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THE DYNAMICS TO SELECTED EXTREME CLIMATIC EVENTS IN POLAND

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ABSTRACT: The article presents the variability to selected extreme climatic phenomena in Poland in the second half of the 20th century. The main attention is paid to the search for exceptional values for indicators or trends that might be regarded as effects of global warming. Among the circulation indicators considered are the variability to the influx of Arctic and tropical air masses in the period 1951–1999, as well as the numbers of days with fronts. In turn, elaborated for the period 1966–1999 was the variability in absolute maxima and minima for pressure, as well as extreme values for pressure tendency, and the occurrence of very strong winds. The greatest changes were found to have occurred in the case of extremes of temperature: from 1982 onwards in the case of absolute maxima and from 1973 on in the case of absolute minima and amplitudes of temperature. These generally attest to an increase in the oceanicity of the Polish climate. In the case of extreme precipitation events, a transition to a rather wetter phase of climate has been noted since 1995. However, there is no sign of any departure for any of the elements studied that has exceeded the values typical for fluctuations of climate in the 20th century, and could therefore be taken as indicating a permanent change in the climate.

KEY WORDS: climatic change, extreme climatic events, Poland.

INTRODUCTION

The issue of extreme climatic phenomena is among the leading ones for those researching the world's climate. It arouses great interest among both such scientific organisations as the WMO, and among the governments and economic institutions of different countries. Most difficult to explain are the causes of climate change, while attempts to predict further changes are also a source of controversy. Many of the changes in question are global in character and may turn out to be of great significance for humankind (Obrębska-Starkel and Starkel 1991; Trepińska et al. 1997; Starkel 1999).

The undertaking of this research is even further justified by the fact that many extremes of climate have been noted in recent years (Cebulak and Limanówka 1997; Cebulak and Niedźwiedź 1997), including changes to the trends for winter temperatures. After the exceptional positive anomalies occurring in the winters between 1989 and 1994 in Poland (and most especially the warm January of 1994), there was the longlasting winter of 1995/96 and the relatively cool one of 1996/97 (Kraków's December of 1996 was the second coldest in the years 1951–1996 inclusive, after that of 1969). Winter 1997/98 was in turn mild. The last decade has also witnessed extreme thermal events in summer (with summer 1992 seeing the greatest thermic anomalies noted in Kraków for 200 years, and July 1994 also proving exceptional). A great positive anomaly to temperature was also to be noted in April 2000 – the warmest in 200 years. The ongoing warming has been associated with perceptible shortages of rain, while the summers of 1992 and 1994 were characterised by catastrophic drought over much of the country. There is a need for detailed recognition of both the scale and scope of such anomalies, and their causes. Since 1995 there has been a steady and noticeable rise in summer precipitation, and even states of excessive rainfall as in the very wet July of 1996 that affected Wielkopolska, and led to flooding in the Carpathians in September. Of course, there has been nothing to compare with the severity of the economic losses and cost in lives (55) associated with the catastrophic July 1997 floods in the south of Poland (the subject of a separate work – Niedźwiedź 1999). Local extreme phenomena have also been marked, with examples being recent extreme storm rainfall events over the Małopolska Upland: near Miechów in September 1995, twice in May 1996 at Sułoszowa in the Prądnik basin, in Kłodzko in July 1998 and at Pałecznica near Proszowice in April 2000. In turn, considerable losses were incurred in the Podkarpacie region in summer 1999 as a result of a large number of local events of an extreme nature (storms, downpours, hail and strong winds).

It is suspected that one of the factors influencing contemporary climatic conditions is human economic activity through the supply to the atmosphere of huge amounts of particulate and gaseous pollutants, including the additional heat and carbon dioxide released by the burning of various substances. All of these processes induce the so-called greenhouse effect favouring a considerable rise in temperature. A working hypothesis that has been advanced holds that the effect will make itself felt in a considerable increase in the frequency of occurrence of extreme events (Starkel 1999; Wigley 1988). It is for this reason that one of the aims of the present study has been to determine the dynamics of selected extremes of climate over the longer term.

MATERIALS AND METHODS

The greater part of the material was collected within the framework of research topic M-2 coordinated by the author and entitled "Extreme climatic phenomena in Poland – spatial structure, dynamics and threats". This has been implemented over the last several years within the Kraków branch of the Institute of Meteorology and Water Management, with account having been taken of the period 1951–1998. In turn, work continued at the Department of Climatology of the University of Silesia in relation to the variability of occurrence of selected extreme climatic phenomena over long periods, with use being made of world climatic bases, including the Global Historical Climate Network made available over the Internet by the NOAA.

Past research on the climate, its variations and long-term changes has largely been confined to the elements of air temperature and atmospheric precipitation. However, the climate is a complex of mutually-interlinked meteorological elements, with research confined to the aforementioned elements being very far from satisfactory when it comnes to an assessment of the climate on every scale. Studies of the causes of change should be sought in the variability to atmospheric circulation, so research on extreme phenomena was linked with the dynamic to extreme circulation phenomena (Ustrnul 1997a, b), with account also being taken of the frequency of occurrence of the masses of Arctic and tropical air generating extreme thermic situations. The variability to indicators of western and southern circulation and cyclonicity was elaborated for the years 1873–1999, with attention being paid to the appearance of extreme values. The occurrence of masses of air and arrival of atmospheric fronts was also presented for the period 1951–1999. These changes are the result of the high dynamic to pressure systems which has been presented in the courses for extremes of atmospheric pressure and the frequency of exceptionally large values for barometric tendency exceeding ±5.0 hPa in the course of a 3-hour period. A supplement to this part of the work has taken the form of a characterisation of very strong winds (stronger than 15 ms^{-1}).

From among the extreme thermic phenomena, the study focused upon the variability of long-term absolute maxima and minima of temperature, as well as absolute values for annual amplitude.

Given in the case of atmospheric precipitation – apart from the extreme daily and annual values – were Polish lowland averages (14 best stations) for the characterisation of daily falls exceeding 20 mm, as well as days without precipitation.

THE ADVECTION OF ARCTIC AND TROPICAL AIR MASSES

Among the extreme circulation characteristics of the climate, advection of Arctic air over Poland has been the subject of a clear upward trend in recent years (Fig. 1), increasing by c. 35 days in the course of 49 years. In an average year, such a cool air mass extended over Poland for 29 days, however in the years 1976–1979 there were 56–60 such days a year, while in 1997 there were 53. It was in this latter year that an increase in the activity of meridional circulation led to the exceptionally high rainfalls noted in southern Poland in July.

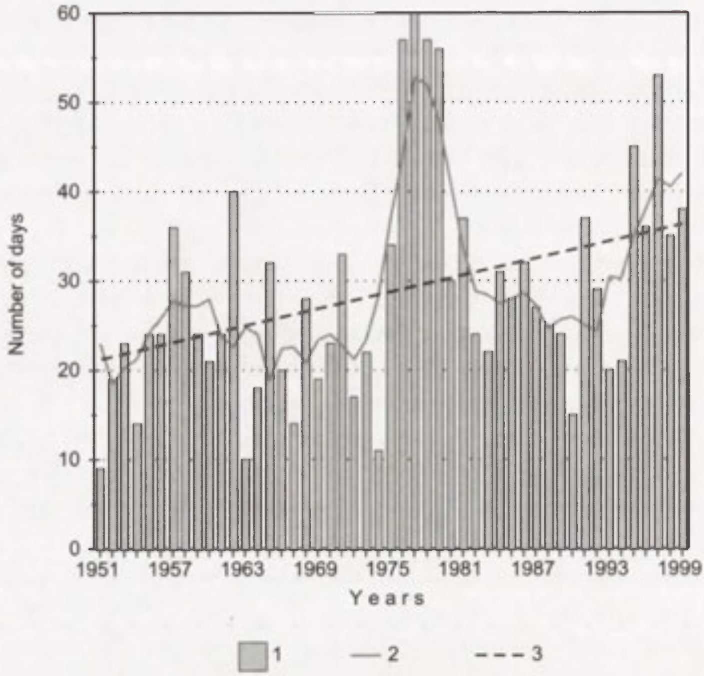

Figure 1. Long-term variability to the frequency of Arctic air-mass advection (1951–1999).
1 – annual number of days, 2 – moving averages (5-year), 3 – linear trend.

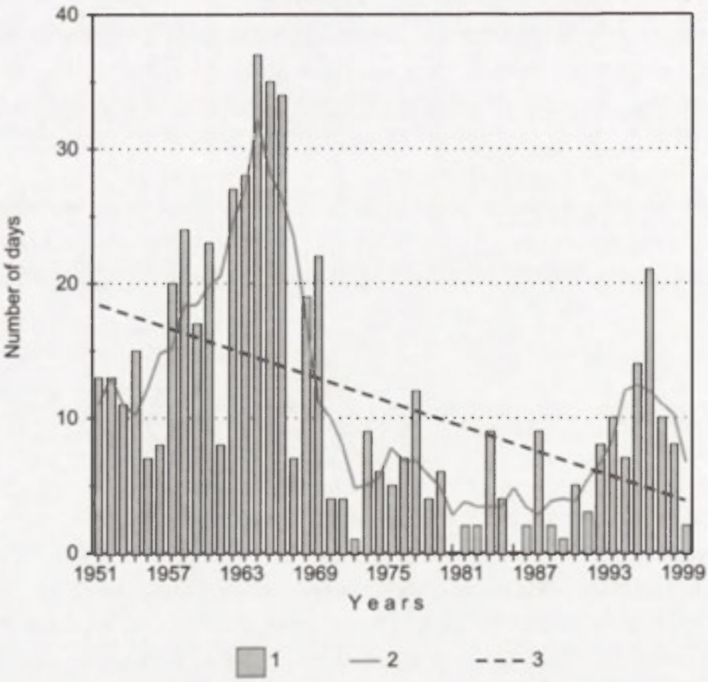

Figure 2. Long-term variability to the frequency of tropical air-mass advection (1951–1999).
1 – annual number of days, 2 – moving averages (5-year), 3 – linear trend.

Maxima for the advection of Arctic air are to be noted through the course of the year, being responsible for the so-called "return of winter" and severe ground frosts as late as April and May, as well as for cold periods in September and October. Overall, Arctic air was observed least often in the years 1951 (9 days), 1963 (10), 1974 (11) and 1990 (15).

Tropical air has in turn shown a marked downward trend for frequency of occurrence – from 18 days a year in the period 1951–1955 to 5 days in the years 1995–1999 (Fig. 2), as compared with the mean figure for the whole period of 11 days per year. It is easy to identify a period of enhanced advection in the years 1951–1969, with a maximum in the period 1962–1966 (with as many as 37 days in 1964). Later, in the period 1970–1994, such tropical air occurred more rarely, to the point where it was not even noted at all in 1980 and 1985. Renewed influxes have however been noted most recently, with 14 days of tropical air in 1995 and 21 in 1996. Interestingly, the years 1970–1994 are characterised not only by the limited frequency of advection of tropical air, but also by the rarity of advections of Arctic air, while the period from 1995 onwards has seen a renewed rise in the frequency of incursion of both of these thermally-extreme kinds of air mass.

THE FREQUENCY OF OCCURRENCE OF ATMOSPHERIC FRONTS

As many extreme climatic phenomena (like storms, very strong winds, etc.) are generated by fronts, their frequency of arrival over Poland is also worth researching (Fig. 3). On average, such fronts are present for around 150 days

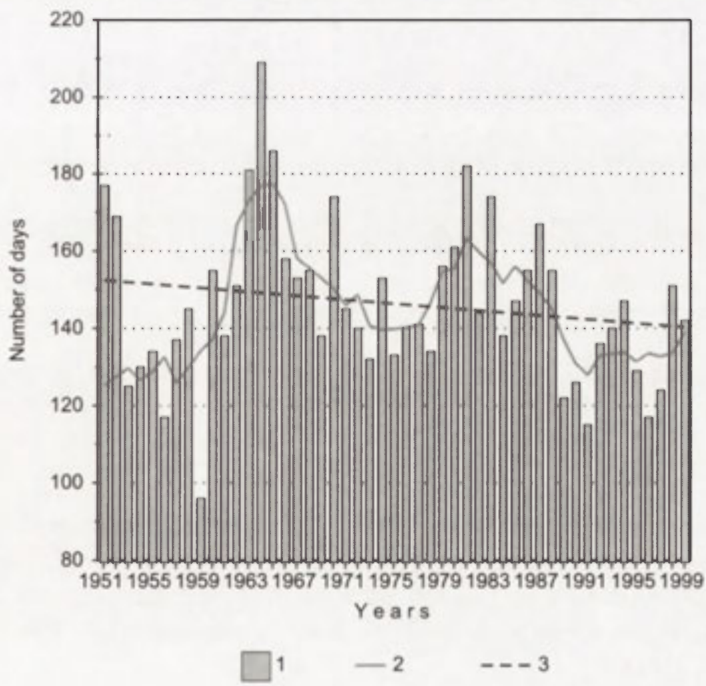

Figure 3. Long-term variability to the frequency of fronts passing over Poland (1951–1999). 1 – annual number of days, 2 – moving averages (5-year), 3 – linear trend.

a year, with the recent trend for their occurrence being downward, albeit with statistical significance not achieved. The last 50 years have included three identifiable periods with a greater number of fronts, i.e. 1951–1952, 1960–1970 (with the peak of 210 days in 1963) and 1979–1988. The most limited occurrence of fronts came in 1959, when they were present over the country for only 97 days.

EXTREME VALUES FOR ATMOSPHERIC PRESSURE

The indicators of atmospheric circulation are often associated with extremes of pressure, as is seen for Warsaw in the years 1966–1999 (Fig. 4). There has been a marked upward trend for absolute pressure maxima, from 1041 to 1046 hPa, while the highest values of all – adjusted to sea level – were of 1050 hPa in 1992 and 1997. However, it was only in 1978 that the highest pressure noted in the year did not exceed 1036 hPa.

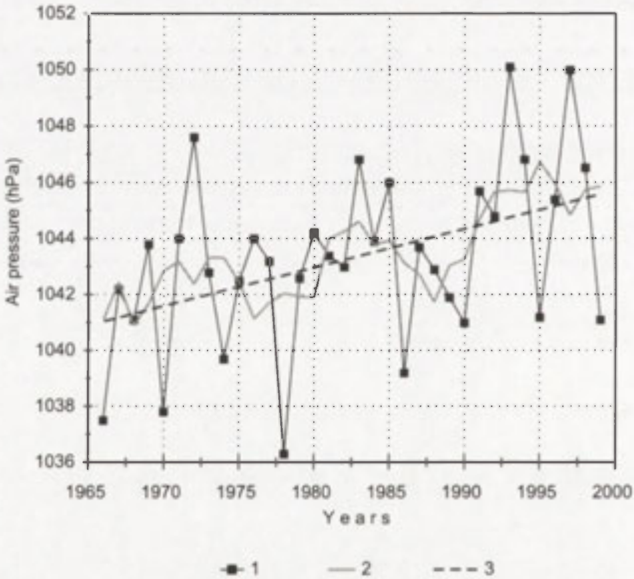

Figure 4. Long-term variability to the absolute maximum of sea-level air pressure in Warsaw (1966–1999).

1 – annual absolute maximum, 2 – moving averages (5-year), 3 – linear trend.

Absolute minima for pressure (Fig. 5) have been characterised by greater fluctuation than the maxima, but with no clear trend to be noted. The pressure fell below 975 hPa as many as four times in the study period, with the lowest figure being the 971 hPa noted in 1989. Falls in pressure below 990 hPa are an almost annual event.

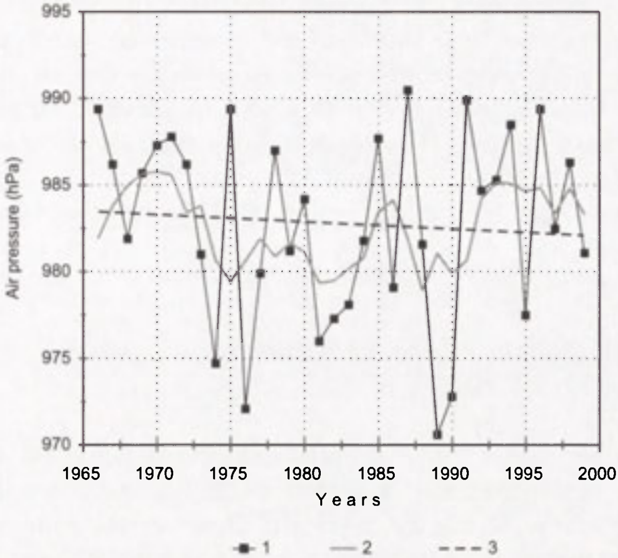

Figure 5. Long-term variability to the absolute minimum of sea-level air pressure in Warsaw (1966–1999).

1 – annual absolute minimum, 2 – moving averages (5-year), 3 – linear trend.

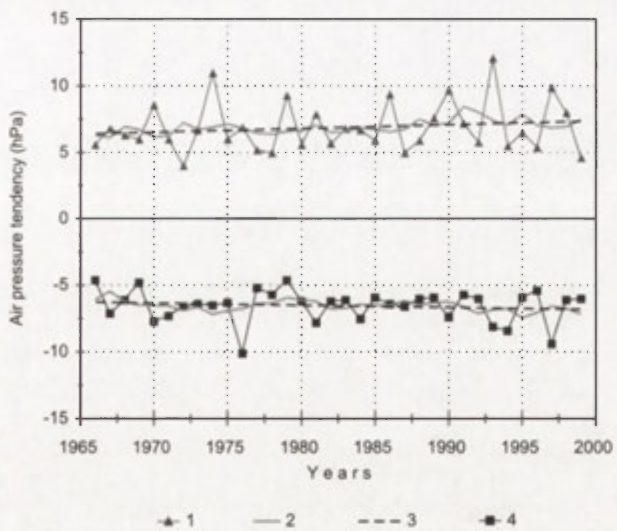

Figure 6. Long-term variability to the extreme values for air pressure tendency (hPa/3h) in Warsaw (1966–1999).

1 – greatest increase in pressure, 2 – moving averages (5-year), 3 – linear trend, 4 – smallest decrease in pressure.

From among the different pressure characteristics, the greatest attention has been paid to the brief but large variations in pressure over 3-hour periods (Falarz 1997) that are noted at meteorological stations as barometric tendencies. In Warsaw, the extreme values for such variations may exceed 10 hPa in 3 hours roughly twice every 50 years (Fig. 6). In turn, three-hour rises or falls in excess of 5.0 hPa are an almost annual event. Analysis of the trends suggests that the last 50 years have witnessed a small increase in the range of variation to such barometric tendencies.

THE VARIABILITY TO THE OCCURRENCE OF VERY STRONG WINDS

Winds stronger than 15 ms^{-1} over 10 minutes do not occur very often in Poland away from the coast and the mountains. In Warsaw, there are on average only 2.5 days a year with such winds (Fig. 7). However, the number does fluctuate markedly from year to year, between the 0 noted in 1977 and 1989 and the 7 days with such winds in 1992. Nevertheless, the fluctuations have been rather irregular and do not conform to any particular trend.

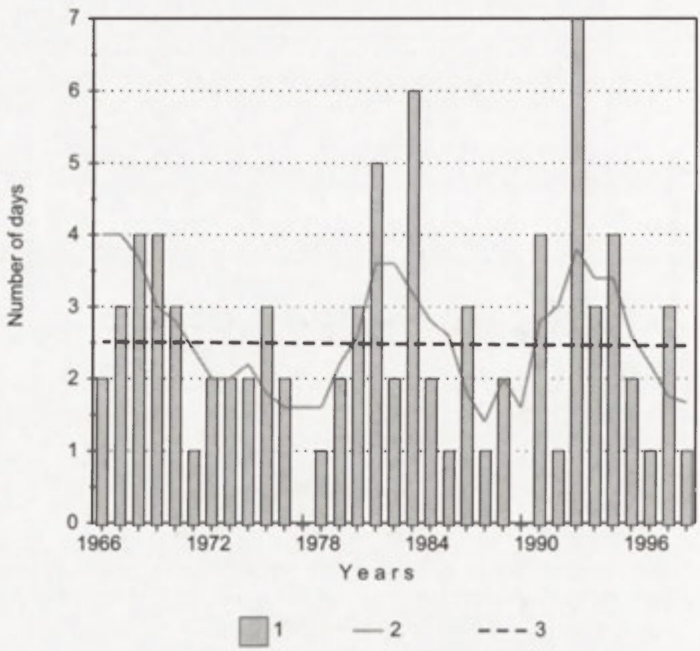

Figure 7. Long-term variability to the occurrence of gales (>15 m/s) in Warsaw (1966–1998).

1 – annual number of days, 2 – moving averages (5-year), 3 – linear trend.

EXTREME VALUES FOR AIR TEMPERATURE

Three weather stations were chosen to present the fluctuation and variability to long-term absolute extremes of air temperature. These are Suwałki, as representative of the coolest part of Poland; Słubice – the warmest, and Warsaw, representing the centre of the country. The highest maximum air temperature noted to date in Poland is taken to be the 40.2°C recorded in Prószków near Opole on July 29th 1921 (Paszyński and Niedźwiedź 1999). D. Kuziemska (1983) in turn quotes a value of 38.9°C noted on August 19th 1892 in Legnica and Zielona Góra. The highest post-War temperature is the 39.5°C which occurred in Słubice on July 30th 1994.

On average, the air temperature over the Silesian Plain and in Wielkopolska is expected to exceed 35°C (e.g. Wroclaw 35.8°C) once a decade. Equally, there is only likely to be a yearly maximum air temperature of less than 30°C there once a decade. The highest maxima for air temperature on the coast are 3–4°C lower than inland. In contrast, the lowering to be noted for this indicator as one moves east is not very great, while the considerable decline in maxima south towards the mountains is mainly a reflection of increasing altitude. On 1602 m Mount Śnieżka for example, the extreme air temperature recorded peaked at 23.6°C, as compared with the 23.0°C noted for 1985 m Kasprowy Wierch in the Tatra Mountains.

All of the stations studied present similar variability for the absolute maximum of temperature (Fig. 8). There is a downward trend of 3–4°C across the

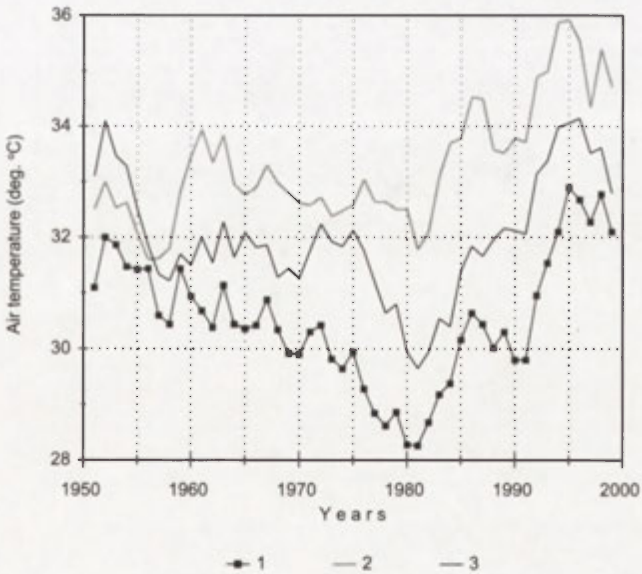

Figure 8. Long-term variability to the absolute maximum of air temperature at selected stations – moving 5-year averages (1951–1999).
Moving averages: 1 – Suwałki, 2 – Słubice, 3 – Warszawa.

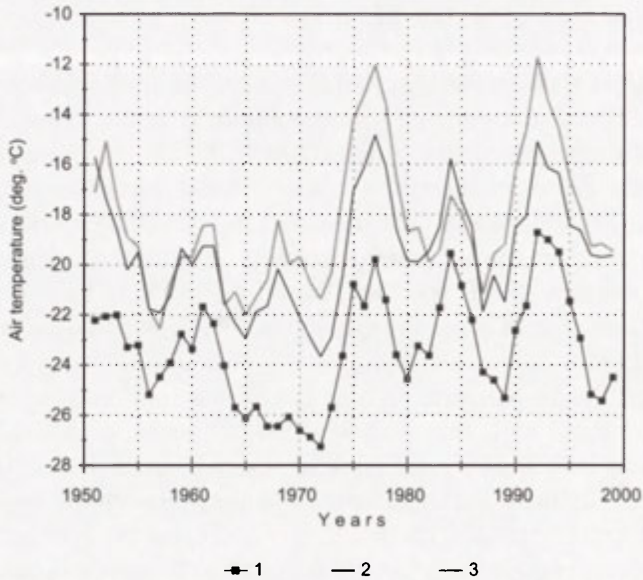

Figure 9. Long-term variability to the absolute minimum of air temperature at selected stations – moving 5-year averages (1951–1999).
Moving averages: 1 – Suwałki, 2 – Słubice, 3 – Warszawa.

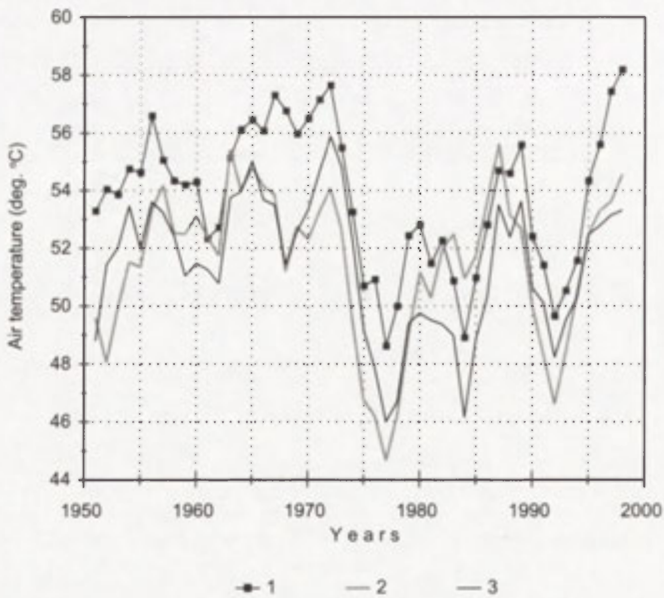

Figure 10. Long-term variability to the absolute amplitude of air temperature at selected stations – moving 5-year averages (1951–1999).
Moving averages: 1 – Suwałki, 2 – Słubice, 3 – Warszawa.

period 1951–1981, as compared with an upward trend of more than 4°C from 1982 onwards, with a maximum in the years 1993–1997. 1973–1985 inclusive were years of a marked cooling, with the Suwałki station not noting absolute maxima in excess of 30°C for 5 years in succession.

According to D. Kuziemska (1983), the lowest minimum air temperature ever recorded in Poland was the –41.0°C noted in Siedlce on January 11th 1940. Falls below –40°C were also recorded on February 10th–11th 1929 at several weather stations situated in concave landforms (Żywiec –40.6°C, Olkusz –40.4°C, Sianki –40.1°C). In the post-War period, the lowest temperature noted at the stations under analysis was the –35.8°C recorded at Rzeszów-Jasionka on February 28th 1963. Still lower values have in fact been obtained in the mountain basins (–37.6°C in Jabłonka on February 27th 1964 and –36.9°C in Jelenia Góra on February 10th 1956). However, many places in central and western Poland have not recorded falls below –30°C (e.g. Gorzów Wielkopolski with its absolute low of –27.1°C). The warming influence of the Baltic is exceptionally clear, with Hel never having recorded a value below –20.0°C, and Świnoujście none below – 23.6°C. Indeed, there are years in which the coastal stations have failed to record any minima below –5°C. Overall, eastern Poland may be expected to record falls below –28°C once a decade, western Poland falls below –21°C with this degree of regularity, and the coast declines in air temperature below –17°C. Only in the mountain basins and in the north-east is there a 10% probability of minima below –30°C being recorded.

The picture for changes among these absolute minima of air temperature is quite different from that obtained for maxima (Fig. 9). A contiguous period of low minima for absolute air temperature lasted between 1956 and 1972, while the years post-1973 witnessed a fundamental change to the rhythm. This took the form of considerable fluctuations over periods lasting around 7–8 years, with the most marked warming falling in the years 1977, 1984 and 1992, and the most distinct cooling in 1980, 1987–1989 and 1998.

It is the minima that determine the variability to long-term values for average annual amplitudes of absolute air temperature (Fig. 10). Thus, there was a distinct and uniform period of high amplitude in the years 1951–1972, attesting to clear continentality of climate. 1973 saw the start of a major change for this element, with the absolute range between maxima and minima in the years 1973–1977 inclusive being around 10 degrees smaller, something that suggests a greater oceanicity of Poland's climate. 1977, 1984 and 1992 were the years with the most limited range between maxima and minima, while a renewed (6°C) increase in annual amplitude was only observed as recently as in the years 1994–1998.

EXTREME PRECIPITATION EVENTS

It is the characteristics of rainfall, from among all the climatic elements, that show the greatest variability over both time and space. Analysis for the purpose

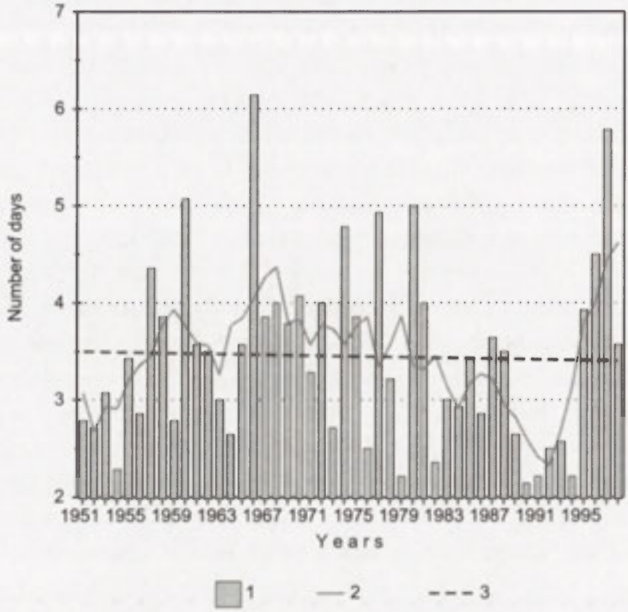

Figure 11. Long-term variability to the number of days with atmospheric precipitation > 20 mm – averages from 14 stations (1951–1998).
1 – annual number of days, 2 – moving averages (5-year), 3 – linear trend.

of the present study made use of two such characteristics for precipitation extremes that were averaged for data from 14 stations distributed evenly across the country (Fig. 11). The number of days with mean precipitation of over 20.0 mm has shown marked fluctuations over the last 50 years, but no clear trend. There is thus no basis for stating that the frequency of extreme precipitation events has been increasing.

Days with heavy precipitation were few in the years 1951–1956, while the period 1957–1981 inclusive was marked by a greater number of days with heavy precipitation as defined above – reaching 6 in 1996. The years 1982–1994 were basically dry years, while the time from 1995 onwards has seen a renewed increase in the average number of days with heavy falls – to almost 6 in 1997. A similar rhythm to changes in daily maximum precipitation has been observed in the Carpathians (Cebulak 1997).

In turn, where the number of days without rain is concerned, the long-term variability averaged for Poland shows a clear downward trend (Fig. 12) – from 208 days without precipitation in the years 1951–1955, to less than 190 days in the years 1995–1999. The lowest number of days without precipitation of all was the 162 noted in 1970, while the greatest number was 238 precipitation-free days in 1982, 1959, 1951 and 1953. Overall, however, there were irregular fluctuations

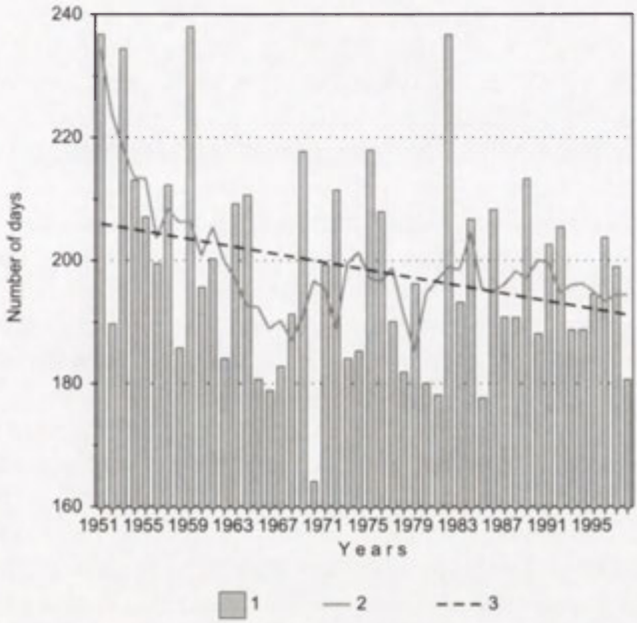

Figure 12. Long-term variability to the number of days without atmospheric precipitation – averages from 14 stations (1951–1998).

1 – annual number of days, 2 – moving averages (5-year), 3 – linear trend.

in the number of precipitation-free days from year to year, with no periodicity being visible.

SUMMARY

The recent variability to indicators of westerly and southerly circulations and cyclonicity in Poland has not been sufficient to depart markedly from the range to such variability noted in earlier periods (data for 1873 onwards). These changes are the result of a considerable dynamic to pressure sytems which is manifested in the course of extremes of atmospheric pressure and the frequency of occurrence of exceptionally high values for changes in pressure greater than 5.0 hPa over 3 hours.

In turn, the long-term course for absolute maxima of temperature shows a high degree of levelling-out of curves, with a larger fall in temperature over the period 1977–1982, followed by an upward trend culminating in the years 1992 and 1994. A considerable lowering of temperature maxima in the years 1975–1980 is hard to explain, but is probably associated with increased cloud cover over Central Europe. The long-term progress of the course for absolute minima of temperature reveals two cooler periods in Poland: in the years 1951–1970 and

1978–1987; as well as two warmer periods culminating around 1974 and 1989–1990. While the fluctuations are quite major, no clear trend may be divined. This said, there are many places, including the cities of Warsaw and Wrocław, in which the period 1973–1998 differed from earlier ones in a clear increase in the variability of absolute minima from year to year. This was reflected in increased absolute amplitude of temperature in different years.

The study of the variability to precipitation phenomena took account not only of extreme totals from year to year, but also in particular of daily maxima. The variability to the frequency of occurrence of days with more than 20 mm is interesting, as the data for Poland over the last half-century suggest two periods of intensification, especially in the south – in the years 1958–1980 and from 1995 onwards (Cebulak et al. 1996; Cebulak 1997).

In short, it is at present hard to offer unambiguous confirmation of the hypothesis that extreme climatic events have become more frequent in the last decade. It would seem rather that their incidence has remained very much linked to irregular fluctuations of atmospheric circulation. Moreover, many of the meteorological phenomena of natural-disaster rank have been local in their scope, frequently escaping direct observation. It is for this reason that further methodological work needs to be carried out to draw up databases on extreme climatic events using voluntary observations from every local community in Poland, along with satellite and radar data. Long-term study of the variability to extreme phenomena requires that all the instrumented measurement sequences be made fully uniform (Niedźwiedź and Ustrnul 1997). Some of them are still spread around a large number of different archives, including abroad (especially in Germany and Austria).

Trends to the variability of selected extreme characteristics of the 20th century climate have also been presented for the United States (Karl et al. 1996). Proposed as a measure of the frequency of extreme phenomena there is the so-called "Climate Extremes Index" (CEI). Karl et al. reported significant changes to this index beginning around the year 1970, especially where increased precipitation and temperatures are concerned. In Poland, the marked change for thermic maxima proceeded after 1982, as linked with major changes in the distribution of cloud cover. In contrast, the absolute temperature minima and amplitude experienced major change from 1973 onwards as a result of greater oceanicity of the Polish climate.

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