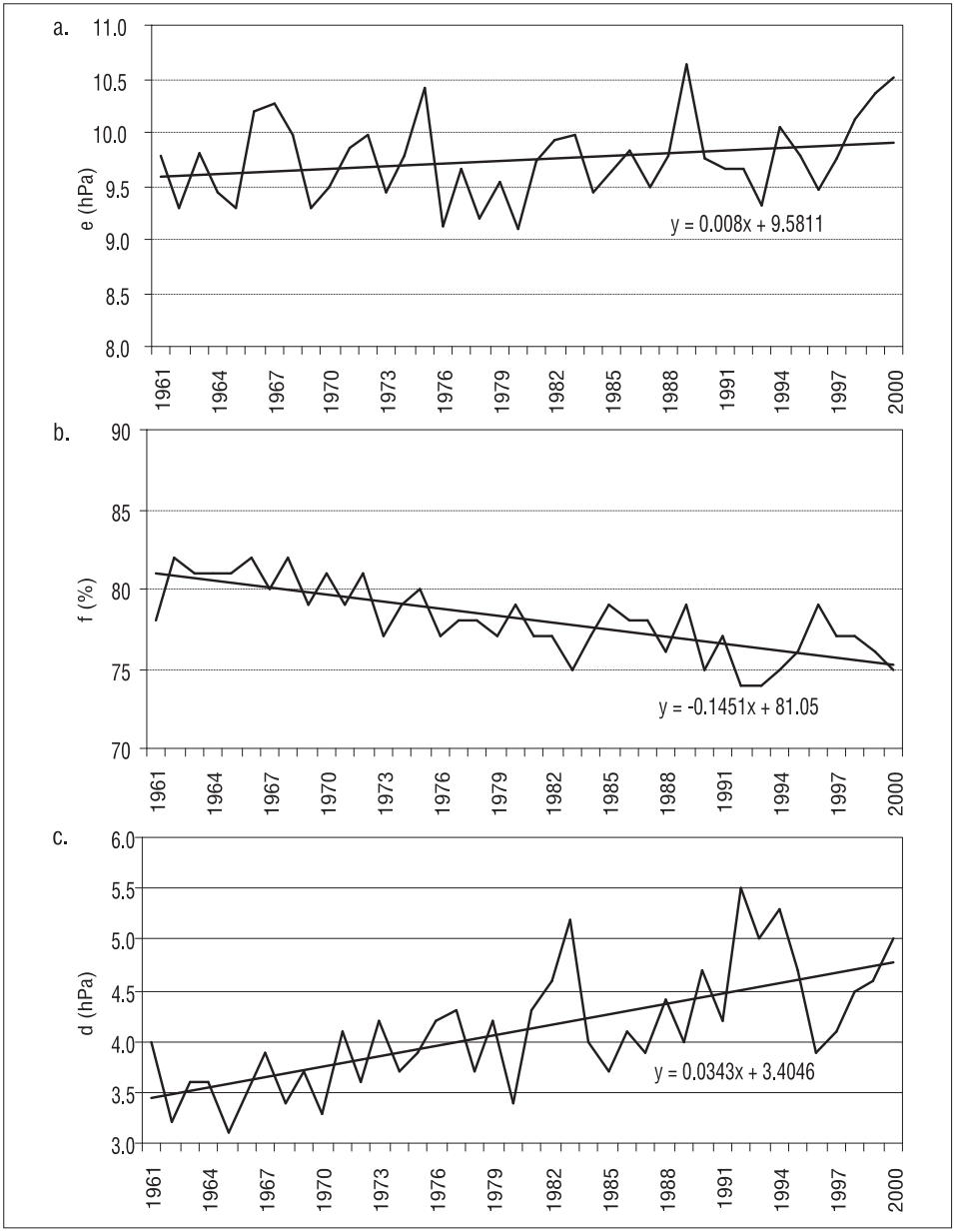

Fig. 1. Multi-annual course of: a. vapour pressure in Cracow (1961-2000) b. relative air humidity in Cracow (1961-2000); c. saturation deficit in Cracow (1961-2000). Straight line – the linear trend

Ryc.1. Wieloletni przebieg: a. prężnosci pary wodnej w Krakowie (1961-2000), b. wilgotności względnej powietrza w Krakowie (1961-2000), c. niedosytu wilgotności w Krakowie (1961-2000). Linia prosta – trend liniowy

the greatest variability of the average monthly values. The range of changes was 10.0 hPa in July and 9.8 hPa in August.

2.2. Annual course of air humidity parameters

The annual courses of saturation deficit and water vapour pressure correlate with the annual course of air temperature. The highest values of these parameters were recorded in summer (June-August) and the lowest in January (Fig. 2a and c). Relative air humidity had the highest values in winter (November-December) and the lowest in spring (April-June) (Fig. 2b). Relative air humidity had the highest (from 70% in May to 86% in December) and saturation deficit the lowest (1.0 hPa in December and January, 8.2 hPa in July) variations in the average monthly values.

The annual courses based on mean daily values of the subsequent days in a year showed less regularity (Fig. 2). Saturation deficit and relative air humidity were subject to most significant variations during the entire year and especially in the warm half-year. Water vapour pressure varied little, some minimal fluctuations occurred in summer (July, August).

2.3. Frequency of occurrence of specific values of air humidity parameters

Values in the range from 3.1 to 6.0 hPa and from 6.1 to 9.0 hPa were the most frequent ones valueof water vapour pressure (22.4 and 24.4%, respectively; Tab. 1). The probability that greater values (9.1-18.0 hPa) may occur is high (45%). Values from other ranges were rare. It is worth noting that the mean daily value of water vapour pressure higher than 24.0 hPa was noted only twice in the examined period.

The values of relative air humidity Tab. 2) usually fell within the range of 71-80% (28.3% of all cases) and 81-90% (32.1% of all cases). The probability of air humidity

Tab. 1. Frequency of particular vapour pressure (e) values in Cracow (1961-2000)

Tab. 1. Częstość występowania określonych wartości prężności pary wodnej (e) w Krakowie (1961-2000)

e (hPa)	frequency (%)
0.0 - 3.0	3.4
3.1 - 6.0	22.4
6.1 - 9.0	24.4
9.1-12.0	17.5
12.1-15.0	16.9
15.1-18.0	10.6
18.1-21.0	4.2
21.1-24.0	0.3
>24.0	0.0

Tab. 2. Frequency of particular relative air humidity (f) values in Cracow (1961-2000)

Tab. 2. Częstość występowania określonych wartości wilgotności względnej powietrza (f) w Krakowie (1961-2000)

f (%)	frequency (%)
≤40	0.0
41-50	0.8
51-60	6.6
61-70	18.2
71-80	28.3
81-90	32.2
91-100	13.9

Tab. 3. Frequency of particular saturation deficit (d) values in Cracow (1961-2000)

Tab. 3. Częstość występowania określonych wartości niedosytu wilgotności (d) w Krakowie (1961-2000)

d (hPa)	frequency (%)
0.0 - 4.0	61.1
4.1 - 8.0	23.4
8.1-12.0	11.1
12.1-16.0	3.6
16.1-20.0	0.7
20.1-24.0	0.1
>24.0	0.0

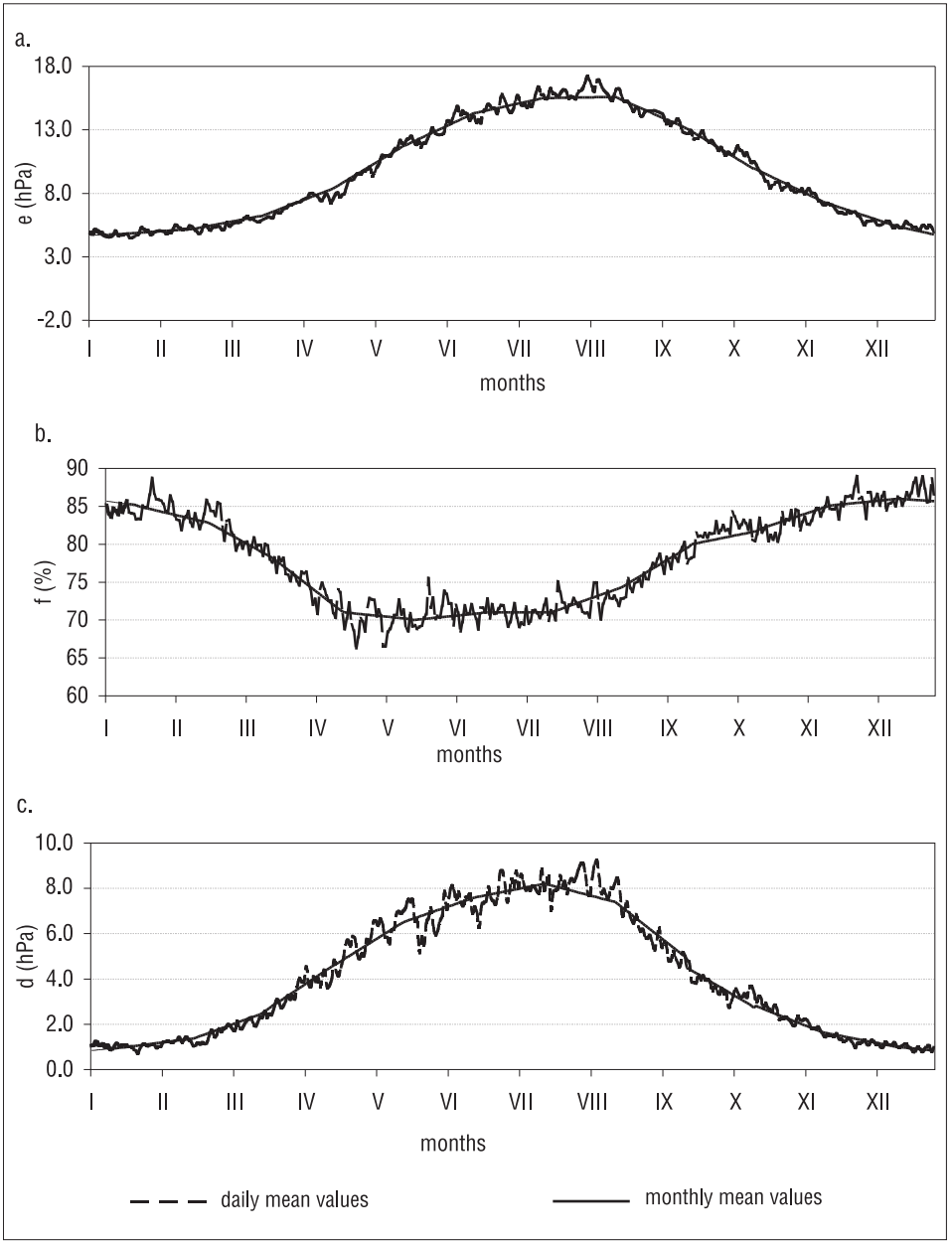

Fig. 2. Annual course of the air humidity parameters in Cracow (1961-2000):
a. vapour pressure (e); b. relative air humidity (f); c.saturaton deficit (d)

Ryc. 2. Przebieg roczny parametrów wilgotności powietrza w Krakowie (1961-2000):
a. prężność pary wodnej (e); b. wilgotność względna (f); c. niedosyt wilgotności (d)

values being higher than 61% was close to 93%. Therefore, values lower than that occurred very rarely. The f value <40% was noted on one day only during the 40 years of data collection.

Saturation deficit is characterised by an asymmetric distribution of values (Tab. 3). Values falling in the range of 0.0-4.0 hPa constituted more than a half of all cases, and more than 90% of d values ≤12.0 hPa. The probability of saturation deficit value being higher than 20.0 hPa is 0.1%. During the examined 40 years, just 18 days with such values were noted.

3. Fogs in Cracow

Fog is an atmospheric phenomenon created by many factors. Cracow is located in a narrow section of the Vistula river valley and surrounded by low hills. Additionally, there are numerous rivers in the city and its surroundings. All those factors increase air humidity and favour fog formation and persistence. The average number of days with fog in Cracow in the period 1861-1960 was 60, and it fluctuated from 8 to 214 days (in 1921 and 1869, respectively) (Morawska 1966).

Based on data from three measurement terms (morning, noon and evening), the number of days with fog and the frequency of fog occurrence in Cracow were calculated for the period 1961-2000.

During the 40-year period, average annual number of days with fog was 54.6 (Tab. 4) and fluctuated from 130 to 15 days (in 1963 and 1992, respectively). A high frequency of fog occurrence was typical for the first decade of the examined period (1961-1970) – on

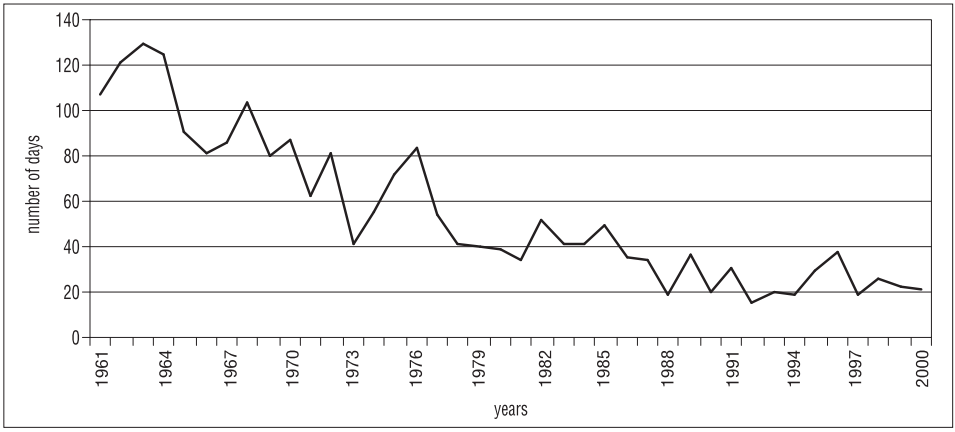

Fig. 3. Multi-annual course of the number of days with fog in Cracow (1961-2000)
Ryc. 3. Wieloletni przebieg liczby dnie z mgłą w Krakowie (1961-2000)

Tab. 4. Number of days with fog in Cracow in the years 1961-2000
Tab. 4. Liczba dni z mgłą w Krakowie w latach 1961-2000

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
1961	23	20	7	4	1	1	0	0	1	15	18	17	107
1962	19	13	15	4	0	0	1	3	7	27	15	17	121
1963	27	24	12	6	6	0	1	3	9	13	9	20	130
1964	22	12	17	10	0	1	2	2	9	7	21	22	125
1965	17	11	15	2	2	0	0	0	2	21	12	9	91
1966	14	15	10	9	3	0	2	1	0	9	10	8	81
1967	9	7	6	6	1	0	0	2	8	16	16	15	86
1968	17	14	8	1	3	1	0	4	9	16	14	16	103
1969	15	9	8	2	2	4	0	1	1	16	13	9	80
1970	18	15	10	6	3	2	0	3	4	8	11	7	87
1971	16	5	7	0	1	0	0	0	3	12	10	8	62
1972	15	12	5	3	0	1	3	1	4	9	6	22	81
1973	13	5	5	0	0	0	0	0	1	10	4	3	41
1974	13	9	5	0	1	0	0	4	6	3	6	8	55
1975	7	5	10	4	3	1	0	1	6	10	14	11	72
1976	4	19	14	6	1	0	1	0	5	15	12	7	84
1977	9	9	4	1	0	0	0	1	5	15	3	7	54
1978	6	3	5	2	1	0	0	0	1	11	7	5	41
1979	8	7	5	2	0	0	0	1	5	4	4	4	40
1980	10	8	3	1	0	1	0	2	8	2	2	2	39
1981	8	3	3	1	1	0	0	0	6	6	2	4	34
1982	12	9	0	0	0	0	0	0	8	11	8	4	52
1983	2	4	4	2	1	0	0	1	4	3	9	11	41
1984	4	2	2	1	0	0	0	1	7	3	13	8	41
1985	9	1	9	0	1	0	1	1	0	14	5	8	49
1986	2	3	4	1	0	0	0	2	4	6	11	2	35
1987	5	10	4	1	1	0	0	0	1	6	2	4	34
1988	5	0	4	1	0	1	0	1	1	5	1	0	19
1989	5	3	4	3	0	0	1	0	8	4	6	2	36
1990	3	4	0	1	0	1	0	0	0	8	3	0	20
1991	4	3	6	1	1	1	0	2	0	3	4	6	31
1992	3	2	1	0	0	0	0	0	2	0	3	4	15
1993	0	0	1	2	1	1	2	0	0	6	6	1	20
1994	1	3	2	0	0	0	0	0	5	5	1	2	19
1995	2	2	1	1	0	1	0	0	3	11	6	3	30
1996	4	4	4	3	1	0	1	1	3	4	3	10	38
1997	7	1	1	0	0	0	0	0	2	0	2	6	19
1998	10	0	1	1	0	0	0	1	2	1	5	5	26
1999	6	0	1	0	0	1	0	1	2	3	5	3	22
2000	0	1	2	1	0	0	0	1	1	4	2	9	21
medium	9.4	6.9	5.6	2.2	0.9	0.5	0.4	1.0	3.8	8.6	7.6	7.7	54.6

average 101 days with fog a year. The number of days with fog decreased significantly in the following decades (to just 24 days in 1991-2000) (Fig. 3). The probability of fog occurrence dropped from 28% in the 1960s to 7% in the 1990s.

The monthly average number of days with fog fluctuated from 0.4 in July to 8.6 in October and 9.4 in January (Tab. 4). During the entire examined period, the number of days with fog in summer months (May-August) was never more than 5. Therefore, the cold half-year (October-March) plays a dominant role in the declining trend.

4. Relation between synoptic situations, air humidity and fog occurrence in Cracow

The analysis of the catalogue of synoptic situations for the upper Vistula river basin suggests that an anticyclonic wedge – K_a, a west cyclonic situation - W_c, and a cyclonic trough – B_c dominated in the period 1961-2000 (11.8%, 10.7% and 10.1% of days, respectively). A central cyclonic situation C_c comprised just a little more than 1% of all cases. Cyclonic situations with the advection of air from the north, north-east and east were equally rare (2-3% of all days).

Anticyclonic situations favour fog formation. The highest probability of fog occurrence was associated with an anticyclonic wedge – K_a (15%), and with anticyclonic situation with air masses advection from the south-west SW_a (7.6%). Fogs also occurred relatively often in a cyclonic trough – B_c (8.0%). An anticyclonic situation with the advection of air masses from the north (N_a) was least favourable for fog formation (just 13 cases of days with fog in the 40-year examined period, which is 0.6%).

Most commonly, fogs occurred when saturation deficit (d) did not exceed 4.0 hPa – 89.6% of all cases, and 15% of them were associated with an anticyclonic wedge. Equally favourable conditions for fog formation existed when water vapour pressure fluctuated in the range from 6.1 to 9.0 hPa and from 3.1 to 6.0 hPa (33.2% and 30.6 % of days with fog, respectively). In both situations an anticyclonic wedge played the dominant role (29.3 and 16.6% of all cases, respectively). Relative humidity higher than 81% also favoured fog creation processes (85% of days with fog); and the highest probability was associated, similarly as with other cases, with an anticyclonic wedge.

5. Conclusion

Both the multi-annual and annual courses of air humidity parameters in Cracow showed clear variability. The highest fluctuations were noted for saturation deficit and relative air humidity. The variability of water vapour pressure was lower. There was an evident decreasing trend in relative air humidity, which was associated with increasing air temperature and continued urban development (i.e. increase of concrete and paved surfaces).

As the aero-sanitary situation of the city has improved in recent years, a considerable decline in the number of days with fog in Cracow was also noticed. Over the last 40 years of the 20th century, the number of days with fog in Cracow decreased significantly and values recorded 40 years ago were 4 times higher than presently observed. A decline

in municipal and industrial smoke emissions decreased the number of condensation nuclei, which in turn decreased the probability of fog occurrence.

Anticyclonic situations (K_a, SW_a) generated the most favourable conditions for fog formation when relative humidity was around 81-90%, water vapour pressure was in the range from 6.1 to 9.0 hPa, and saturation deficit remained below 4.0 hPa. The probability that these factors occur simultaneously was calculated to be 13% in Cracow.

References

Kostyrko K., Szumowski J., Szerszeń A., 1982, *Tablice psychrometryczne i higrometryczne*, PWN, Warszawa.

Morawska M., 1966, *Mgły w Krakowie (1861-1960)*, Przegl. Geofiz., 11 (19), 3, 171-181.

Niedźwiedź T., 1988, *Kalendarz sytuacji synoptycznych dla dorzecza górnej Wisły (1951-1985)*, Zesz. Nauk. UJ, Prace Geogr. 71, 31-86.

Niedźwiedź T., *Kalendarz sytuacji synoptycznych dla dorzecza górnej Wisły (1986-2000)*, a computer file provided by the author.

Trepińska J., Kowanetz L., 1997, *Wieloletni przebieg średnich miesięcznych wartości temperatury powietrza w Krakowie (1792-1995)*, [in:] J. Trepińska (ed.) *Wahania klimatu w Krakowie (1792-1995)*, Wyd. IGiGP UJ, Kraków, 99-130.

Wilgotność powietrza i mgły w Krakowie w latach 1961-2000 na tle sytuacji synoptycznych

Streszczenie

Artykuł prezentuje charakterystykę warunków wilgotnościowych i mgieł w Krakowie w latach 1961-2000, oraz związki między sytuacjami synoptycznymi, wilgotnością powietrza i powstawaniem mgły. Analiza została oparta na danych ze Stacji HistorycznejZakładu Klimatologii IG i GP UJ w Krakowie (Ogród Botaniczny) z trzech głównych terminów pomiarowych, a także na katalogu sytuacji synoptycznych dla dorzecza górnej Wisły T. Niedźwiedzia.

Zmienność parametrów wilgotności powietrza jest widoczna zarówno w przebiegu wieloletnim jak też rocznym. Największe fluktuacje są obserwowane dla wilgotności względnej i niedosytu wilgotności. Wyraźny trend spadkowy dla wilgotności względnej był skutkiem wzrostu temperatury spowodowanego rozwojem miasta. W ostatnich latach poprawiła się sytuacja aerosanitarna miasta i zaobserwowano spadek liczby dni z mgłą.

Warunki najbardziej sprzyjające powstawaniu mgły panują w czasie sytuacji antycyklonalnych (K_a, SW_a) i przy wilgotności względnej 81-90%, prężności pary wodnej 6.1-9.0 hPa i niedosycie wilgotności poniżej 4.0 hPa. Prawdopodobieństwo wystąpienia takich warunków w Krakowie wynosi 13%.

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