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CLIMATE OF POLAND 2022

When the First Report of the Intergovernmental Panel of Experts on Climate Change (FAR IPCC) was published in 1990, the material contained therein on the contemporary change of the Earth's climate and its causes, consequences, and the scope of necessary actions to avoid the associated risks was considered in many countries to be merely a scientific vision – one of many. Since then, however, each successive IPCC report has confirmed and stated more and more clearly that the Earth's climate has been changing since the mid-19th century at an unprecedented pace and that progressive warming threatens the well-being of the planet, its ecosystems, and human life. The impact of modern warming is widespread – the next 2-3 decades will be critical to the Earth's future – and threatens, in particular, agricultural production, water resources, human safety, and health. All this is due, among others, to the progressive intensification of extreme phenomena occurrence – both meteorological and climatic – and consequently also hydrological. In more than 30 years that have passed since the publication of the FAR IPCC, the international community has begun to perceive contemporary climate change as a real threat that leads to the exhaustion of the civilizational resources of the Earth's current climate.

Therefore, it is necessary to monitor the climate system continuously, take actions to slow down or even eliminate the causes of contemporary climate change, as well as forecast the future evolution of the climate system, and develop adaptation strategies, i.e., taking adaptation measures.

The Institute of Meteorology and Water Management – National Research Institute has been monitoring Poland's climate for over 100 years on an ongoing basis, conducting observations and measurements of all relevant climate variables. We inform society and public administration about the climate system condition and the threats resulting from climate variability and change. We are the National Service, the meaning of which was well understood by the fathers of independent Poland, including the first President of the Republic of Poland, Gabriel Narutowicz.

We present the study "Climate of Poland 2022". It is already the third report since 2020, providing a synthetic description of Poland's climate in the past year, presented in the context of the long-term climate characteristics and from the perspective of contemporary global warming.

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Director of the Research and Development Center
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The presentation was prepared based on the POLISH CLIMATE MONITORING BULLETIN developed by the team consisting of:
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Supplementary materials were prepared by the team: Prof. MIROSŁAW MIĘTUS, JANUSZ FILIPIAK, Ph.D., MICHAŁ KITOWSKI, EDWARD ŁASZYCA, Ph.D, DAWID BIERNACIK, MICHAŁ MAROSZ, Ph.D., BEATA KOWALSKA. Comments: Prof. MIROSŁAW MIĘTUS.

POLISH CLIMATE MONITORING BULLETIN was created as part of the CLIMATE project and has been published since 2010. The multi-annual series data were used in the presentation: Warsaw (temperature: Halina Lorenc 2010, precipitation: Halina Lorenc 2005), Poznań (temperature: Leszek Kolendowicz et al. 2019), Gdańsk (temperature: Mirosław Miętus 1996, precipitation: Janusz Filipiak 2011) and Wrocław (temperature and precipitation: Krystyna and Tadeusz Bryś 2010) extended by Janusz Filipiak. The precipitation series from Krakow was developed and shared by prof. Robert Twardosz.

IMGW-PIB own study 2023.

Design: Michał Seredin (IMGW-PIB).

CLIMATE OF POLAND IN 2022

The area average air temperature in Poland in 2022 reached 9.5°C and was 0.8°C higher than the annual long-term average (climatological normal period 1991-2020). The year 2022 should be classified as very warm if you consider the average temperature for Poland.

The warmest region was the Podkarpacie, where the area average air temperature amounted to 9.9°C, and was higher than the standard normal by 0.9°C. The coldest was in the Sudetes Mountains and Carpathian Mountains, where the average annual air temperature reached 8.9°C and was higher than the standard normal by 0.8°C.

Let's look at the lake districts and lowlands, considering their division into the western and eastern parts (along the 19°E meridian). There is clearly a strong thermal differentiation in the western and eastern parts of the two largest regions of Poland. In the case of lake districts, the difference in mean annual values between the western and eastern parts of this area was as much as 1.4°C. After taking these differences into account, it can be concluded that the warmest region of Poland in 2022 was the western part of the lowlands belt, with an average annual air temperature of 10.5°C.

Last year, June, August, October, and December were particularly warm. In contrast, April and September were the coldest months, with an average air temperature over one degree below normal.

The highest temperature (38.3°C) was recorded on 19 June in Słubice. In turn, the lowest temperature at 2 m above ground (–18.6°C) was recorded on 14 December in Zamość. The lowest air temperature near the ground, i.e., at 5 cm height, was recorded on 19 December at the Terespol station; its value was –25.6°C.

The summer of 2022, i.e., the period from June to August, was the second warmest summer in Poland since the mid-20th century.

The strong upward trend in air temperature in Poland, which has been occurring for many years, continued in 2022. Since 1951, the total annual temperature increase has been estimated at 2.09°C. The trend coefficient's value differs in the country's individual climatic regions. The strongest temperature increase occurs in the lake districts, Podkarpacie, and the Carpathian Mountains, where it exceeds 2.16°C, and the weakest in the uplands and the Sudetes Mountains, reaching nearly 1.87°C.

The analysis of the historical series shows that, since 1851, the air temperature in selected large Polish cities has increased from 1.49°C to 2.30°C. It should be emphasized that the rate of temperature increase in large urban agglomerations has increased significantly over the past 40 years.

The area-averaged precipitation total in Poland in 2022 was 534.4 mm, nearly 87.4% of the so-called normal value determined based on 30 years of measurements (1991-2020). According to Kaczorowska's pluvial conditions classification, the past year should be classified as a dry year.

In 2022, precipitation was characterized by a strong spatial variability. The area average annual precipitation total ranged from over 350 mm to nearly 950 mm. Compared to the long-term normal (1991-2020), they ranged between 70% and 110% of the normal. The highest annual precipitation total was recorded in the Tatra Mountains. The precipitation with the highest daily total (130.4 mm) occurred on 8 September in Gorzów Wielkopolski.

In the central part of the Coast and Pomerania, there was a rainfall deficit, locally reaching just over 20% of the long-term normal, while in Eastern Poland and Lower Silesia, annual precipitation was 10% higher compared to the 1991-2020 normal.

The highest predominance of evaporation from the ground surface over precipitation was recorded in 2022 in the country's southwestern part, including the upper and middle Oder River basin.

The annual value of sunshine duration ranged from 1642.8 hours at Kasprowy Wierch to 2312.6 hours in Łeba.

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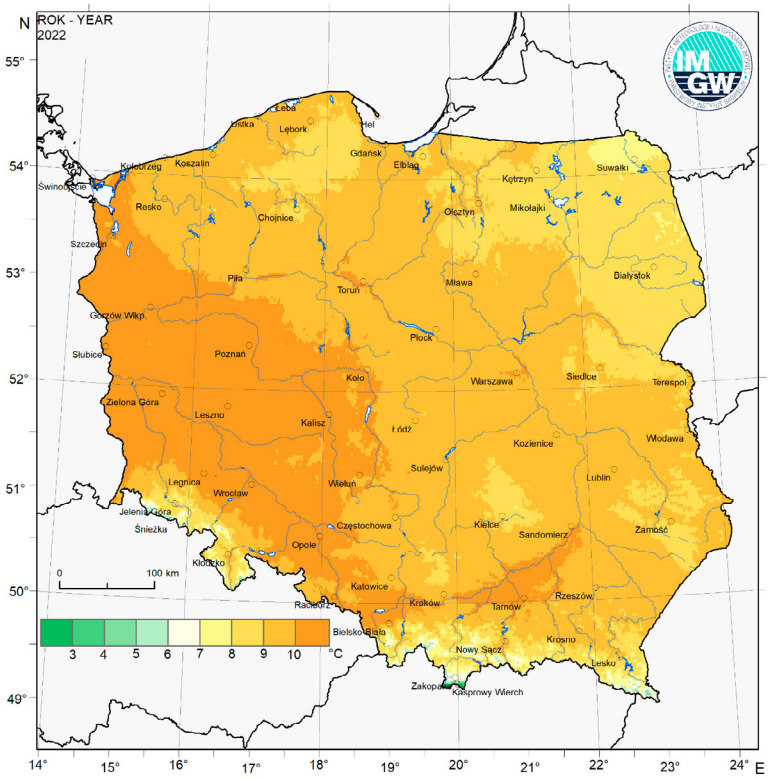
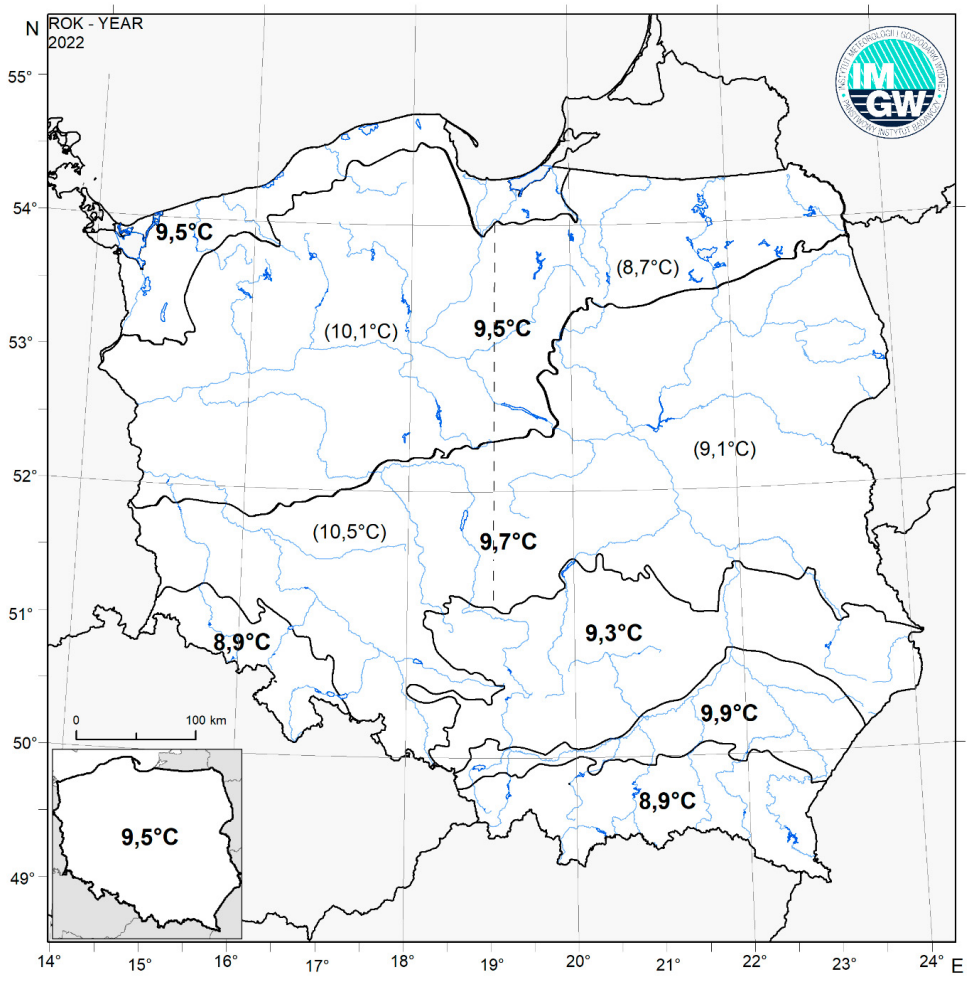
AIR TEMPERATURE

The spatial variability of air temperature in 2022 is a consequence of the quantity of incoming solar radiation over the territory of Poland (partially described by the sunshine duration), the advection of warm air masses and the influence of local factors. The warmest regions of the country in 2022 were the western and south-western parts of Poland and parts of the upper Vistula valley from Krakow to Sandomierz, where the mean annual air temperature exceeded 10°C. In contrast, the coldest areas were, apart from the higher parts of the Sudetes and the Carpathian Mountains, in north-eastern Poland in the vicinity of Suwałki, part of the Great Masurian Lakes Region and in the Kashubian Lake District. The location of the warmest and coolest areas on an annual basis is practically an exact reflection of the temperature variability in the long-term period 1991-2020.



The spatial variability of the average air temperature anomaly compared to the so-called climatological standard normal, i.e., the average value for the period 1991-2020, shows that the anomaly values were positive throughout the country, and exceeded 1°C in western Poland and in the vicinity of Rzeszów.

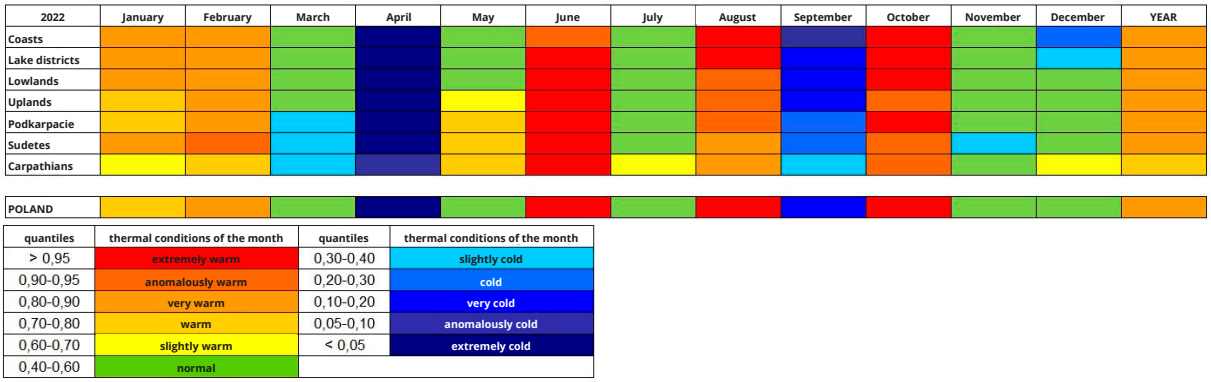


The area average air temperature is an indicator allowing the synthetic description of the thermal conditions in a given area. Moreover, it allows a comparison between regions and provides references to values determining temperature on a regional or global scale. For this purpose, area average temperature values are calculated for the basic physio-geographical units of Poland. These are (from the north): the Coast belt and the Southern-Baltic Coastlands belt, the lake districts belt, the lowlands belt, the uplands belt, the Podkarpacie, the Carpathians, and the Sudetes. In addition, to reflect the impact of the Atlantic Ocean and the Asian continent, the lowlands belt and the lake districts belt were divided into western and eastern parts along the 19°E meridian. Such a division allows for showing possible differences related to the thermal regionalization of Poland.
The warmest regions of Poland in 2022 were the western part of the lowlands belt (10.5°C; 1.1°C above 1991-2020 normal), the western part of the lake districts belt (10.1°C; 1.0°C above the 1991-2020 normal) and the Podkarpacie (9.9°C; 0.9°C above 1991-2020 normal). The coldest region was the eastern part of the lake districts belt (8.7°C; anomaly +0.7°C) and the mountain areas (Carpathians and Sudetes) with a mean annual air temperature value of 8.9°C (anomaly +0.8°C). It is noteworthy that the differences between the eastern and western parts of the lake districts and lowlands belt were significant, amounting to 1.4°C in both cases.

AIR TEMPERATURE
Thermal conditions clasification

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Z	W	L	J	YEAR
2022	1.1	3.2	3.2	6.7	13.5	18.6	18.9	20.5	12.3	11.2	4.3	0.4	1.2	7.8	19.3	9.3	9.5
Delta	2.2	3.4	0.1	−2.0	0.1	1.8	0.1	2.1	−1.4	2.5	0.3	0.2	1.6	−0.6	1.3	0.4	0.8

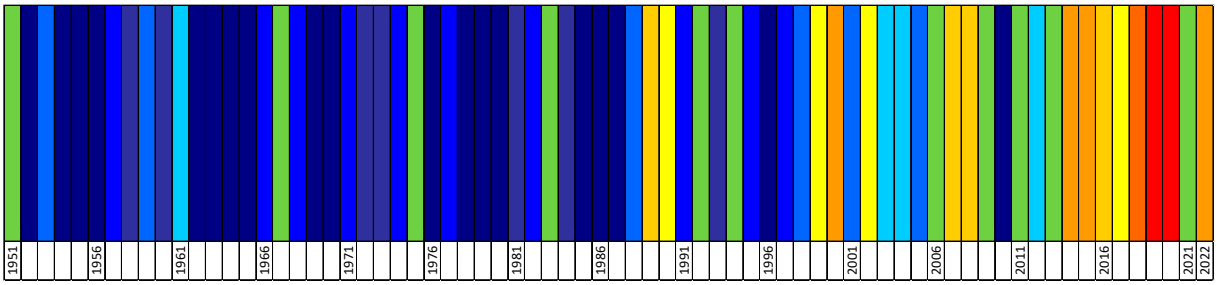
The air temperature is characterized by inter-annual variability. The warmest month in 2022 was August. The average temperature this month reached 20.5°C. It was 2.1°C higher than the average long-term temperature for this month. In contrast, the coldest month was December, when the average monthly temperature reached 0.4°C and was 0.2°C higher than the climatological standard normal. April was particularly cold compared to the long-term normal (the anomaly was −2.0°C). February, October, January, and August were particularly warm compared to the long-term normal. Anomalies were exceeding +2.0°C. The highest anomaly was recorded in February (+3.4°C). Winter and summer stand out with clearly positive anomalies in the context of the seasonal variability.



quantiles	thermal conditions of the month	quantiles	thermal conditions of the month
> 0,95	extremely warm	0,30-0,40	slightly cold
0,90-0,95	anomalously warm	0,20-0,30	cold
0,80-0,90	very warm	0,10-0,20	very cold
0,70-0,80	warm	0,05-0,10	anomalously cold
0,60-0,70	slightly warm	< 0,05	extremely cold
0,40-0,60	normal		

Descriptive classifications are often used to determine to what extent the thermal conditions of the month, climatic season or year differ from typical conditions. One such qualification is based on an empirical cumulative distribution function of average air temperature values for each month, season or year in the normal period 1991-2020, allowing the determination of threshold values of the classes based on a certain probability. Each class is given a descriptive name, as shown above.

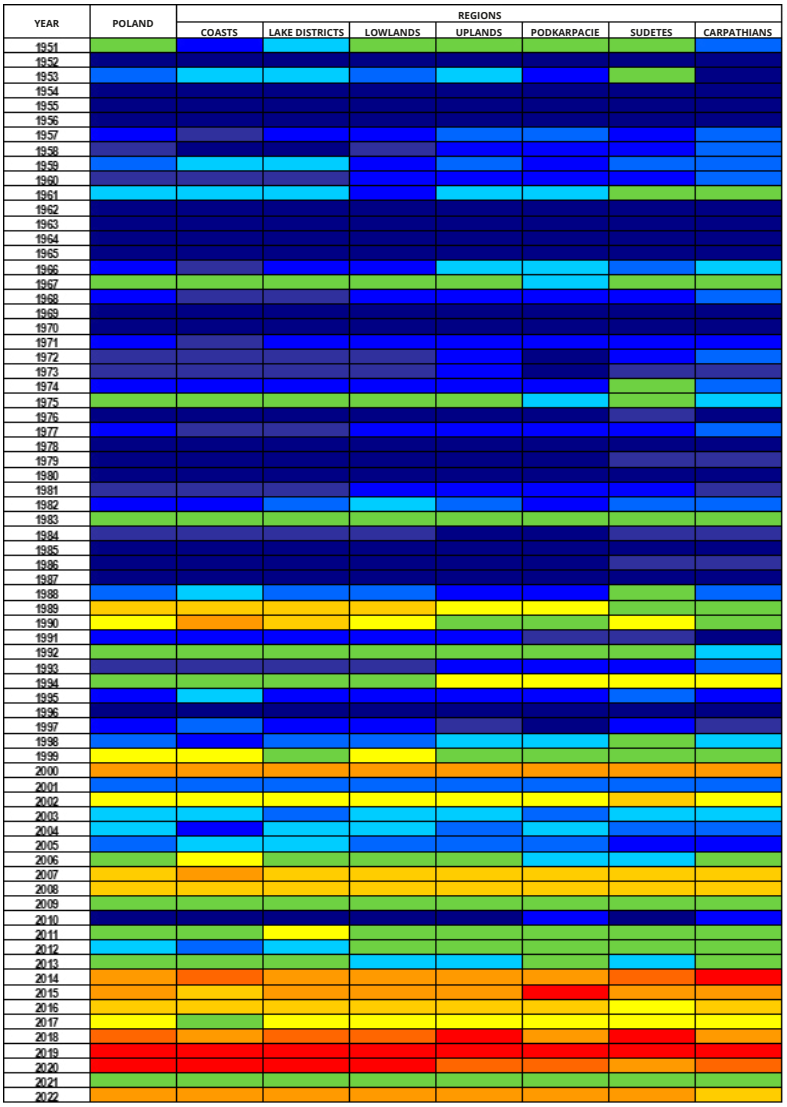
Based on this classification, thermal conditions in 2022 in almost all climate regions were classified as: extremely warm in June, anomalously and extremely warm in August and October, very warm or warm in January and February, and extremely cold in April. In September, there was a slightly greater spatial diversity of thermal classes, while generally the conditions can be described as cold. On an annual basis, thermal conditions in all regions (except the Carpathians) were classified as very warm.



It is possible to illustrate how the thermal conditions have changed in Poland, year by year, since the beginning of the second half of the 20th century by using a descriptive classification of thermal conditions . It is visible that the thermal conditions until the mid-1980s in each year were classified in the group of cold and cool conditions. In turn, from the second half of the 1980s, there were more often conditions referred to as normal or warmer. The last decade has seen a predominance of conditions ranging from very warm to extremely warm. Since 2013, only the years 2013 and 2021 have been classified as thermally normal; the others have been slightly warm (2017), warm (2016), very warm (2014, 2015, 2022), or extremely warm (2019, 2020).

This warm period has two exception – years 1996 and 2010. The year 1996 was extremely cold. The average temperature was 6.6°C, and the year 2010 was very cold. The average temperature was 7.5°C. In 1996, it was determined by very cold winter months, both from January to February and in December. In 2010, January, February and December were cold, while July was very warm (20.8°C).

The temperatures are rising! In individual years, physio-geographic regions differ in terms of thermal conditions. These differences are not significant. However, there are some differences in the analyzed periods. There were years in which the differences in thermal conditions in the regions were considerable (e.g., 1951, 1966 and 1997). The warming process is clearly visible. As you move along the timeline, the cool colors are replaced by warm colors. This color change reflects the global warming process in all regions. The year 2022 was again marked as very warm (after a break with normal conditions in 2021). However, it was not as extremely warm as in 2019 and 2020. Apart from the Carpathians, which were "only" warm, the other regions were characterized by uniform thermal conditions and were very warm.



AIR TEMPERATURE
Thermal conditions variability, 1951-2022

Decade	Average air temperature (°C)		Normal period
1951-1960	7.61		
1961-1970	7.43		
1971-1980	7.61	7.55	1951-1980
1981-1990	7.97	7.67	1961-1990
1991-2000	8.27	7.95	1971-2000
2001-2010	8.59	8.28	1981-2010
2011-2020	9.33	8.73	1991-2020
2013-2022	**9.41**	**8.79**	**1993-2022**

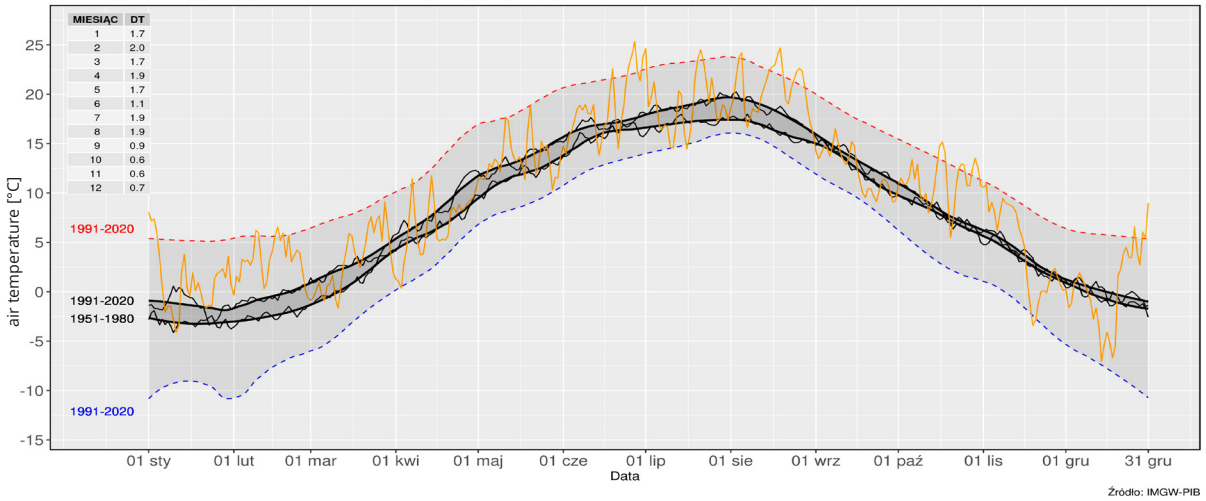
The average air temperature values in the individual decades of the period 1951-2020 are between 7.4°C (more precisely 7.43° in the decade 1961-1970) and 9.3°C (more precisely 9.33°C in the last decade 2011-2020). The table showing those values illustrates the progressive increase in air temperature from decade to decade. The situation analyzed from the point of view of average values for 30-year periods (the so-called normal climatological periods) is similar. In this case, the increase is unambiguous, from 7.55°C in the period 1951-1980 up to 8.73°C for the last 30-year period, i.e. 1991-2020. It represents an increase of 1.2°C in terms of 30-year normals. Note that for the 30-year period 1993-2022, atypical in the climatological description, the average long-term air temperature value in Poland is 8.79°C. It has been the warmest 30-year period since 1951!

YEAR	Air temperature (°C)				
	Winter	Spring	Summer	Autumn	YEAR
2000	0.8	9.9	16.9	10.2	9.5
2001	0.5	7.9	17.6	8.7	8.3
2002	0.2	9.7	19.0	8.3	9.1
2003	–3.8	8.2	18.6	8.3	8.3
2004	–0.9	7.9	17.1	9.1	8.3
2005	–0.1	7.3	17.2	9.3	8.3
2006	–3.2	7.0	18.7	**11.0**	8.7
2007	2.7	**10.0**	18.3	7.6	9.4
2008	1.7	8.4	18.0	9.1	9.4
2009	–0.7	8.8	17.5	9.3	8.5
2010	–3.2	7.9	18.7	8.0	7.5
2011	–3.0	8.9	17.9	9.0	8.9
2012	–1.2	9.3	18.0	9.4	8.5
2013	–1.8	6.8	18.3	9.2	8.5
2014	1.3	9.8	17.9	10.0	9.6
2015	1.1	8.5	18.9	9.3	9.7
2016	1.8	9.0	18.2	8.9	9.2
2017	–0.9	8.8	18.2	9.4	9.0
2018	0.1	9.8	19.5	10.2	9.8
2019	1.0	9.2	**19.9**	10.4	**10.2**
2020	**3.1**	8.1	18.6	10.4	9.9
2021	–0.2	7.1	19.1	9.5	8.7
2022	**1.2**	**7.8**	**19.3**	**9.3**	**9.5**

As mentioned before, the last 22 years have been the warmest period since the mid-20th century. During this period, the warmest winter was in the season December 2019-February 2020 (season temperature 3.1°C), the warmest spring (March-May) occurred in 2007 (10.0°C), the warmest summer (June-August) in 2019 (19.9°C), and the warmest autumn (September-November) in 2006 (11.0°C). The warmest year was 2019 (10.2°C). The year 2022 was 0.7°C colder than the warmest year (2019), but in the last 72 years, it was the 7th warmest, with an anomaly of +0.8°C relative to the long-term average (1991-2020).

YEAR	Air temperature (°C)		
	YEAR	Anomaly relative to 1981-2010	Anomaly relative to 1991-2020
2019	10.2	1.9	1.5
2020	9.9	1.6	1.2
2018	9.8	1.5	1.1
2015	9.7	1.4	1.0
2014	9.6	1.3	0.9
2022	**9.5**	**1.2**	**0.8**
2008	9.4	1.1	0.7
2007	9.4	1.1	0.7
2016	9.2	0.9	0.5
2002	9.1	0.8	0.4
2017	9.0	0.7	0.3
2011	8.9	0.6	0.2
2006	8.7	0.4	0.0
2021	8.7	0.4	0.0
2009	8.5	0.2	–0.2
2013	8.5	0.2	–0.2
2012	8.5	0.2	–0.2
2004	8.3	0.0	–0.4
2003	8.3	0.0	–0.4
2005	8.3	0.0	–0.4
2001	8.3	0.0	–0.4
2010	7.5	–0.8	–1.2

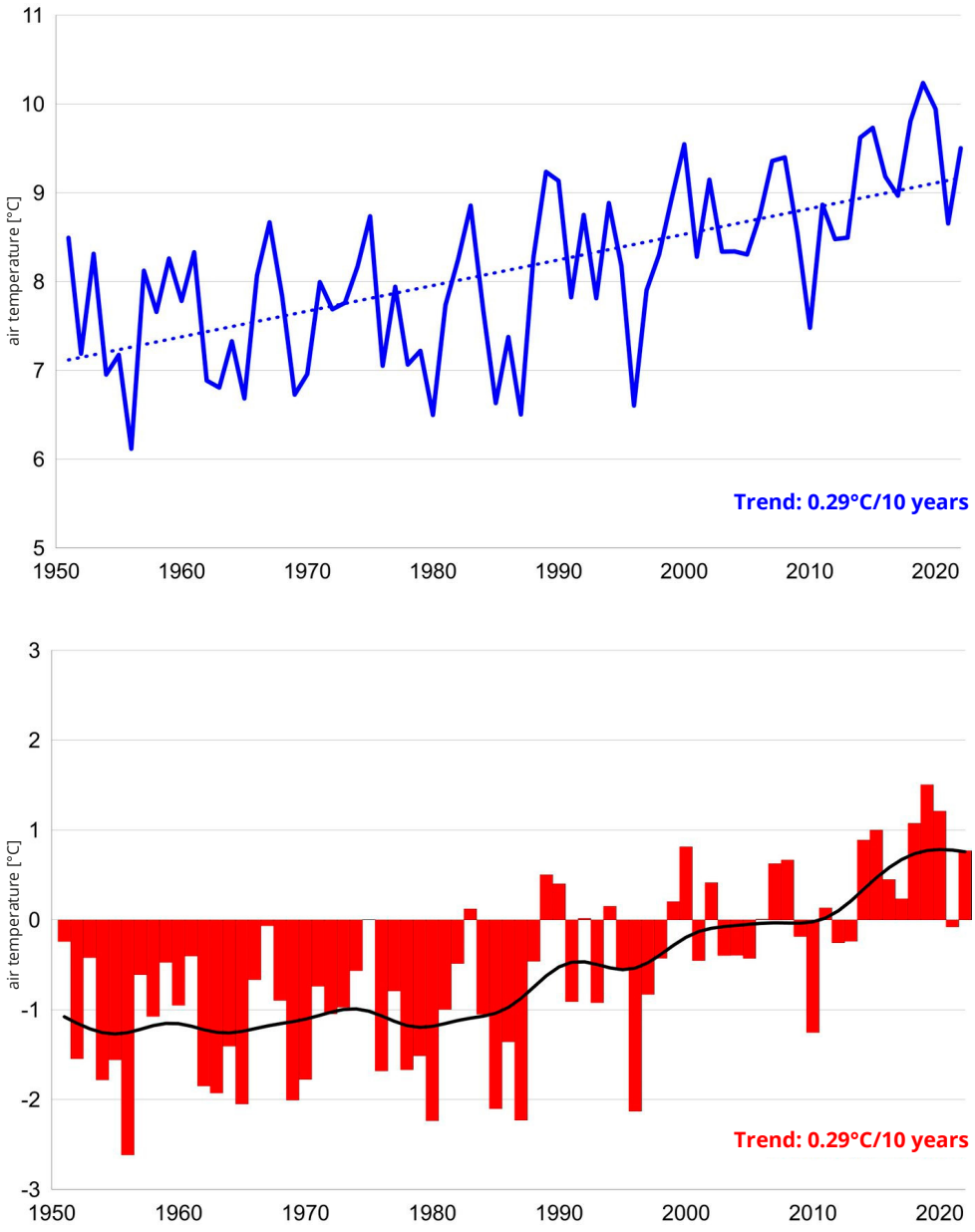
In the last 22 years (since 2001), only in 2010, the annual mean air temperature was below the long-term average for the period 1981-2010. The anomaly reached –0.8°C resulting from an extremely cold beginning of the year (January-February) and cold December. However, if we look at this issue from the perspective of the new climatological standards normal for the period 1991-2020, there are more years in which the annual mean temperature was below the normal, precisely eight. This is because the last 30-year period (1991-2020), was the warmest since the middle of the 20th century. Over the last 22-year period, 2022 was the 6th warmest.



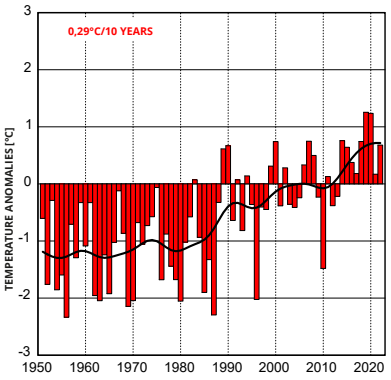
In 2022, the daily mean air temperature values (area average for Poland) were usually between 5% and 95% of quantiles' values of average temperature (determined for measurements in 1991-2020). The episodes of heat waves, i.e., those in which the daily mean air temperature exceeded its 95% quantile value, were more frequent and much longer-lasting in the past year than the episodes of cold waves (daily mean air temperature below its 5% quantile value).

It is worth mentioning the very warm beginning and the extremely warm end of 2022 when the air temperature values approached 20°C. Prolonged heat waves in June and August are also noteworthy. The maximum temperature often exceeded 30°C then. Another interesting case is December 2022, which was only 0.2°C warmer than the long-term normal as a month. However, when looking at the temperature variability, there is a clear extreme variability with the lowest annual area average air temperature reaching –7.5°C (approaching the 5% quantile) and, on the other hand with values close to +10°C recorded at the end of the year, which were significantly above the 95% quantile.

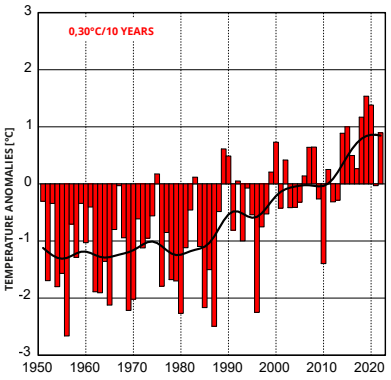
In order to illustrate the scale of climate warming, the discussed diurnal variability is presented against the variability of the long-term mean daily temperature values for the period 1951-1980 and 1991-2020. There is a constant difference between the mean daily values in the multiannual period 1991-2020 and 1951-1980. This difference is positive for each day. Characteristically, these differences are higher in January-August (between 1.1°C and 2.0°C) and lower in September-December (between 0.6°C and 0.9°C).



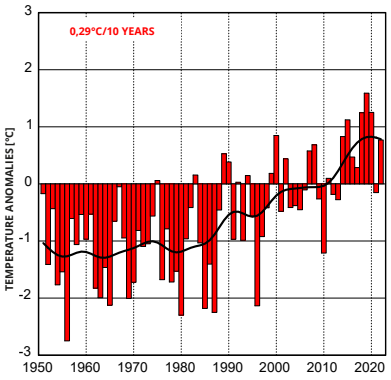
The increase in the average annual temperature during the period 1951-2020 has a positive, statistically significant (at level 1 – α = 0.95) trend of 0.29°C/10 years. It corresponds to a 2.0°C temperature increase in the given period since 1951. To illustrate the variability of temperatures, series are often presented as anomalies from the climatological standard normal, i.e., the average for the last normal period, instead of a series of absolute values. Such a series presents positive values when a given year was warmer than normal, and negative when it was colder. Using a series of anomalies (deviation) in the presentation allows for quick visual identification of colder and warmer periods. In addition to a series of anomalies, the graph presents a curve showing the course of the series of anomalies after smoothing it with a Gaussian filter with a 10-year window, i.e., after filtering out short-term temperature fluctuation.



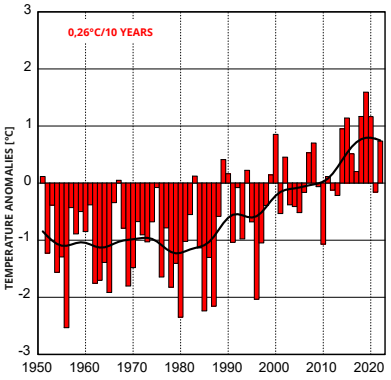
REGION 1 – COASTS



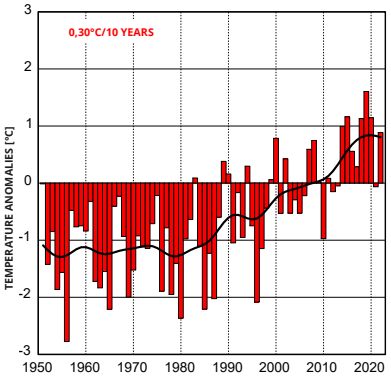
REGION 2 – LAKE DISTRICTS



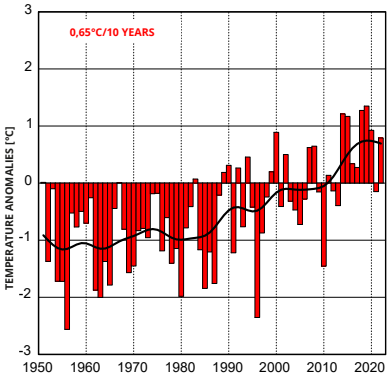
REGION 3 – LOWLANDS



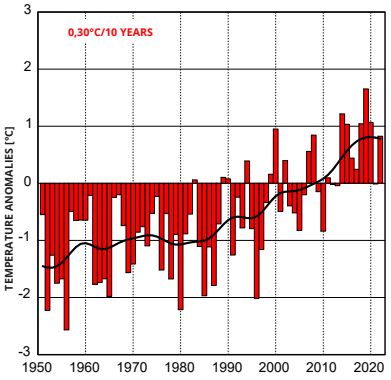
REGION 4 – UPLANDS



REGION 5 – PODKARPACIE



REGION 6 – SUDETES

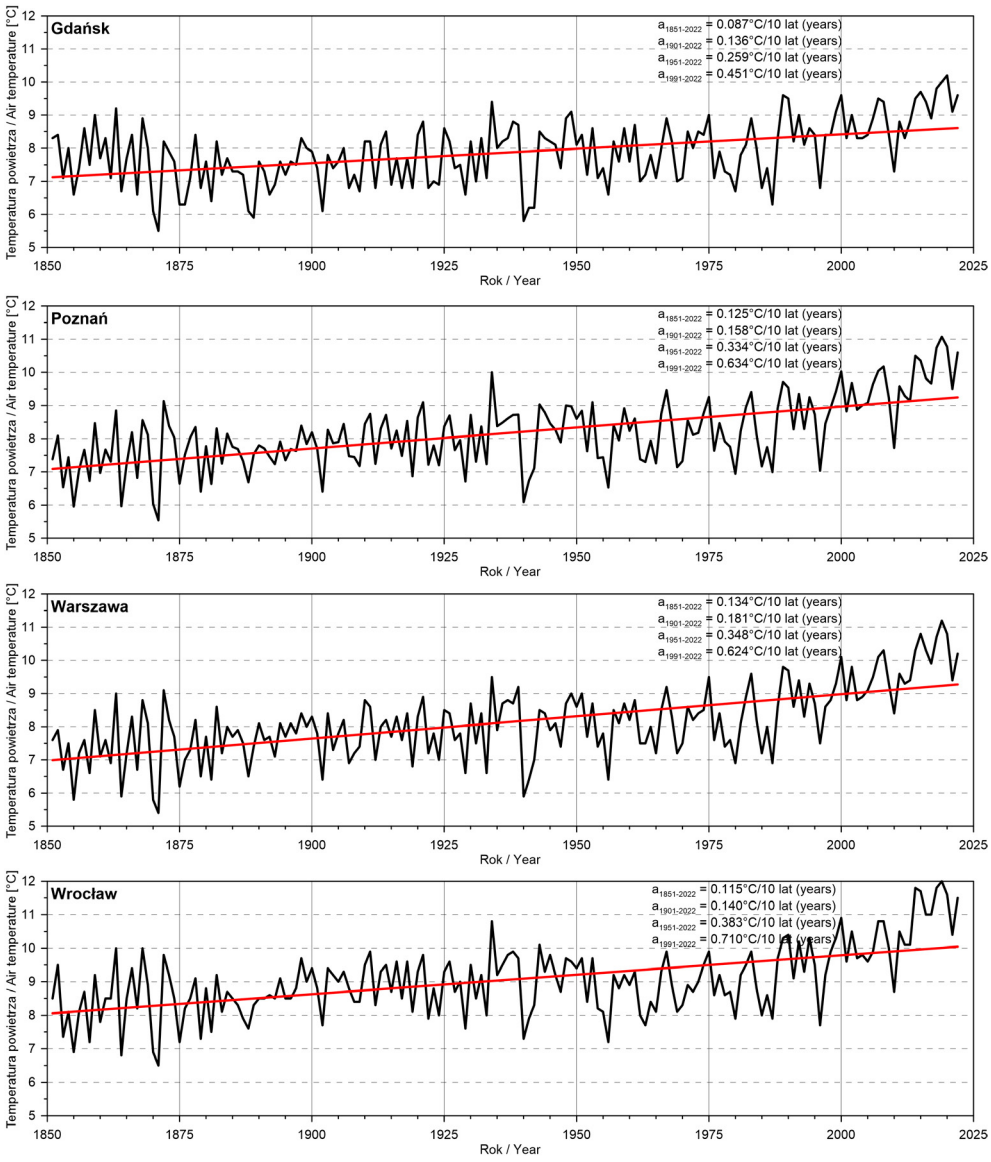


REGION 7 – CARPATHIANS

The series of anomalies show the temperature variability in particular physio-geographical regions in the period 1951-2022. Differences in variability between regions can be compared, and regions where temperature changes are the strongest and those where they are the weakest can be identified. The value of the trend coefficient varies in the particular climatic regions of the country. The strongest temperature increase occurs in lake districts and Podkarpacie (2.16°C), the weakest is in the Sudetes and the uplands, where air temperature increased by 1.87°C over 72 years.

AIR TEMPERATURE

Thermal conditions variability, 1851-2022

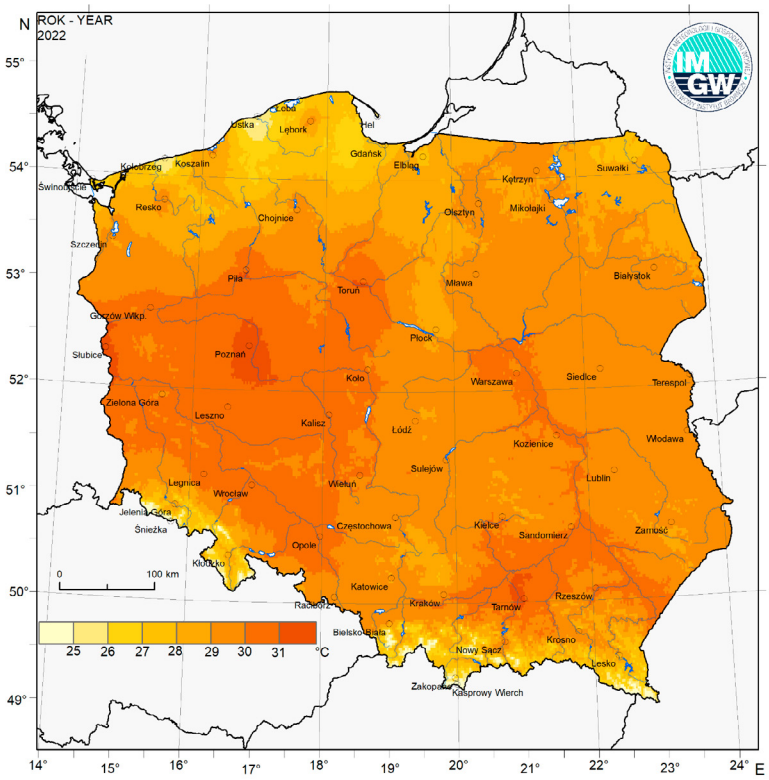


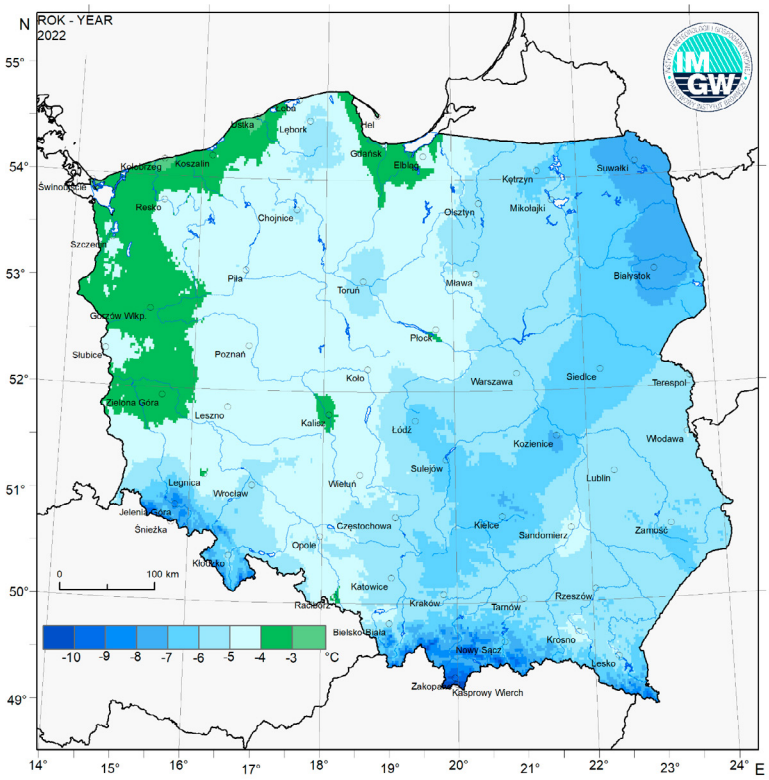
Regular instrumental temperature measurements began in Poland in the 18th century, including Warsaw (in 1779), Wrocław (in 1791), and Krakow (in 1792). However, at the earliest, they commenced in Gdansk in 1739. Regular meteorological measurements started in other Polish cities in the first half of the 19th century. The Intergovernmental Panel on Climate Change (IPCC) has systematically published temperature variability analyses for the global and regional series since 1851. For this reason, we also present the temperature variability in Gdańsk, Poznań, Warsaw, and Wrocław in the period 1851-2022. Each series documents an increase in air temperature, although the rate of change varies. The weakest temperature rise (1.49°C) occurs in Gdańsk and the strongest (2.30°C) in Warsaw. The presented series clearly illustrate that the rate of warming is steadily increasing. The trend coefficients calculated for the period 1901-2022 are higher than those for 1851-2022, and these calculated for the period since 1951 are even higher. The values of the trend coefficients increased sharply after 1980. In each analyzed city, the rate of increase in air temperature was several times higher than for the entire analyzed period. The highest rate of temperature increase (0.71°C/decade) was recorded in Wrocław, the lowest was in Gdańsk (0.45°C/decade).

AIR TEMPERATURE

Extreme temperatures – quantiles

Spatial variability of the 95% percentile of the maximum air temperature identifies the areas where the occurrence probability of a higher temperature than the map shows is lower or equal to 5%. A clear general gradient is directed from western Poland (the warmest areas) to the north and east (the coldest areas). Mountainous areas (Sudetes and Carpathians) are also characterized by lower values. The influence of the southern Baltic's cold water masses, responsible for the "flattening" of the highest temperature values in late spring and summer, is clearly visible. In turn, the warming influence of the Baltic Sea is reflected in the spatial distribution of the 5% percentile of the minimum temperature. Its values are clearly higher on the coast and the coastlands belt, the central and western parts of Pomerania, and on the western edge of the country. The lowest values of this characteristic occur (except for mountain areas) in north-eastern Poland and the highest along the coast and on the country's western edge.



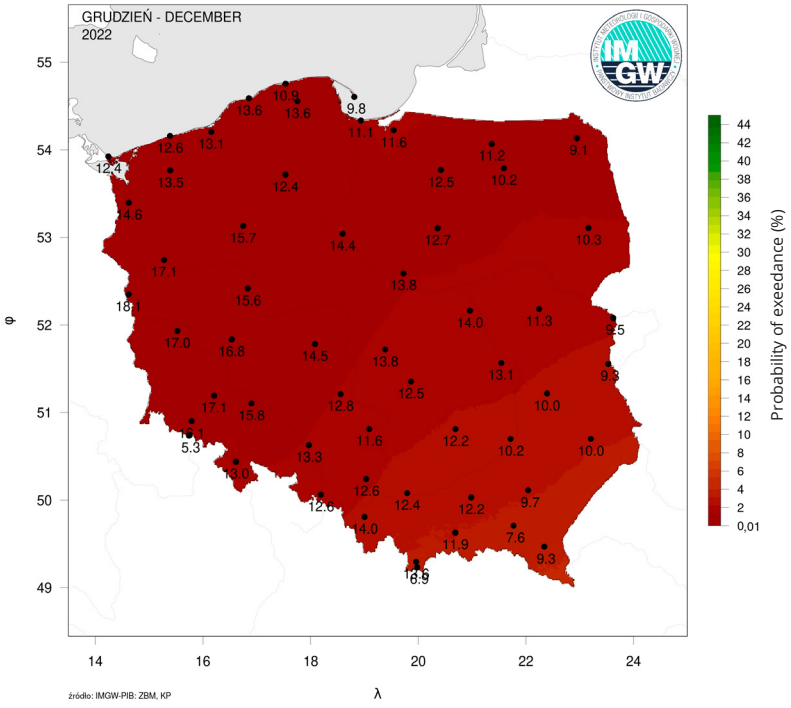


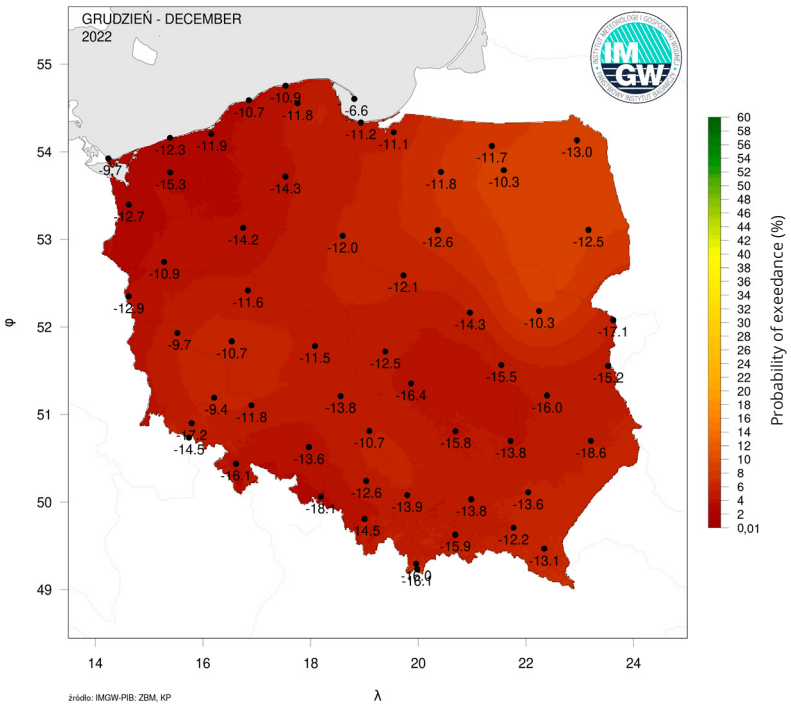
AIR TEMPERATURE

Extreme temperature in December 2022 – thermal hazards risk

Last December was a month with high temperature amplitudes, even though the monthly average was only 0.2°C higher than the long-term average. The significant temperature variability (amplitudes exceeding 30°C) clearly indicates its exceptionality caused by the variability of the atmospheric circulation conditions.

Such significant temperature variability cause numerous hazards – both for the natural environment, infrastructure, especially roads, municipal and energy infrastructure, agriculture, and human health and life.
The maximum temperature values recorded in December at most stations in Poland corresponded to values with the probability of exceeding 5% or less.
The probability of recording values lower than the minimum recorded was also small.

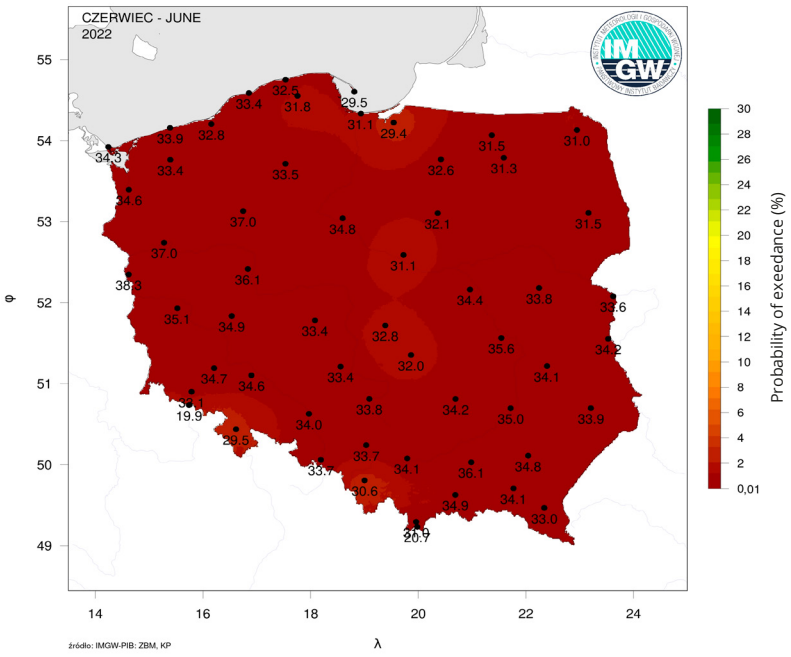


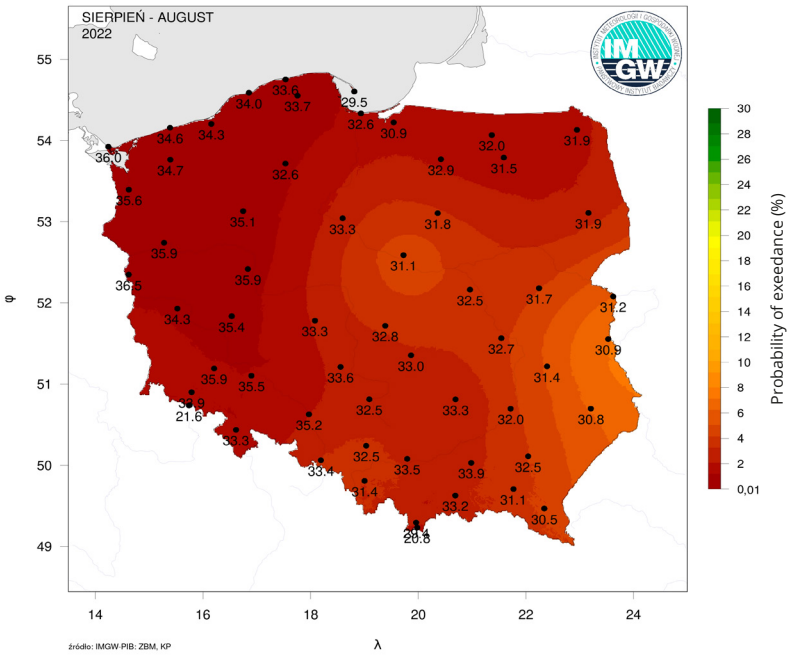


AIR TEMPERATURE

Extreme temperature in June and August 2022 – thermal hazards risk

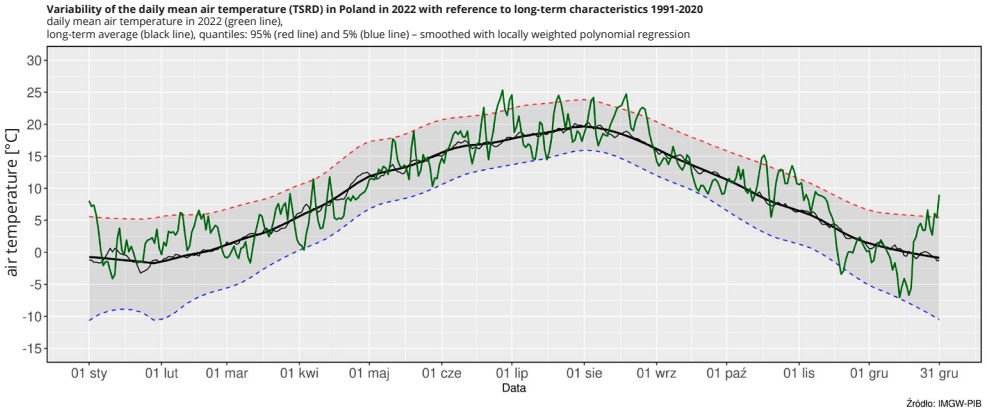
Last August was the hottest month, with an average air temperature of 20.5°C and an anomaly to the normal of 2.1°C. Similarly as in winter, also in summer, strong temperature variability cause numerous hazards to the natural environment, human health, agriculture, the availability of surface water resources, infrastructure, etc. The maximum temperature values recorded in August at most stations corresponded to values which the probability of exceeding is lower than 4%, with clear spatial variability with the lowest probability below 2% in the western and north-western parts of the country and slightly higher values (approx. 10%) in the eastern borders. June 2022 was the month in which the maximum values of air temperature with the probability of exceeding less than 1% were recorded almost throughout the country.





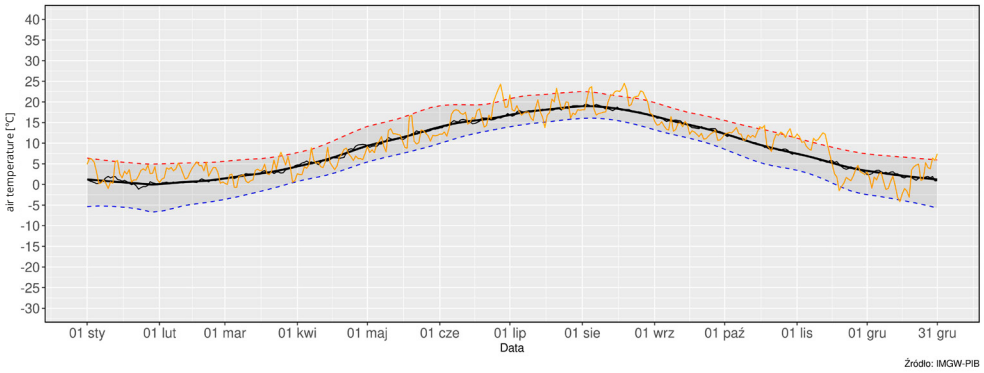
AIR TEMPERATURE
Interannual variability

DAILY VARIABILITY OF THE AREA AVERAGE TEMPERATURE



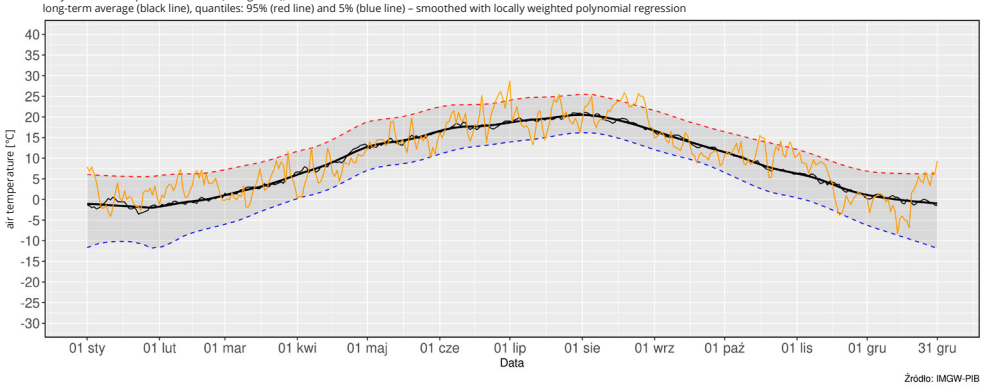
In 2022, the daily mean air temperature values (area average for Poland) were usually between the 5% and 95% quantiles values of the mean temperature (determined based on measurements in 1991-2020). Heat waves episodes, i.e. those in which the daily mean air temperature exceeded the 95% quantile of this element, were more frequent and long-lasting in the past year than the cold waves episodes (daily mean air temperature below the 5% quantile value of this element). The heat waves in June and August are clearly visible. The heat wave experienced in the last week of December 2022 is also noteworthy.

HEL – variability of the daily mean air temperature (TSRD) in 2022 with reference to long-term characteristics 1991-2020
daily mean air temperature in 2022 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression



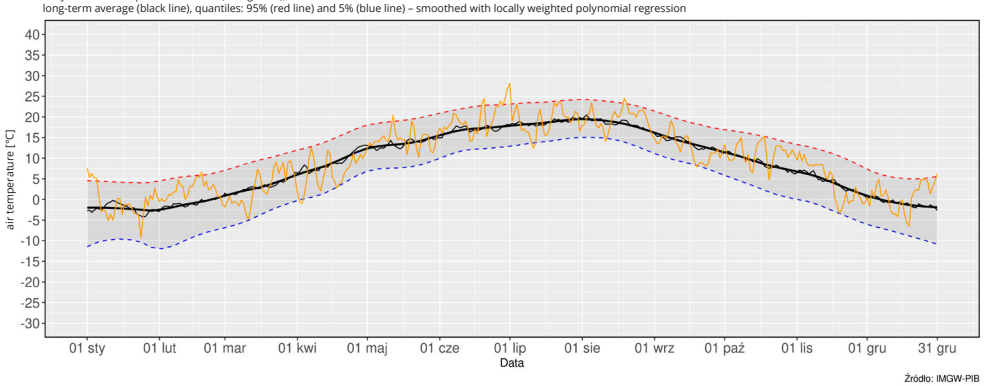
Źródło: IMGW-PIB

WARSAW-OKĘCIE – variability of the daily mean air temperature (TSRD) in 2022 with reference to long-term characteristics 1991-2020
daily mean air temperature in 2022 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression



Źródło: IMGW-PIB

KROSNO – variability of the daily mean air temperature (TSRD) in 2022 with reference to long-term characteristics 1991-2020
daily mean air temperature in 2022 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression

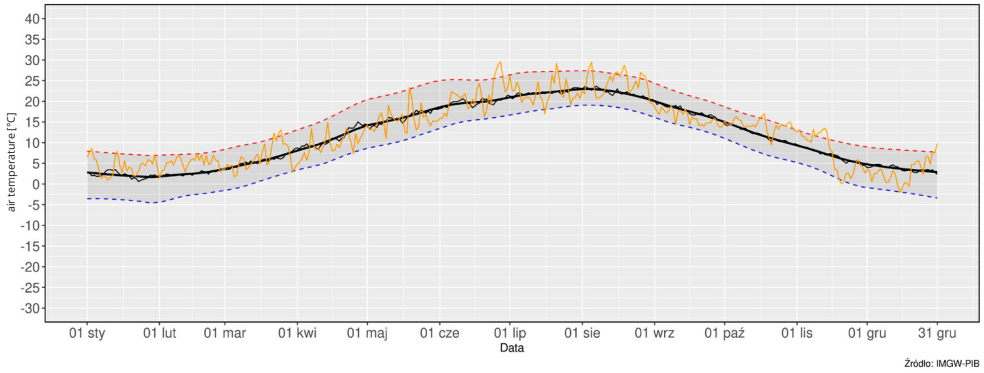


Źródło: IMGW-PIB

The inter-annual variability of daily mean air temperature at selected stations shows a picture very similar to that presented in the graph showing the variability of the daily area averaged temperature. However, there are differences in the occurrence of the so-called heat waves and cold waves, i.e., periods when temperature values exceeded the values determined by the 95% and 5% quantiles of this element. Cold episodes in April and December are clearly visible at all stations, as are heat waves in July and August.

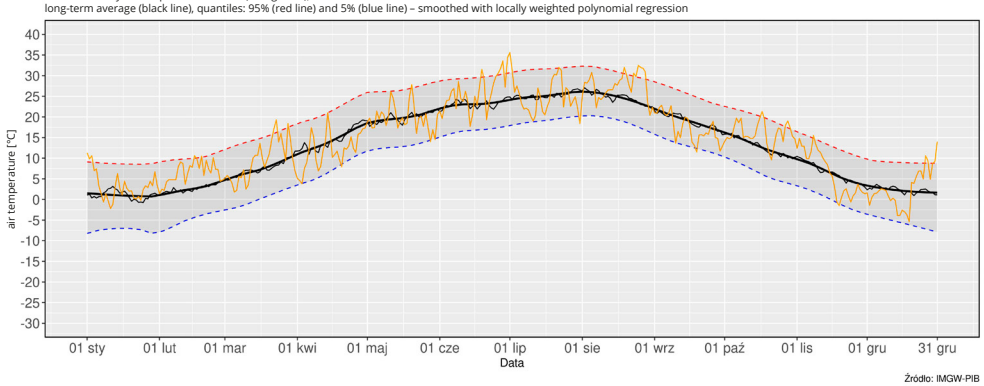
ANNUAL VARIABILITY OF MAXIMUM DAILY TEMPERATURE

HEL – variability of the maximum daily air temperature (TMAX) in 2022 with reference to long-term characteristics 1991-2020;
maximum daily air temperature in 2022 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression



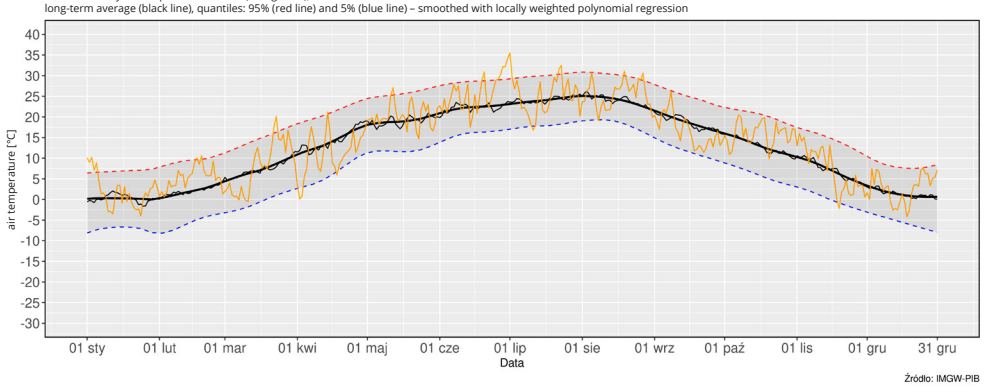
Źródło: IMGW-PIB

WARSAW-OKĘCIE – variability of the maximum daily air temperature (TMAX) in 2022 with reference to long-term characteristics 1991-2020
maximum daily air temperature in 2022 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression



Źródło: IMGW-PIB

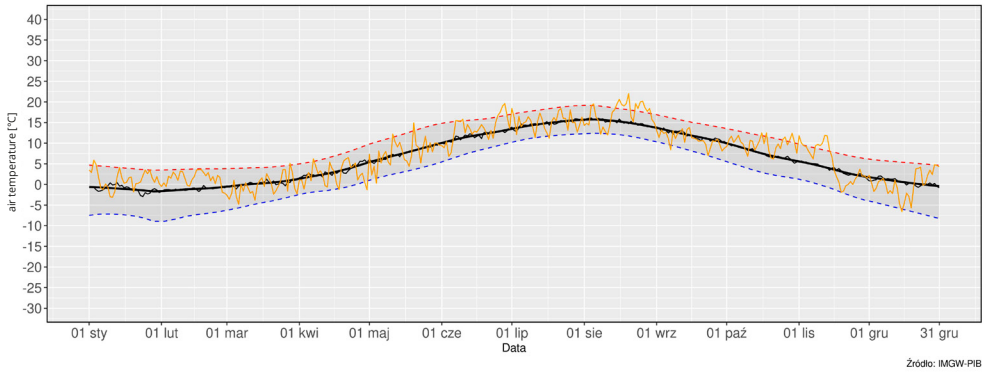
KROSNO – variability of the maximum daily air temperature (TMAX) in 2022 with reference to long-term characteristics 1991-2020;
maximum daily air temperature in 2022 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression



Źródło: IMGW-PIB

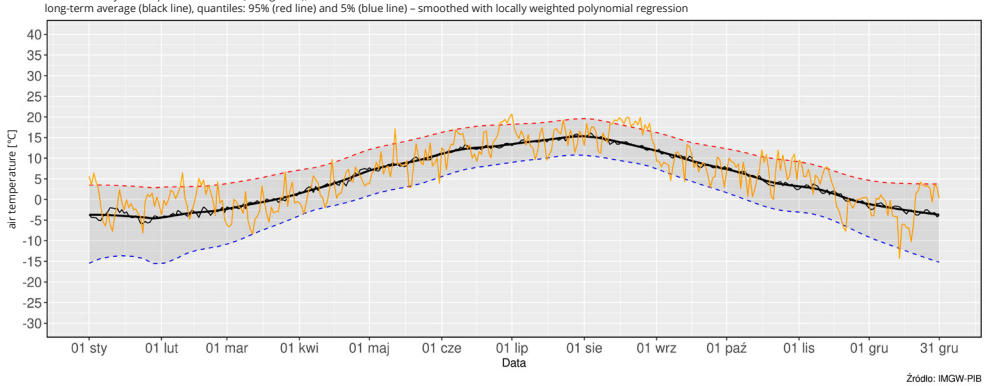
The interannual variability of the maximum daily temperature is reflected in the variability of the daily mean temperature. It is worth noting that the cold episodes occurring in April and from mid-November were so strong that they were also confirmed by the variability of the maximum temperature at stations located outside the Baltic coast.

HEL – variability of the minimum daily air temperature (TMIN) in 2022 with reference to the long-term characteristics 1991-2020
minimum daily air temperature in 2022 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression



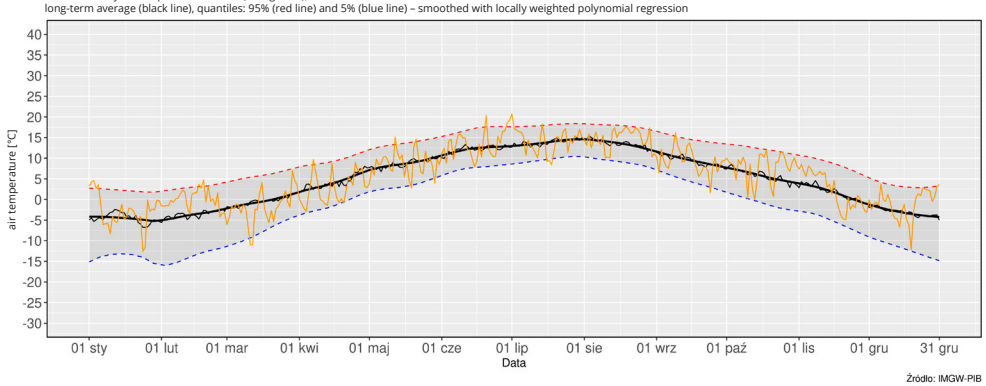
Źródło: IMGW-PIB

WARSAW-OKĘCIE – variability of the minimum daily air temperature (TMIN) in 2022 with reference to long-term characteristics 1991-2020
minimum daily air temperature in 2022 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression



Źródło: IMGW-PIB

KROSNO – variability of the minimum daily air temperature (TMIN) in 2022 with reference to long-term characteristics 1991-2020
minimum daily air temperature in 2022 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression

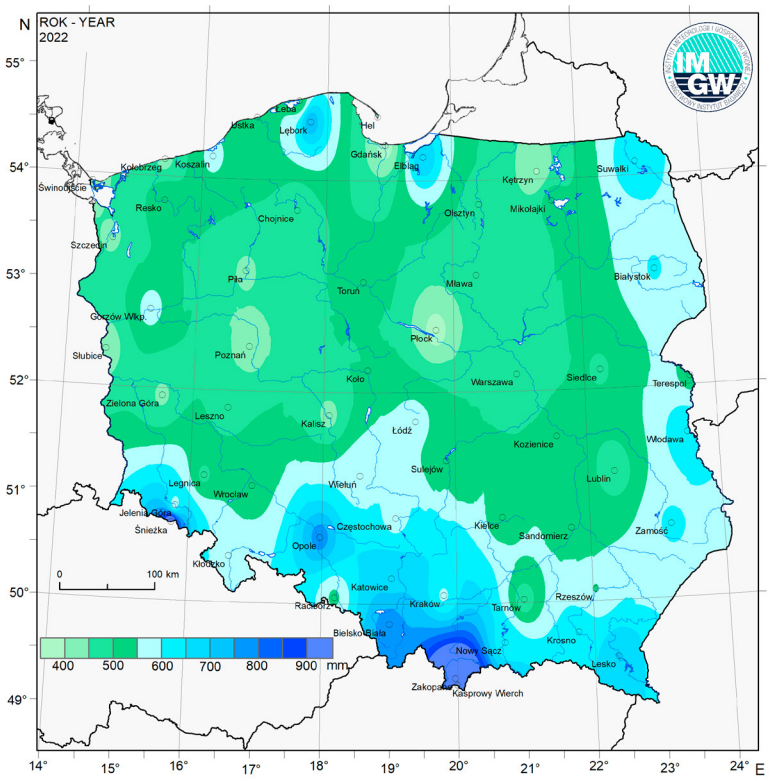


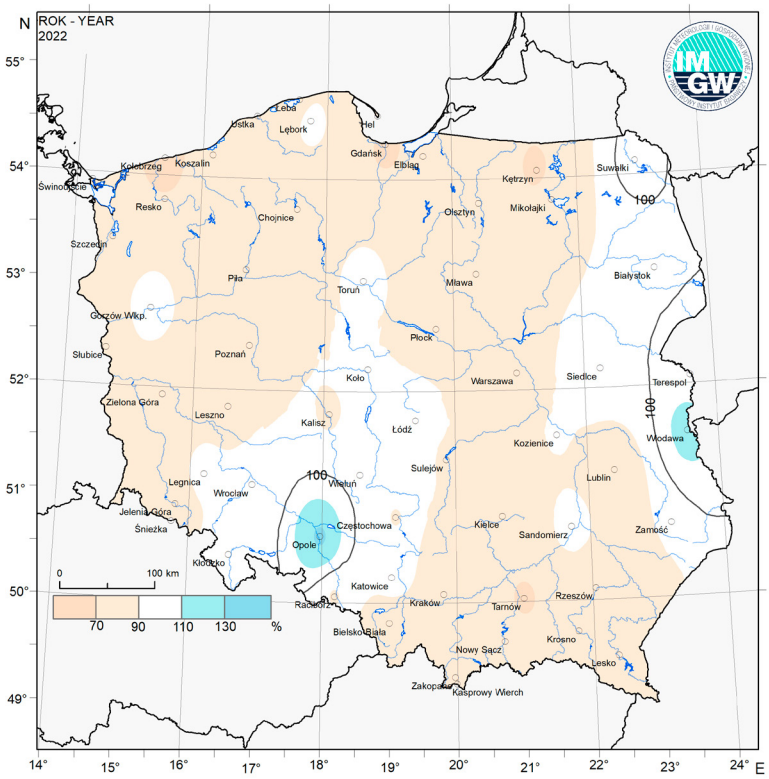
Źródło: IMGW-PIB

The interannual changes occurred similarly in the case of the minimum daily temperature values.

PRECIPITATION

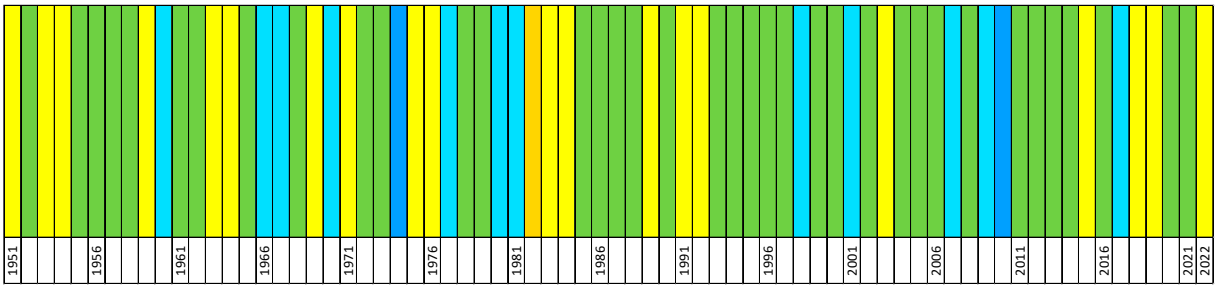
In 2022, the area-averaged annual total precipitation in Poland was 534.4 mm, only 87% of the normal determined based on measurements from 1991 to 2020. According to the rank classification of area average total precipitation, covering the period since 1951, last year ranks only 59th. The highest amount of rainfall was in 2010 (with an area average total precipitation of 804.1 mm, which was 132% of the normal). The least amount of rainfall was in 1982 (with only 422.6 mm, 69% of the normal). Precipitation totals in 2022 ranged from slightly less than 400 mm to over 900 mm, and the highest was recorded in the Tatra Mountains. Precipitation ranged from 62% (Kołobrzeg) to 133% (Opole) of the long-term normal (1991-2020).



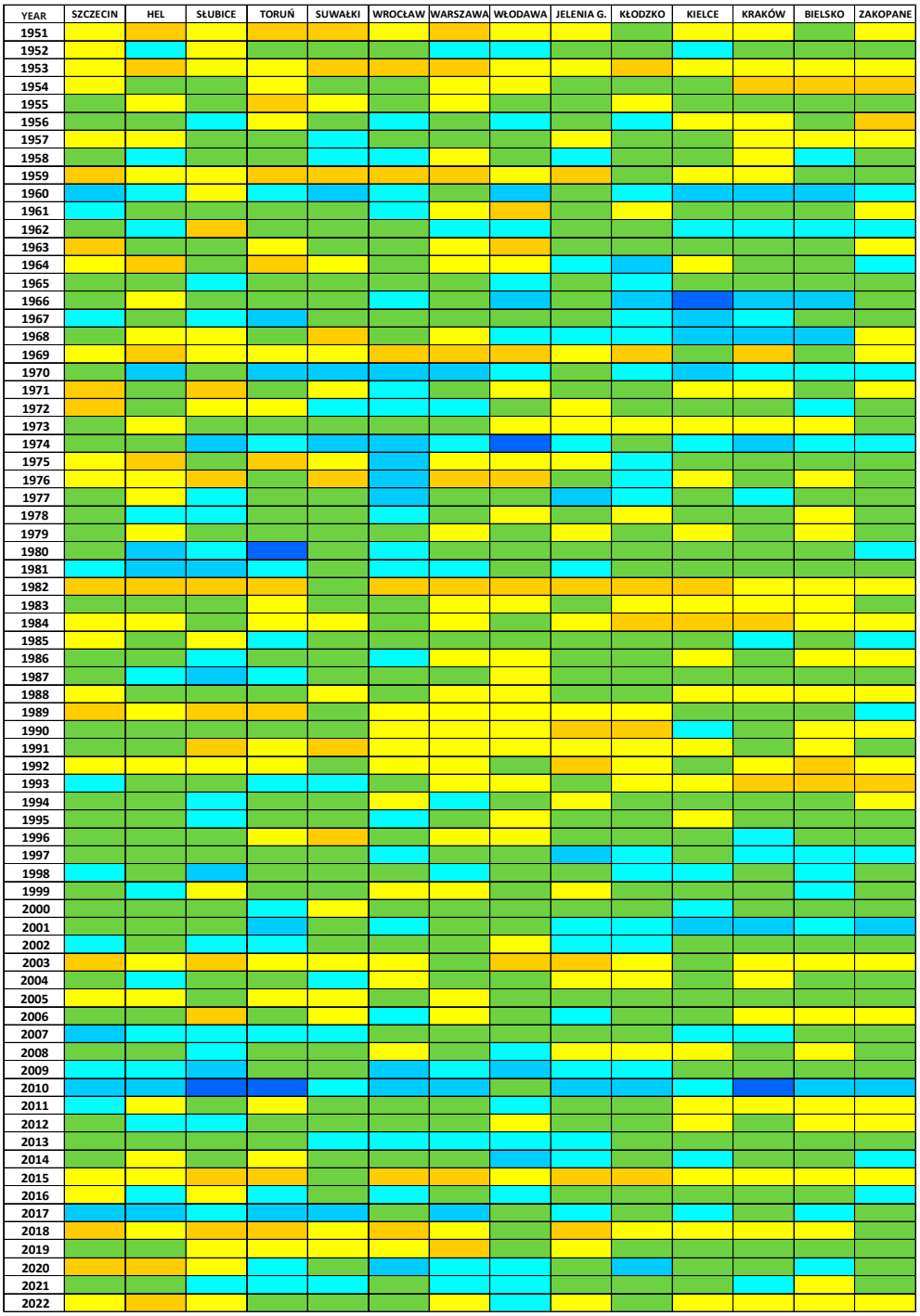


PRECIPITATION
Pluvial conditions classification

Descriptive classifications are often used to describe the pluvial conditions, specifying to what extent the pluvial conditions of a given month, climatic season, or year differed from typical conditions. One of Poland's most popular classifications of pluvial conditions is the Kaczorowska classification, which is based on the percentage deviation from the precipitation normal for a given location. Individual classes are given descriptive names, as presented below. According to Kaczorowska's classification of pluvial conditions, the past year should be classified as a dry year.

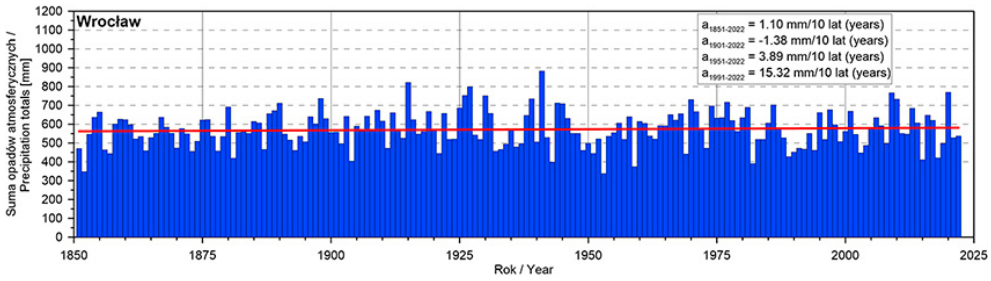


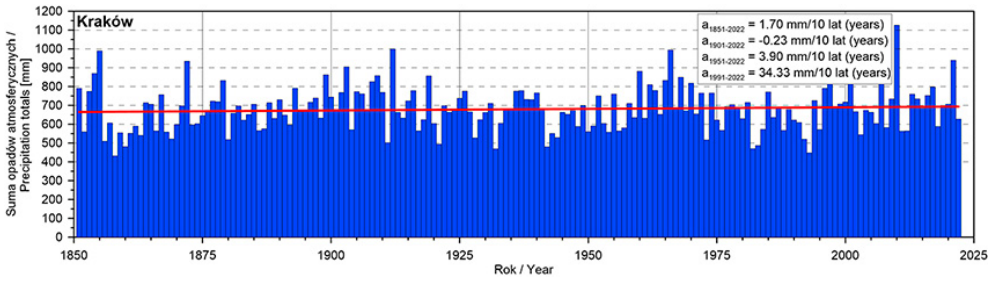
SCALE OF PLUVIAL CLASSIFICATION		%
1	extremely dry	< 50
2	very dry	50-74
3	dry	75-89
4	normal	90-110
5	humid	111-125
6	very humid	126-150
7	extremely humid	> 150

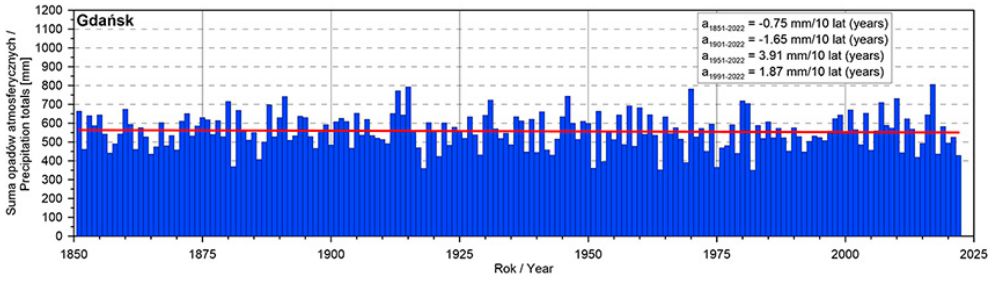


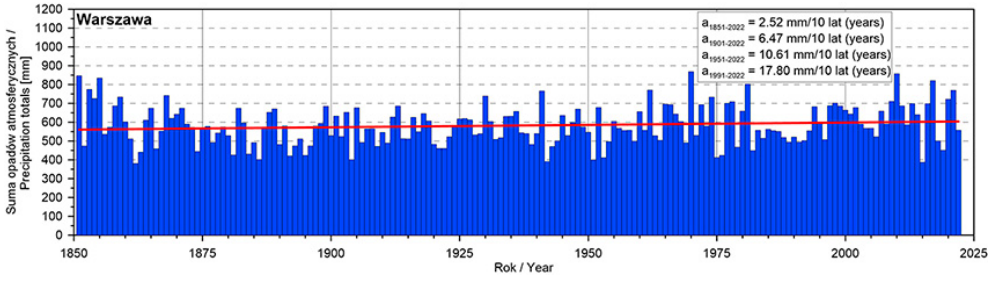
Expressing of the amount of precipitation in a given year as a percentage relate to the amount of rainfall in the normal period permits the introduction of a classification that allows a descriptive presentation of the pluvial conditions prevailing at a given station or area of interest. Contrary to thermal conditions, precipitation characteristics are characterized by high spatial variability. With reference to the long-term period 1951-2020, we can say that spatial variability of precipitation was significant in 2022. At the same time, we can see that the past year was another period in which many stations recorded below normal precipitation.

PRECIPITATION
Long-term variability









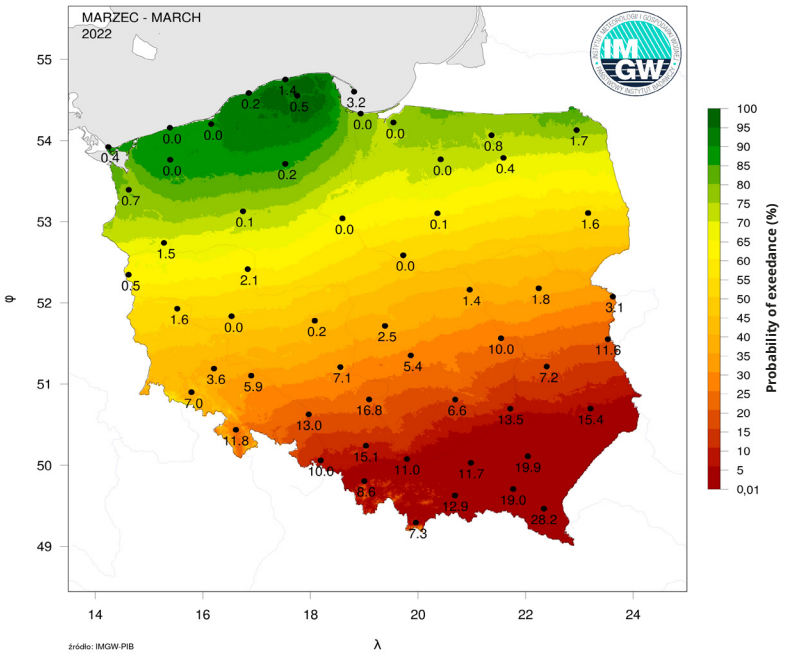
The analysis of the long-term variability of pluvial conditions in Poland shows slight differences. Over the period of 172 years, the most significant changes were recorded in Warsaw (an increase of 43 mm), much smaller in Cracow (29.2 mm) and Wrocław (18.9 mm). In the north of the country, a slight decrease in total precipitation over the whole period is observed in Gdansk (–12.9 mm). More significant changes have been visible over the last 72 years (1951-2022). Increases in annual precipitation totals are observed for all analyzed stations. The highest rate is in Warsaw (total increase of 76.4 mm). At the other stations, the rate of change was similar, amounting to about 3.9 mm/decade, resulting in an increase of 28.1 mm over 72 years. The last 32 years (1991-2022) have been marked by significant variation in the rate of change: from 1.87 mm/10 years in Gdańsk, 15.32 mm/10 years in Wrocław, 17.80 mm/10 years in Warsaw to 34.33 mm/10 years in Cracow. We can see that the rate of change is an order of magnitude higher in southern Poland than in the north.

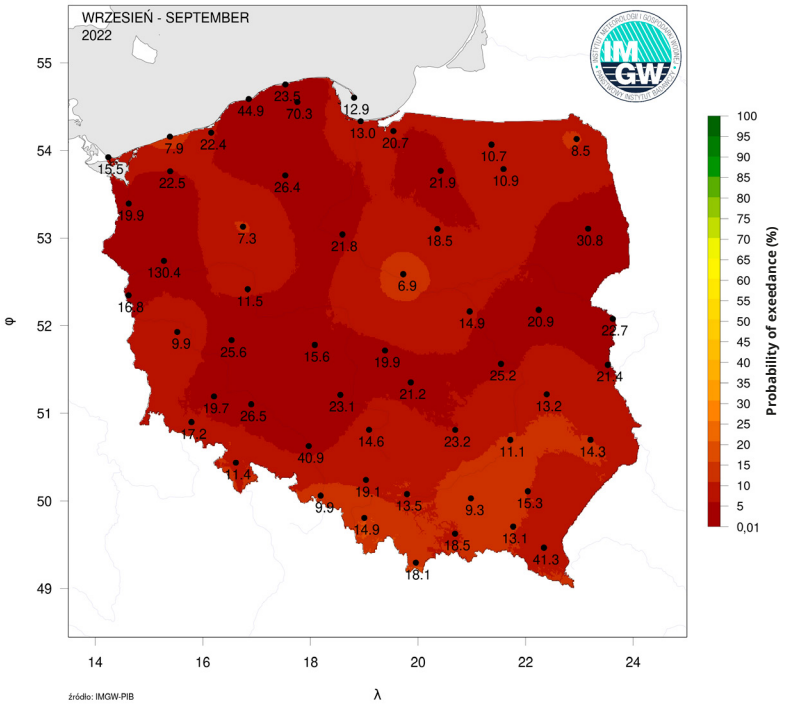
PRECIPITATION

Probabilities of exceedance of the maximum daily precipitation totals in March and September 2022

The presented maps of the exceedance probability of the maximum daily precipitation in March (the second driest March since 1951) and September 2022 show both the diversity of pluvial conditions in these two months and illustrate the occurrence of high precipitation in several large cities in Poland (Gorzów Wielkopolski, 8.09.2022, 130.4 mm), which resulted in the so-called urban flash floods. The spatial variability of the maximum recorded precipitation totals is clearly visible in March. In the northwest, it was a month with an extremely high probability of exceeding, while in the southeast, extremely high values were recorded (very low probability of exceedance).

In September, extremely high maximum daily precipitation totals were recorded across the entire country, with the probability of exceedance locally falling below 5%.

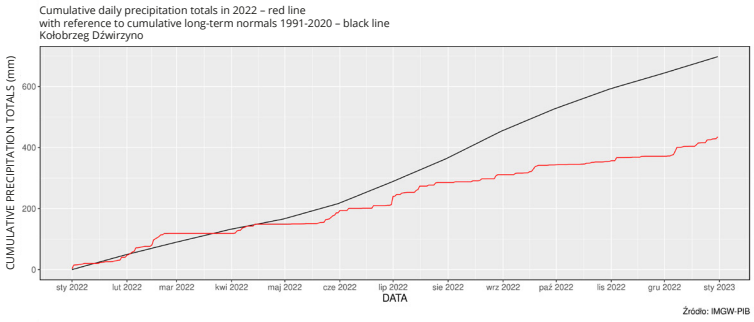


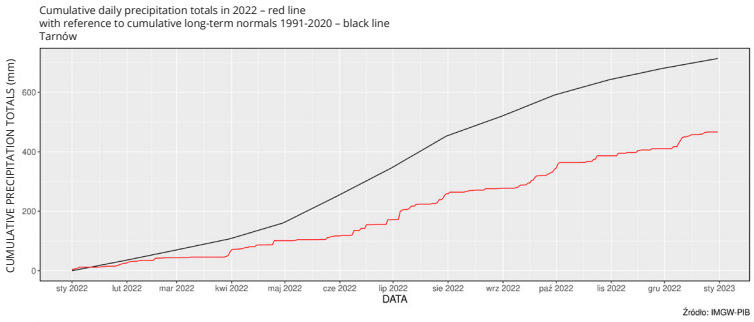


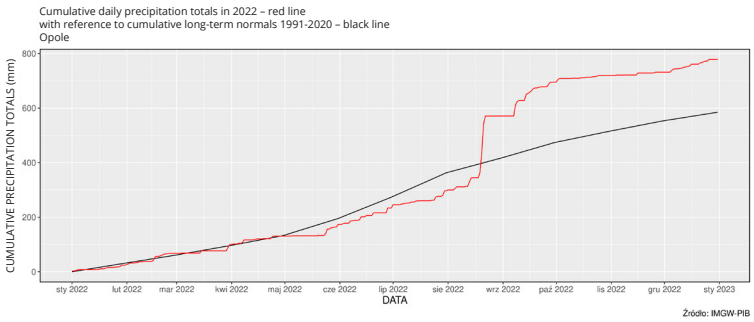
PRECIPITATION

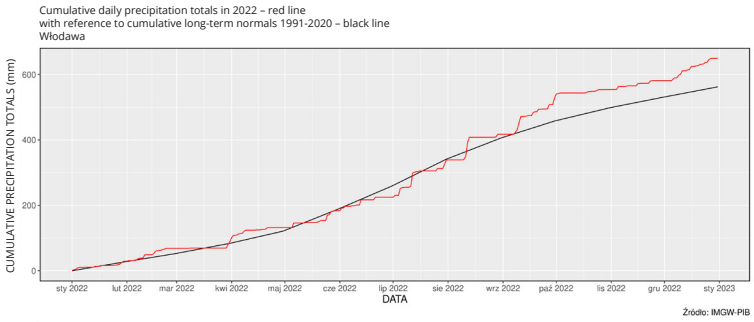
Cumulative precipitation totals and cumulative number of days with precipitation

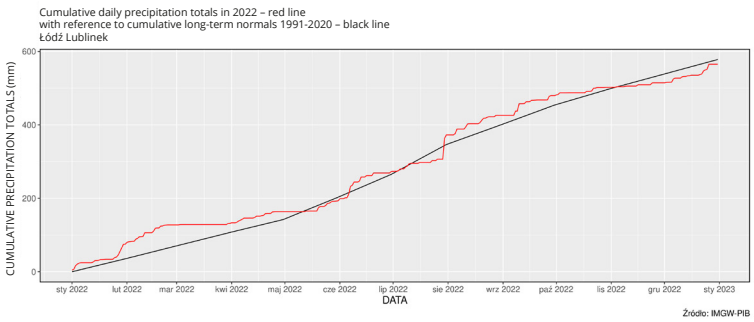
The graphs of cumulative precipitation totals in 2022 at selected stations enable us to visualize how the precipitation totals evolved over time during the past year with reference to the long-term normal. The periods of excess rainfall and their deficit compared to the normal are clearly visible. It is simple to identify non-precipitation periods and efficient precipitation events with large sums. The presented material also illustrates a strong variability of precipitation at individual stations with reference to the normals characterizing precipitation at a given station – starting from stations characterized by higher than normal annual precipitation totals (Opole, Włodawa), as well as those where the annual precipitation total in 2022 was significantly below the normal (Kołobrzeg, Tarnów). In the case of Opole, it is worth emphasizing that the positive anomaly of the annual precipitation total results from heavy rainfall recorded in August 2022.





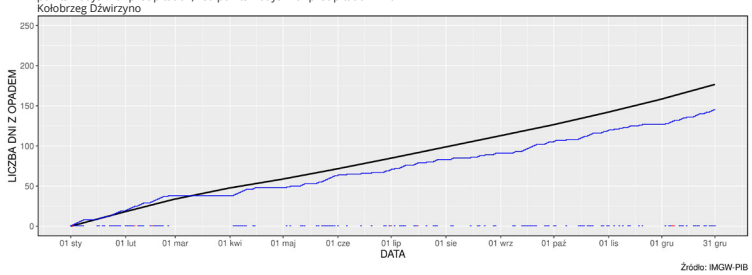






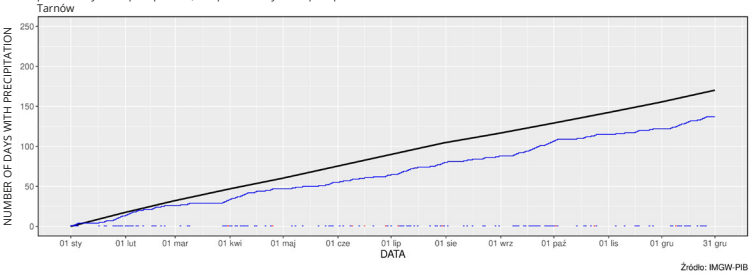
The interpretation of the cumulative number of days with precipitation with reference to the normals informs us how often precipitation occurred in 2022 and whether there were more or less days with precipitation. If the annual precipitation was much higher/lower than the normal, and the number of days with rainfall was within the normal, it can be clearly stated that the precipitation was more or less efficient than usual at a particular station.

Cumulative number of days with precipitation (daily precipitation total > = 0.1 mm) in 2022 – blue line
with reference to the cumulative mean monthly number of days with precipitation in the long-term period 1991-2020 – bold black line, blue points – days with precipitation, red points – days with precipitation > 10 mm
Kołobrzeg Dźwirzyno



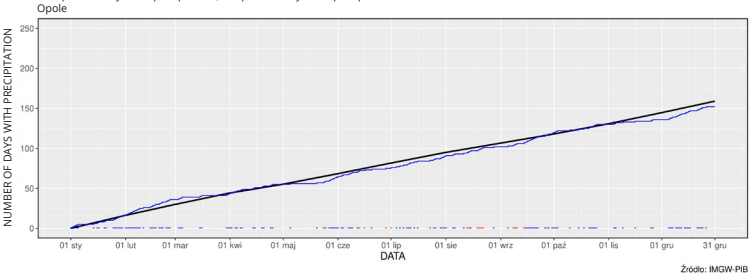
Źródło: IMGW-PIB

Cumulative number of days with precipitation (daily precipitation total > = 0.1 mm) in 2022 – blue line
with reference to the cumulative mean monthly number of days with precipitation in the long-term period 1991-2020 – bold black line, blue points – days with precipitation, red points – days with precipitation > 10 mm
Tarnów



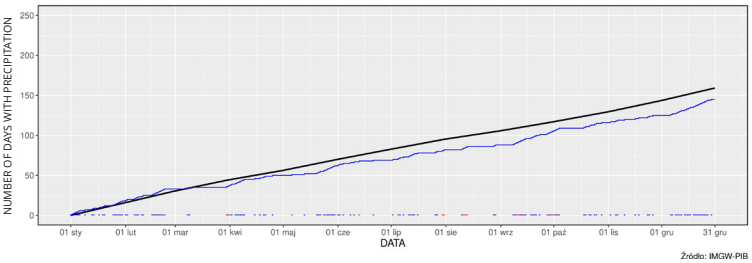
Źródło: IMGW-PIB

Cumulative number of days with precipitation (daily precipitation total > = 0.1 mm) in 2022 – blue line
with reference to the cumulative mean monthly number of days with precipitation in the long-term period 1991-2020 – bold black line
blue points – days with precipitation, red points – days with precipitation > 10 mm
Opole



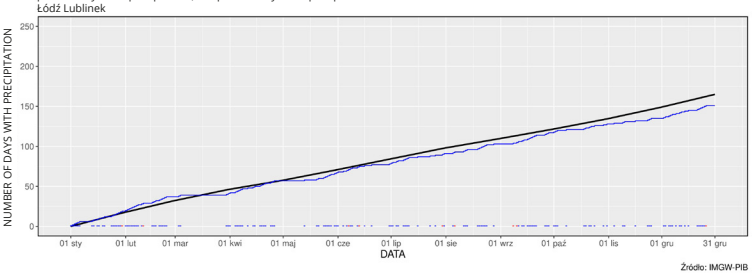
Źródło: IMGW-PIB

Cumulative number of days with precipitation (daily precipitation total > = 0.1 mm) in 2022 – blue line
with reference to the cumulative mean monthly number of days with precipitation in the long-term period 1991-2020 – bold black line, blue points – days with precipitation, red points – days with precipitation > 10 mm
Włodawa



Źródło: IMGW-PIB

Cumulative number of days with precipitation (daily precipitation total > = 0.1 mm) in 2022 – blue line
with reference to the cumulative mean monthly number of days with precipitation in the long-term period 1991-2020 – bold black line, blue points – days with precipitation, red points – days with precipitation > 10 mm
Łódź Lublinek



Źródło: IMGW-PIB

PRECIPITATION

Thunderstorms and distant thunderstorms at selected stations*

2022	June			July			August			YEAR
Station	thnder-storm	distant thunder-storm	Total	thunder-storm	distant thunder-storm	Total	thunder-storm	distant thunder-storm	Total	Total
GDAŃSK-ŚWIBNO	3	9	12	4	5	9	2	7	9	32
KASPROWY WIERCH	4	10	14	3	7	10	2	23	25	56
KATOWICE-MUCHOWIEC	4	13	17	1	8	9	9	22	31	87
KOZIENICE	3	15	18	4	9	13	4	11	15	64
KRAKÓW-BALICE	6	14	20	8	17	25	12	15	27	91
ŁEBA	1	6	7	2	5	7	3	11	14	35
ŁÓDŹ-LUBLINEK	13	12	25	4	6	10	7	8	15	64
POZNAŃ-ŁAWICA	8	14	22	8	4	12	2	3	5	50
RZESZÓW-JASIONKA		4	4	4	14	18	1	10	11	45
ŚNIEŻKA	6	6	12	2	3	5	1	9	10	37
WARSZAWA-OKĘCIE	8	16	24	10	5	15	4	6	10	55
WROCŁAW-STRACHOWICE	9	16	25	5	7	12	6	9	15	65

** only synoptic stations with a full-time 24-hour service are included*

Thunderstorms are a dangerous phenomenon. The thunderstorm season in Poland culminates in the summer, from June to August. In 2022, almost 150 thunderstorms were observed at selected stations in July. Most in Krakow Balice (25), Rzeszów (18) and Warsaw (15).

PRECIPITATION
Hail at selected stations*

2022	The number of days with hail by month 2022												YEAR
Station	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**Total**
GDAŃSK-ŚWIBNO													
KASPROWY WIERCH					1	1	3	2					7
KATOWICE-MUCHOWIEC	1	1		1									3
KOZIENICE	1						1						2
KRAKÓW-BALICE													
ŁEBA													
ŁÓDŹ-LUBLINEK					1								1
POZNAŃ-ŁAWICA													
RZESZÓW-JASIONKA							1						1
ŚNIEŻKA						1							1
WARSZAWA-OKĘCIE													
WROCŁAW-STRACHOWICE							1						1

**only synoptic stations with a full-time 24-hour service are included*

Hail is one of the most dangerous phenomena associated with convection. It poses a threat to infrastructure, agriculture, and human life. Among the selected stations in 2022, this phenomenon occurred most frequently at Kasprowy Wierch (7) and in Katowice (3).

PRECIPITATION
Fog at selected stations*

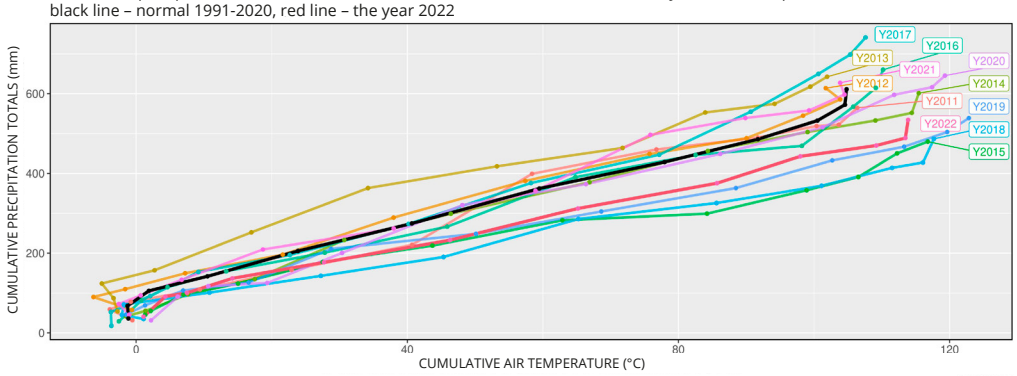
2022	The number of days with fog by month 2022												YEAR
Station	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**Total**
GDAŃSK-ŚWIBNO	0	0	4	3	0	0	0	0	0	6	3	4	20
KASPROWY WIERCH	29	28	16	26	20	18	23	26	30	24	23	26	289
KATOWICE-MUCHOWIEC	4	2	1	6	2	1	0	9	13	19	15	7	79
KOZIENICE	1	0	1	2	0	4	2	4	5	12	12	4	47
KRAKÓW-BALICE	2	2	0	3	3	5	4	8	8	20	17	10	82
ŁEBA	2	0	13	7	11	10	9	12	13	9	5	7	98
ŁÓDŹ-LUBLINEK	3	5	5	10	14	16	13	13	16	24	18	4	141
POZNAŃ-ŁAWICA	4	1	1	3	4	4	0	2	12	18	13	7	69
RZESZÓW-JASIONKA	2	0	0	2	2	2	0	3	4	5	9	1	30
ŚNIEŻKA	30	27	18	24	17	18	20	21	28	26	26	30	285
WARSZAWA-OKĘCIE	2	0	1	3	3	4	0	1	11	18	9	5	57
WROCŁAW-STRACHOWICE	7	2	2	8	7	6	2	8	11	15	14	2	84

** only synoptic stations with a full-time 24-hour service are included*

Fog is a phenomenon associated with the condensation of water vapor in the near-surface air layer, which reduces visibility to less than 1 km. It is essential from the point of view of transport safety. As can be seen, in 2022, the number of days with fog did not exceed 100 at most of the analyzed stations. Apart from high-mountain stations with specific location features, where the number of days with fog in 2022 exceeded 200 (Kasprowy Wierch, Śnieżka), only at the Łódź Lublinek station more than 140 days with fog were recorded. The lowest number was recorded in Gdańsk-Świbno (20) and Rzeszów Jasionka (30).

PRECIPITATION AND TEMPERATURE

Cumulative precipitation totals (mm) in 2022 with reference to a cumulative monthly mean air temperature (˚C) 2011-2023
black line – normal 1991-2020, red line – the year 2022



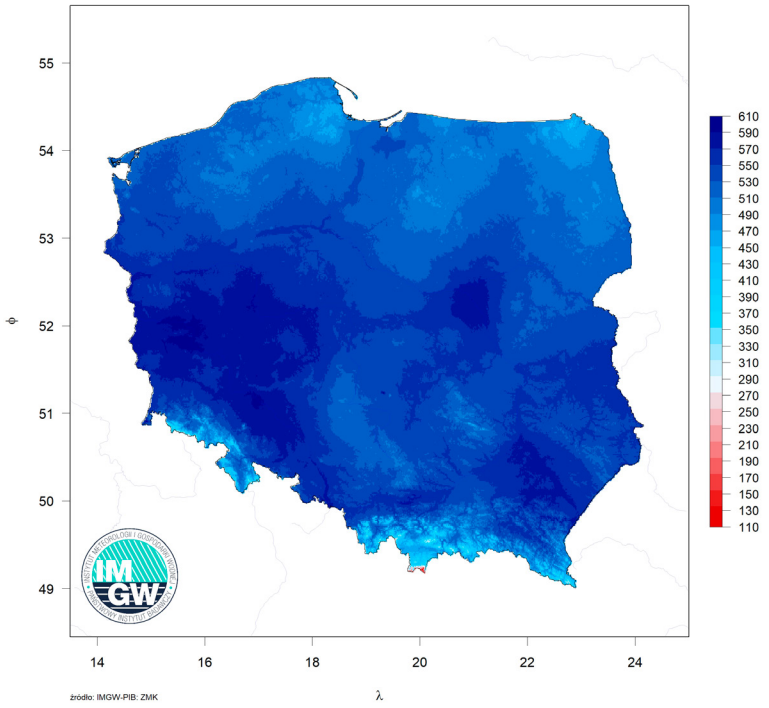
Using cumulative monthly mean air temperature and precipitation totals allows for a synthetic reference to thermal and pluvial conditions. 2022 can be considered one of the drier years since 2011. Lower cumulative precipitation totals were recorded only in 2015 and 2018. 2022 was also one of the warmer years (the cumulative air temperature values can be considered, in a certain simplification, as a cumulative heat storage). It is worth emphasizing that the cumulative precipitation total until December 2022, compared to the long-term average values, was equal to the cumulative total until October. We can venture to state that in 2022, there was a lack of precipitation from two months (XI, XII) for the whole year to be considered average.

CLIMATIC WATER BALANCE
Warm half-year

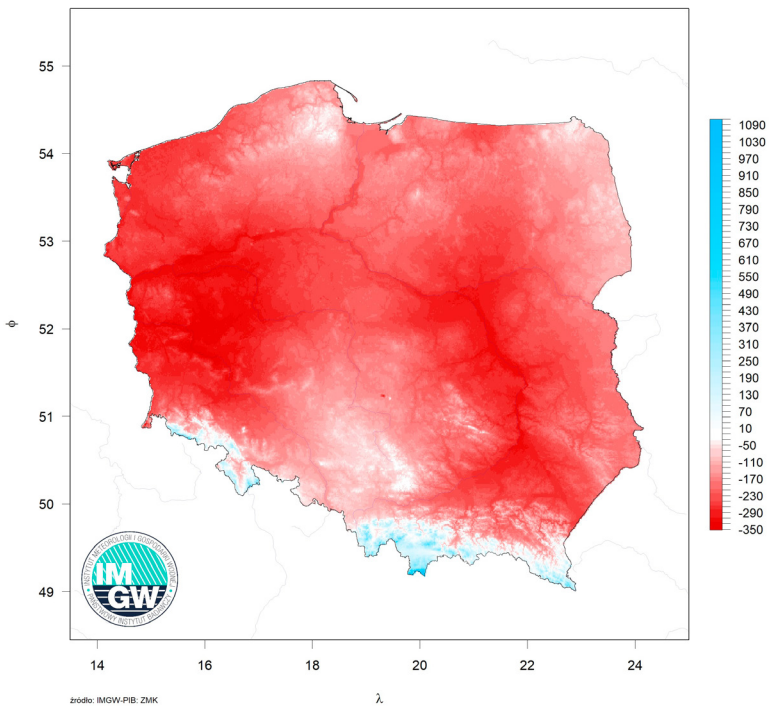
The climatic water balance (CWB) is the difference between the precipitation, i.e., precipitation total, and evapotranspiration, which can be determined based on measurements or using empirical formulas. A positive CWB value means that there was more precipitation than evaporation during the analyzed period. In the case of a negative CWB value, it is the opposite; evaporation prevails over precipitation.

From the economic point of view, information on CWB in the warm season, i.e., when there is a high demand for water in Poland in such an essential sector of the economy as agriculture, is of great significance. The evaporation values are high. They range between 350 mm and 610 mm, which is between 75% and 125% of the amount of precipitation in the warm season. Despite the relatively high rainfall in the warm half of the year, positive or close to zero CWB values were generally present in the higher parts of the Sudetes and the Carpathians Mountains, Podkarpacie, Kashubian Lake District, and in north-eastern Poland. In the remaining area of Poland, the CWB in May-October 2022 was negative. The loss of moisture in western Poland and the basin of the middle course of the Vistula, reaching nearly 300 mm in the warm season, is of particular concern.

Total Evapotranspiration – May-October 2022



Total Climatic Water Balance – May-October 2022

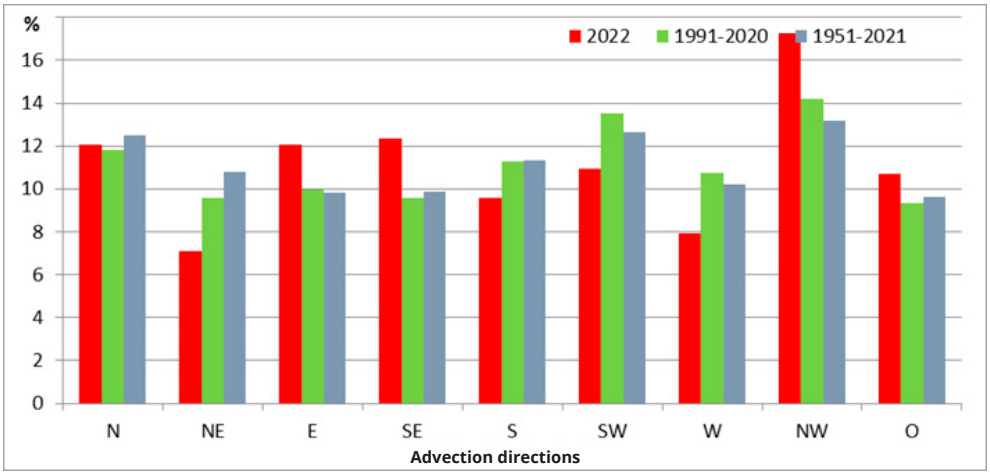


ATMOSPHERIC CIRCULATION
Indices and surface wind

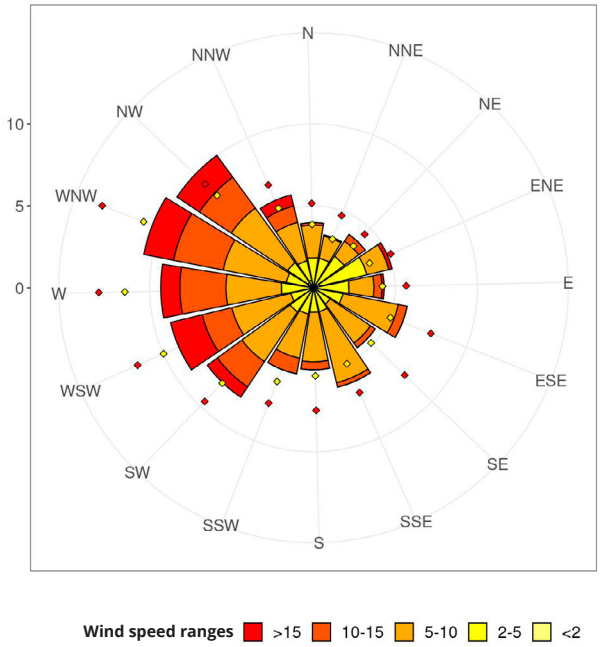
Types of atmospheric circulation according to Litynski in particular days and months of the year 2022 (Pianko-Kluczynska 2018)

Day/Month	1	2	3	4	5	6	7	8	9	10	11	12
1	No	NWc	Oa	NEc	Oa	So	SEc	Oo	NEa	SWo	SWo	SEa
2	SWc	Nc	Na	Nc	NWa	Oa	Sa	Sa	Ea	NWc	Wo	SEa
3	Wc	Oo	NEo	NWo	No	Na	Sa	SWa	Ea	No	SWa	SEa
4	SWc	SWc	NEa	Wc	Wa	Na	Sa	SWa	Ea	NEo	Sc	SEa
5	NWc	Wc	NEa	NWc	Wa	Na	NWa	Oo	Ea	NEo	So	Oa
6	Nc	Wc	Na	Wc	SWa	Oo	NWa	Na	Ea	NEc	Sa	Oo
7	Wo	NWc	NEa	SWc	Na	Oo	Na	NEa	SEa	Ec	SWo	Oc
8	Sc	NWo	Ea	NWc	Na	Sc	Na	Ea	SEo	Ec	SWo	Sc
9	Ec	NWo	SEa	NWc	Sa	Nc	Na	Ea	SEo	Ec	SWo	SEc
10	Ea	NWo	Sa	NWo	SWa	Oa	NEo	Oa	Ec	Oc	SWa	Ec
11	Ea	NWo	Sa	NWa	SWc	Sa	Na	Oa	Ec	Oc	Wa	Ec
12	NWa	Wa	Sa	Oa	NWo	NWa	Wa	Ea	So	Oc	NWa	Ec
13	NWa	SWo	Sa	Ea	NWo	NWo	Wo	Ea	Wc	Oc	Ea	Oc
14	NWo	SWo	Sa	NEa	NWo	Na	NWo	SEc	SWc	Oc	Sa	Sc
15	NWa	SWc	SWa	NEa	NWa	NWa	NWa	SEc	NWc	Oo	SEo	Oc
16	NWo	SWc	Sa	NEa	Na	NWa	NWo	SEc	NWc	Oc	SEc	Oo
17	NWc	NWc	SEa	Ea	NEa	Wa	Wa	Ec	NWc	No	SEc	Oa
18	NWa	Wc	Oa	NEa	Na	SWa	Wa	SEo	Nc	Oa	SEc	Wa
19	NWo	NWc	Oa	Eo	Wa	Wc	Sa	Sc	Nc	SEa	Eo	SWa
20	NWc	Wc	Ea	Ec	SWo	Oc	Na	Sc	NEo	SEc	SEc	SWo
21	No	NWc	Oa	Eo	NWc	Nc	Na	Sc	NEa	SEc	SEc	SWo
22	Na	NWc	Oa	SEo	Oc	Wo	Na	Eo	Oa	SEc	SEc	Wc
23	Na	Wo	Na	SEc	Sc	SWa	No	SEo	Oo	SEc	SEc	NWc
24	NWa	SWo	Na	Ec	Sc	So	Sa	SEa	No	SWc	SEo	NWc
25	Na	NWo	NWa	Nc	SWo	So	SWo	Ea	SWc	Wc	Eo	SWa
26	NWa	Oa	Na	NEa	NWo	SEa	NWc	Eo	SWc	Wc	Ea	SWc
27	NWc	Sa	NWa	NEa	NWc	SEa	Na	Ec	SEc	Wc	Sa	Wo
28	NWo	Oa	NWo	NEa	NWc	SEa	Ea	NEc	Ec	So	SEa	SWo
29	NWo		NWc	NEa	Nc	SEa	Ea	NEo	SEc	Eo	SEa	SWc
30	NWc		Nc	Na	SEc	SEo	Oo	NEa	Sc	Ec	SEa	SWo
31	Nc		Ec		SEa		Oc	NEa		Eo		SWo

Atmospheric circulation is one of the essential weather and climate factors. Because of atmosphere circulation, the weather in Poland changes from day to day, and even several times a day. There are many methods describing atmospheric circulation. One of the most popular is characterizing it by indicating the direction of the advection of air masses over the area of interest and by defining the nature of the air movement (whether it is cyclonic or anticyclonic). In a given season of the year, these parameters determine the thermal and humidity characteristics of air masses flowing over the studied area.



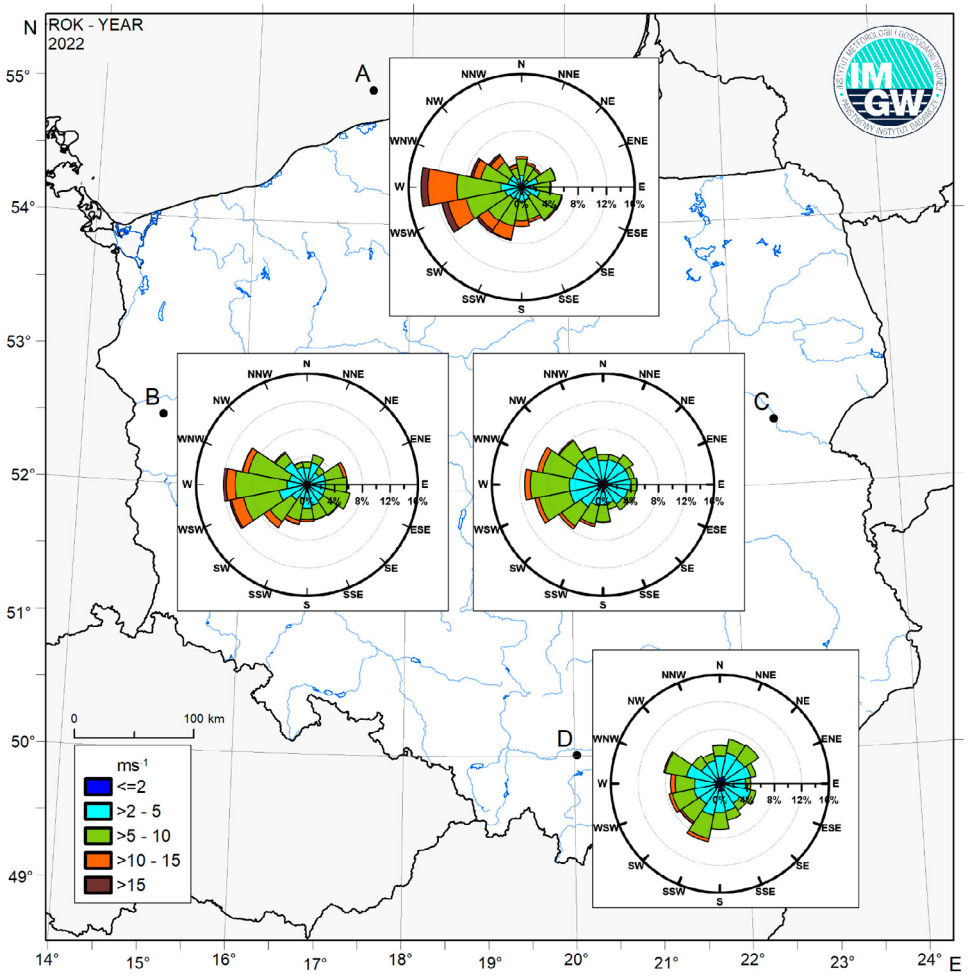
The circulation index's calendar indicates that in 2022, air masses flowing from the western sector (from NW to SW, 35%) and then from the southern sector (from SE to SW, about 33%) slightly predominated in 2022. Compared to the normal period, the frequency of the flow of air masses from the western sector was higher by about 2% than in the long-term period 1991-2020.



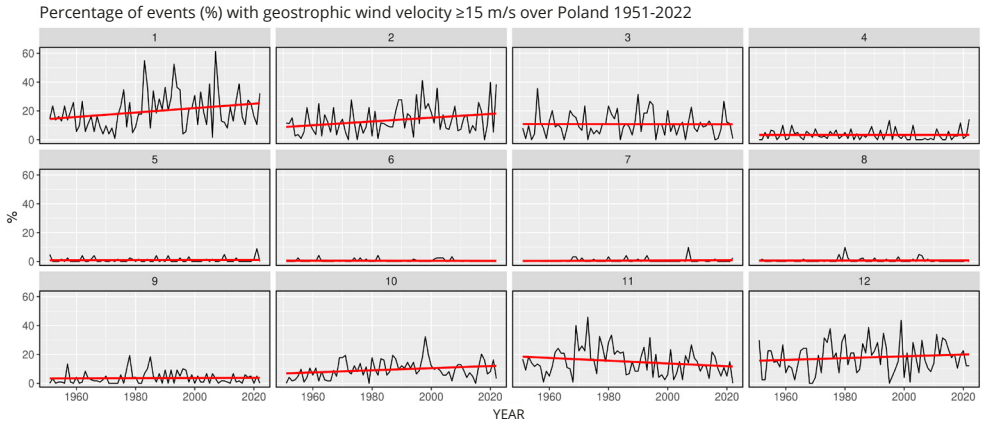
Characteristic	V (m/s)	u (m/s)	v (m/s)
Mean (1991-2020)	8.2	2.7	0.5
Mean	7.9	2.9	0.0
Minimum	0.4	-18.1	-23.4
Quantile 10%	3.1	-4.2	-6.1
Quantile 50%	6.8	1.9	0.0
Quantile 90%	14.2	11.8	6.5
Maximum	30.1	29.2	14.1
Mean direction (1991-2020)	259		
Mean direction	270		
Stability coefficient (η)	0.37		
η (1991-2020)	0.34		

Another type of index describing the atmospheric circulation over a given area is the geostrophic wind vector, which determines the direction and strength (velocity) of the inflow of air masses over a given area based on the baric (Sea Level Pressure) field. If the current thermal and pressure conditions are taken into account, then by correcting the air density, actual values of the index are obtained. The geostrophic wind vector does not consider, among others, the frictional effect resulting from both the variability of the topography and land use. However, it is the maximum wind speed at which the wind would blow in a given area without the factors mentioned above.

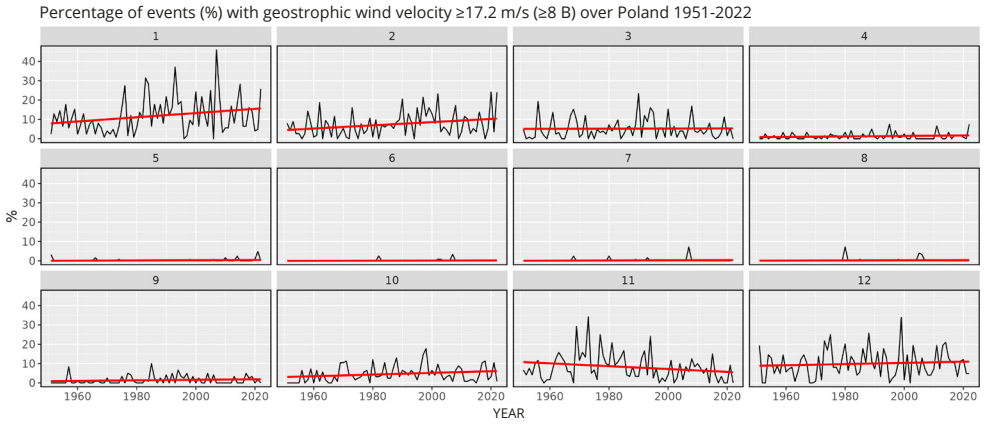
The average annual wind vector in 2022 was similar to the vector characteristic of the long-term period 1991-2020. The anomaly of the average geostrophic wind speed was only –0.3 m/s. As for the direction, in 2022, it was shifted by 11 degrees clockwise and was exactly 270 degrees (advection from the west) relative to the long-term average of 259 degrees. The directional-velocity structure indicates a moderate advection of air masses from the west. It is also reflected in the wind rose, showing the dominance of advection from the SW to NW sectors.



This characteristic of the flow direction of air masses is reflected in the wind directional structure at the surface with significant regional variability.

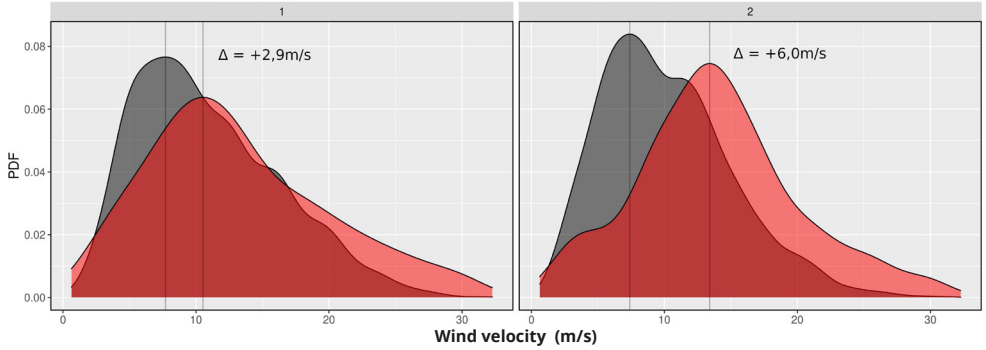


The increase in danger associated with strong winds, especially from October to March, has been observed for many years. For wind with a velocity exceeding 15 ms^{-1}, we observe an increase in the frequency of such winds by 6% in October, more than 5% in December, 10% in January, and 7.8% in February. In January and February 2022, there are clearly high (reaching 40% in February) shares of events exceeding this value. The threshold of 15 ms^{-1} is a critical value, the exceedance of which is the basis for issuing a 1st-level warning.



A wind speed of at least 17.2 ms^{-1} is called a strong gale – it is the wind force threshold for 8 on the Beaufort scale. At sea, the waves reach a height of around 5 m, tree branches can be broken on land, and motor vehicles may have difficulties keeping their tracks. As the speed increases, the destructive force of the wind increases, and the damage becomes more severe and extensive. There is also a systematic increase in winter months (XII-II) in the frequency of wind events above 17.2 ms^{-1}.

Probability density distribution of geostrophic wind velocity over Poland in January and February 2022 (red color) relative to the long-term period 1991-2020 (grey color)
vertical black lines – mode values;
in addition, the difference between the values of 2022 and the value of the long-term period (1991-2020) is indicated

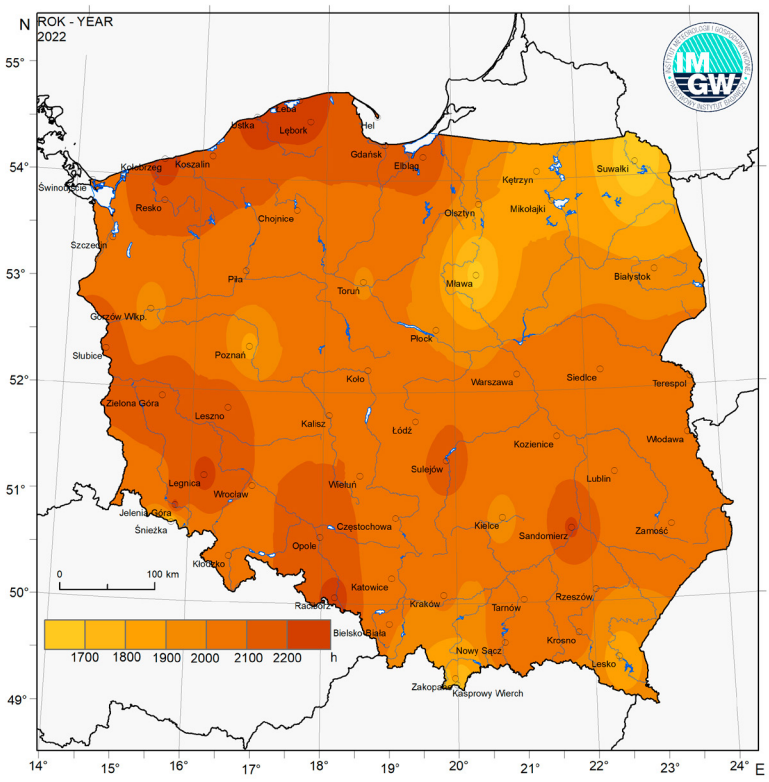


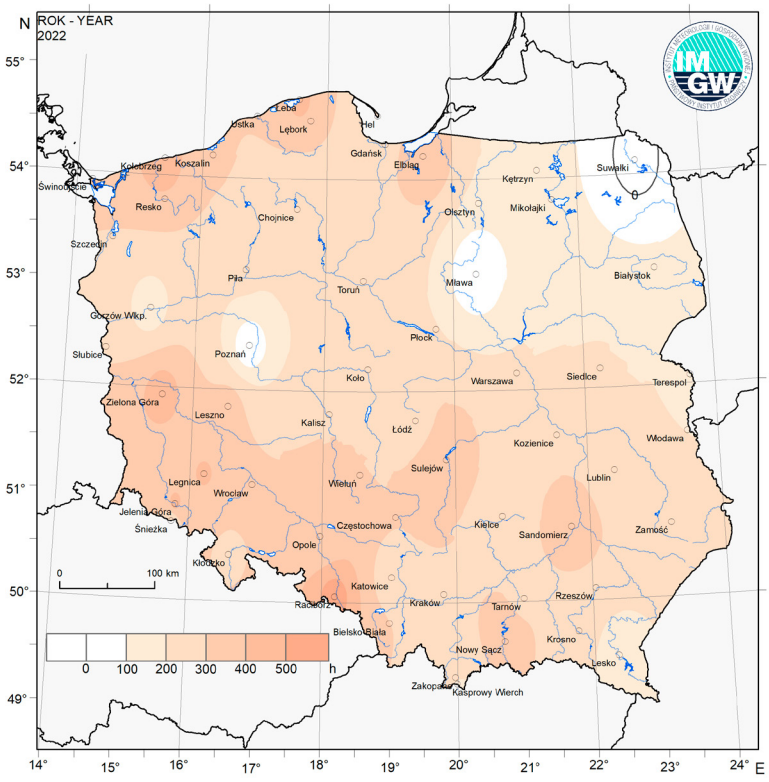
January and February 2022 were exceptional regarding the frequency of high-velocity air flow relative to long-term values. It is visible primarily in the shift of the distribution of recorded velocities toward higher values and the thickening of the so-called tails of the distribution. Analysis of the dominant values (the most frequent values) relative to the long-term values (1991-2020) indicates that the anemological conditions in January and February were characterized by higher values. In January, the positive anomaly was 2.9 m/s, while in February, it was as high as 6.0 m/s.

SUNSHINE DURATION

Sunshine duration, or the length of time when the solar disk is visible, depends on the location, topography, and cloud cover – both the amount of cloud coverage and the cloud genera in the area concerned. Relative sunshine duration, that is the ratio of sunshine duration to the maximum possible, determined by the length of the day (i.e., from sunrise to sunset), was between 38% and 51% in 2022.

The annual total of sunshine duration in Poland was between 1,640 and 2,320 hours. In most of the country, it was higher than the climatological normal – from –35 (near Suwałki) to 547 hours in the southwestern part (Racibórz). The sun shone the longest in Łeba, for 2,320 hours. The lowest number of hours with the sun was recorded in 2022 on Kasprowy Wierch (1,642 hours) and in Suwałki (1,643 hours).

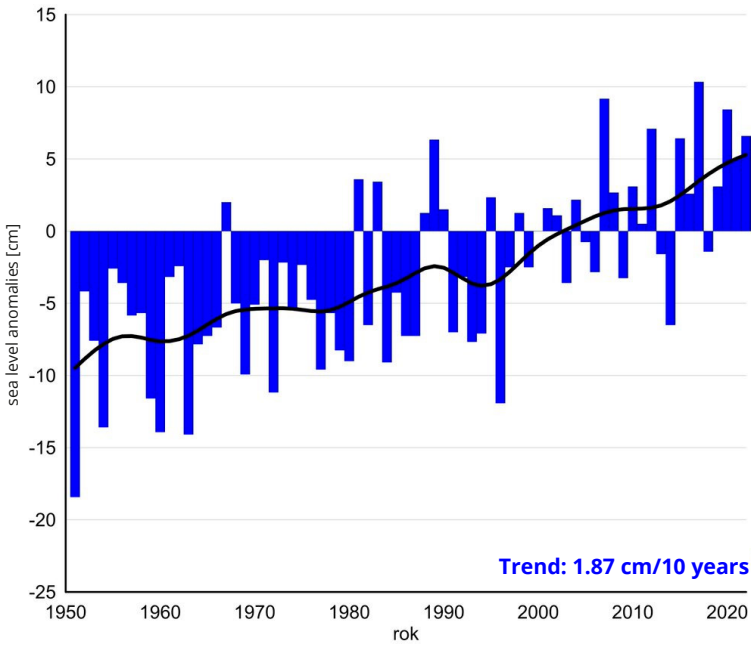




Sunshine duration anomaly in 2022 relative to long-term values (1991-2020)

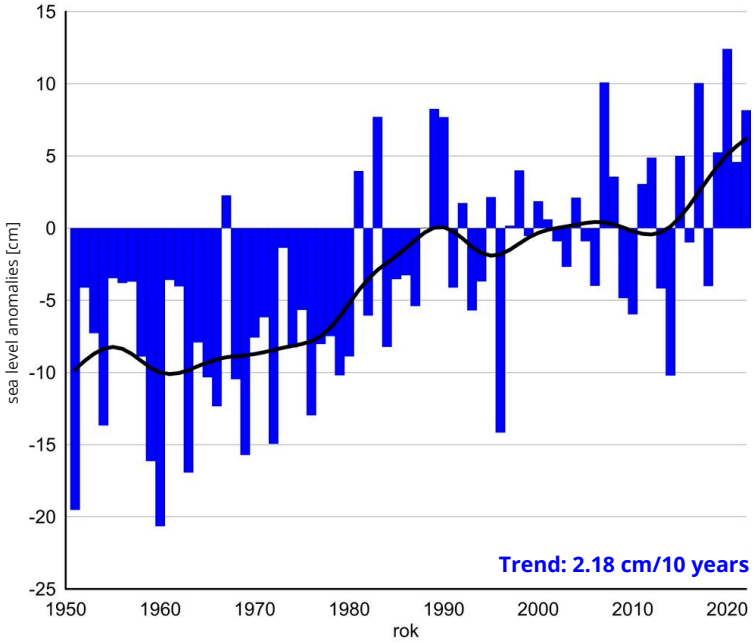
SEA LEVEL

The sea level in the Southern Baltic region is steadily increasing, which is the result of the increase of temperature on a global scale and the dominance of the western zonal circulation of the atmosphere in this area. The rate of sea increase varies. It is higher in the eastern part of the coast (the mean sea level increase by nearly 13.5 cm in Świnoujście and by about 15.7 cm in Władysławowo). This is a consequence of the dominance mentioned above of the western zonal circulation, which maintains a constant inclination of the Baltic Sea water plane , increasing from west to east.



In Świnoujscie in 2022, the observed maximum mean daily level was 571 cm, while the observed lowest mean daily level was 445 cm. Mean daily levels above the warning level, equal to 560 cm, accounted for 0.83%, above the alarm level did not occur. Similarly, no mean daily levels below the SNW (416 cm) were recorded. The most frequent mean daily sea levels were in the range of 510-520 cm (29.3%) and 501-510 cm (20.3%).

In Władysławowo in 2022, the observed maximum mean daily level was 586 cm, while the observed lowest mean daily level was 473 cm. The mean daily water level exceeded the alarm level of 570 cm four times (21.01: 584 cm, 30.01: 586 cm, 31.01: 572 cm, 22.02: 574 cm), but no levels below the SNW (445 cm) were recorded. The most frequent mean daily sea levels were in the range of 511-520 cm (27.12%) and 501-510 cm (20.27%).

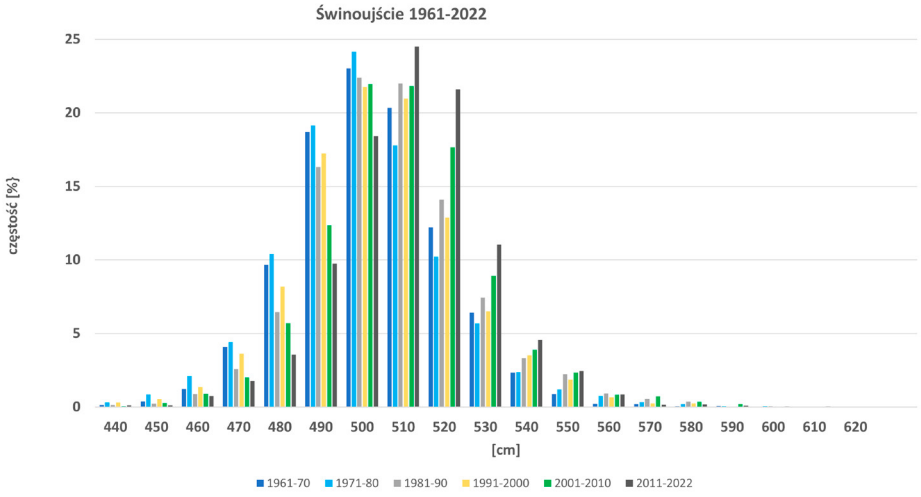


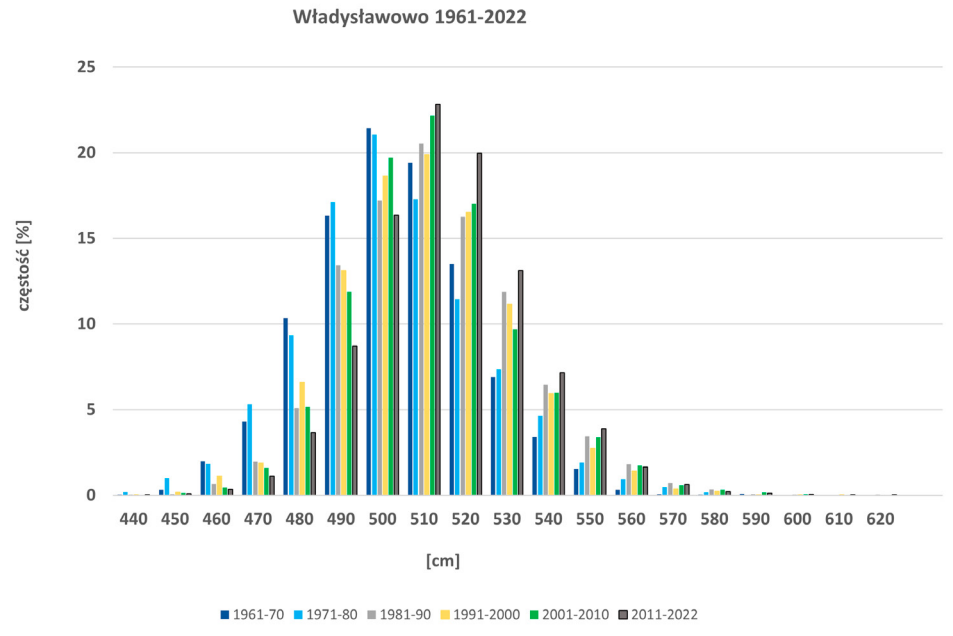
The change in the frequency of sea levels from a low range of values, below the so-called mean level, visibly stands-out from decade to decade. In the western and eastern parts of the coast, we can observe a decrease in the number of low levels, especially in Świnoujście. At the same time, we can observe an increasing trend in the number of cases of higher than mean levels, particularly to the alarm levels.

Occurrence (%) of sea levels below the SNW and above the alert level in Świnoujście and Władysławowo for selected periods from 1961-2022

Świnoujście	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	2011-2022
Below SNW [%]	0.000	0.028	0.000	0.027	0.000	0.068
Above the alarm level [%]	0.137	0.110	0.084	0.055	0.220	0.205

Władysławowo	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	2011-2022
Below SNW [%]	0.082	0.547	0.027	0.109	0.055	0.068
Above the alarm level [%]	0.110	0.164	0.465	0.328	0.549	0.433





EXTREMES

VARIABLE		VARIABLE	DATE	STATION
Temperature* (T°C)	max	**38.3**	19.06.2022	Słubice
	min	**-18.6**	14.12.2022	Zamość
	min 5 cm**	**-25.6**	19.12.2022	Terespol
Precipitation (RR mm)	Σ max doba	**130.4**	7.09.2022	Gorzów Wielkopolski
	Σ max	**1446.0**		Kasprowy Wierch
	Σ min	**376.2**		Gdańsk Świbno
Sunshine duration (U h)	Σ max doba	**16.5**	24.06.2022	Ustka
	Σ max	**2312.6**		Łeba
	Σ min	**1642.8**		Kasprowy Wierch

*temperature value without high mountain stations (Śnieżka and Kasprowy Wierch)
** temperature at a height of 5 cm above ground level

SUMMARY OF EXTREME WEATHER AND CLIMATE EVENTS IN POLAND IN 2022

Observed extreme weather or climate event	Physical characteristics of event						Interferences occurring
	Event Start	Event End	Duration	Location/Area	Rarity	Description of event	
Snowstorms	2022-01-17	2022-01-17	1 day	Entire country	Unprecedented	As a result of the movement of a deep low center from the north to the south of Poland, a linear thunderstorm formation with a squall line was formed, with heavy snowfall, hail and graupel, and gusty wind (e.g., station Koło - wind gusts reached 133 km/h. The PERUN lightning detection system recorded a total of 27,494 atmospheric lightning, which is a record value for January.	Transportation problems. 5,000 fire service interventions. 600 broken or damaged roofs on residential and farm buildings. Over 320,000 customers without electricity.
Tornado	2022-02-17	2022-02-17	1 day	Entire county, especially: Dobrzyca (51°51'54"N 17°36'07"E) Pleszew (51°53'50"N 17°47'08"E) Smaszków (51°39'31"N 18°27'57"E) Kraków (50°04'40"N 19°47'42"E)	Unprecedented	At night and in the morning, a storm formation in the form of a squall moved through Poland, characterized by destructive gusts of wind and several tornadoes, formed on the active trough of low pressure associated with the Dudley low (Ylenia). In the Dobrzyca commune, the scale of damage indicates a wind force of at least F2 on the Fujita scale. Strong gusts of wind were recorded at the measuring stations (e.g. Leszno station – 117.4 km/h, Dziwnów station – 133.9 km/h).	More than 320,000 customers without electricity. Numerous damages to residential and commercial buildings. Broken trees, power poles, damaged cars, overturned construction crane. Several people injured, including 3 fatalities.
Drought	2022-03-01	2022-03-31	31 days	Entire country	Unusual	Due to the predominance of an anticyclonic situation, sunny, rainless weather prevailed over the country. No precipitation was recorded at several measurement stations throughout the month (e.g. measurement station Kołobrzeg, Koszalin). In most of the country, record sunshine was recorded this month, exceeding 230 hours in a large area (satellite data from EUMETSAT CM SAT).	Agricultural losses: the continuation of the drought will reduce crop yields by at least 20 percent on a municipal scale compared to yields obtained under average long-term weather conditions.
Cold wave	2022-04-01	2022-04-30	30 days	Entire country	Unusual	In terms of temperature, April was below the long-term normal across the country; the most significant deviation was recorded at the synoptic station in Kielce –2.6˚C below the normal (monthly mean temperature 5.8˚C).	
Heat wave	2022-05-11	2022-05-11	1 day	Entire country	Unusual	Tmax values much higher than average were recorded throughout Poland - this was related to the inflow of warm air from the southwest. Up to 28°C in Wroclaw and Legnica. At 69 percent (34) of the stations, positive Tmax anomaly values exceeded 3°C, and at five stations: Legnica, Wroclaw, Jelenia Gora, Leszno, and Bielsko Biala, they exceeded 6°C.	
Tornado – condensation funnel	2022-06-01	2022-06-01	1 day	Vicinity of Baborowa (50°09'28"N 17°58'48"E) Vicinity of Pawłowiczek (50°14'29"N 18°02'46"E) Opole voivodship	Unusual	Contact with the earth's surface due to a significant vertical extension.	None, the tornado occurred in an uninhabited area.
Heavy thunderstroms with hail	2022-06-07	2022-06-07	1 day	Southern and central part of the country	Unusual	Thunderstorms occurred in the form of clusters that merged into larger systems, moving from the southwest to the northeast, mainly in the area of the atmospheric front.	Broken trees, property damage.
Heavy thunderstroms	2022-06-09	2022-06-09	1 day	Southern part of the country	Unusual	The slow movement of heavily moist convective systems causing heavy rain and local flooding. Rainfall totals up to 60 mm, hail 3-4 cm in diameter, and strong wind gusts up to 90 km/h.	Property damage due to flooding, obstructed traffic by flooding streets in Gliwice, broken trees; paint shop fire caused by a lightning strike in Sanok.
Heavy thunderstorms	2022-06-13	2022-06-13	1 day	Lubelszczyzna	Unusual	A high-precipitation supercell thunderstorm, carrying a hail of 2-4 cm in diameter, heavy, at places, torrential rain, which led to flooding. An arcus formed at the head of the storm, containing a rotating updraught. Wind gusts of up to 104 km/h at Lublin Airport.	Property losses caused by flooding, broken trees, torn roofs of farms.
Heat wave	2022-06-18	2022-06-19	2 days	Entire country	Unusual	In the Lubuskie Land, Wielkopolska or the north of Lower Silesia, the temperature exceeded 35°C, and locally even 37°C, due to the trough of low pressure from the Norwegian Sea with a warm atmospheric front, followed by a very warm air mass of tropical origin.	

SUMMARY OF EXTREME WEATHER AND CLIMATE EVENTS IN POLAND IN 2022

Observed extreme weather or climate event	Physical characteristics of event						Interferences occurring
	Event Start	Event End	Duration	Location/Area	Rarity	Description of event	
Severe thunderstorms	2022-06-20	2022-06-20	1 day	Southern part of the country	Unusual	A cold atmospheric front crossed Poland from the southwest to the northeast, where additionally shallow Petra low developed. In the area of this front, there was a moving zone of precipitation, and at places, severe thunderstorms, locally with hail and very strong wind gusts.	Firefighters intervened more than 700 times after the storms. No injuries - informs the State Fire Service. Most interventions were recorded in the following voivodeships: Silesian (163), Opolskie (116), Wielkopolskie (69), Mazovia (64) and Lower Silesia (63). Thunderstorms locally generated torrential rainfall. There were numerous floods and flooding, especially in Lower Silesia.
Heat wave	2022-06-26	2022-06-26	1 day	Entire country	Unusual	Throughout Poland, Tmax values were much higher than average. The cause was the inflow of warm air from the southwest. The highest values (32°C) occurred in Gorzów, Zielona Góra and Koszalin. At 42 stations, the positive Tmax anomaly values exceeded 6°C (as much as 10°C in Koszalin), and at 10 stations, the Tmax values exceeded the 95% quantile of Tmax.	
Severe thunderstorms with hail	2022-06-29	2022-06-29	1 day	Silesia	Unusual	Severe thunderstorm with hail up to 5 cm in diameter. The cause of the phenomenon was the occurrence of a strong rotating updraught. The appearance of a hook echo with a V-notch signature was noted on the radar image.	Material losses caused by hailstorms.
Heat record	2022-06-30	2022-06-30	1 day	Tarnów (50°01'48"N 20°59'02"E)	Unprecedented	A temperature record of 37.7 °C was recorded for Tarnów, caused by a moving front that ended a several-day heat wave.	
Strong thunderstorms with bow echo, hail and tornadoes	2022-06-30	2022-07-01	1 day	Northern part of the country	Unusual	A linear structure extending from the northwest into the interior of the country. Formation of Line Echo Wave Pattern along with Bow Echo. Occurrence of strong wind with gusts up to 120 km/h. The heat wave in Poland was ended by the rapid passage of a cold atmospheric front with the preceding wind convergence line, which triggered the formation of thunderstorms. Between July 1 and 2, a zone of showers and thunderstorms moved from west to east of Poland at places, locally with hail. The phenomena that occurred were strong, even torrential. A 3rd highest level of severe thunderstorm warning was issued.	The situation in Szczecin was difficult. Torrential rainfall caused floods and flooding in places. The roads became temporarily impassable. The rain also paralyzed public transport. Most tram lines were stuck due to flooding of the tracks. In many regions, the wind ripped the roofs of residential buildings. In addition, roads and properties were flooded; hailstorms damaged cars and crops. In Gdynia, a festival was evacuated, while in Chojnice, a broken tree fell on a car with a traveling family. The fire brigade intervened more than 3,600 times, most in the West Pomeranian, Pomeranian, and Kuyavian-Pomeranian voivodeships, where nearly 1,500 incidents were recorded. Twenty scout camps were evacuated. More than 260,000 atmospheric lightning were recorded in 24 hours. 7 people were injured, including 2 firefighters. No fatalities.
Waterspouts	2022-07-11	2022-07-11	1 day	Baltic Sea, Gulf of Vistula River	Unprecedented	Numerous waterspouts; such phenomena are favored by the advection of cold air over relatively warm sea waters. An additional factor is currently the presence of an upper low, which drives the development of Cumulus clouds.	
Violent thunderstorms	2022-07-22	2022-07-22	1 day	Małopolska	Unusual	Supercell in the Krakow area, with strong wind gusts reaching up to 140 km/h.	Two people died as a result of thunderstorms.
Multicell thunderstorm	2022-08-14	2022-08-14	1 day	Sucha Beskidzka (49°44'25"N 19°35'19"E)	Unusual	A multicell thunderstorm with strong, near-stationary precipitation cores causing flooding.	As a result of a violent weather phenomenon, firefighters were called to 17 rescue interventions related to the removal of the effects of rainfall and wind.
Heavy thunderstorms with tornadoes	2022-08-19	2022-08-19	1 day	Koszalin (54°12'16"N 16°09'19"E)	Unusual	The occurrence of tornadoes, strong winds and hail due to a strong mesocyclone.	Broken branches of trees.
Multicell thunderstorm, Flash flood	2022-08-20	2022-08-21	2 days	Podhale	Unusual	The occurrence of training storms system in the area of Zakopane and Nowy Targ contributed to the occurrence of numerous flooding. At the precipitation station in Nowe Bystre, a rainfall of 77.9 mm was recorded in just 1.5 hours.	Thunderstorms passing locally one after another over the same area (the training storms phenomenon) caused not only flooding but also flash flood, especially in the Podhale region in southern Małopolska. The villages of Ciche, Ratułów Górny, and Nowe Bystre, among others, were flooded. Torrential rainfall and, in consequence accumulating water flooded houses, broke asphalt, and destroyed possessions.
Heavy rainfall accompanying thunderstorm	2022-08-28	2022-08-28	1 day	Katowice (50°14'26"N 19°01'58"E)	Unusual	Heavy rainfall: as much as 97 mm was recorded in just a few hours by developing a wind convergence zone directly ahead of the front, which supported the development of convection.	Numerous flooding, road difficulties.

SUMMARY OF EXTREME WEATHER AND CLIMATE EVENTS IN POLAND IN 2022

Observed extreme weather or climate event	Physical characteristics of event						Interferences occurring
	Event Start	Event End	Duration	Location/Area	Rarity	Description of event	
Stationary thunderstorm, downpour	2022-09-08	2022-09-08	1 day	Gorzów Wielkopolski (52°44'28"N 15°16'38"E)	Unprecedented	The stationary storm caused a downpour; a record daily precipitation of 131 mm was recorded, and as much as 77.6 mm in one hour.	Strong gusts of wind broke branches, which blocked the roadway.
Cold wave	2022-09-01	2022-09-30	30 days	Entire country	Unusual	In terms of temperature, September was below the long-term normal across the country. The area average air temperature was 12.3°C and was as much as 1.5 degrees lower than the long-term average for that month.	
Heat wave	2022-10-01	2022-10-31	31 days	Entire country	Unusual	In terms of temperature, October was extremely warm in almost the entire country. The area average air temperature was 11.2°C and was as much as 2.4 degrees higher than the long-term average for that month (climatological normal period 1991-2020). It was the second warmest October in the 21st century. The highest deviation was recorded in Zielona Góra, where the monthly mean air temperature was 12.6°C, 3.3 degrees above normal. The highest monthly mean temperature (12.6°C) occurred in Zielona Góra, Słubice, and Legnica, and the lowest in Suwałki (9.7°C). The highest maximum temperature (25.5°C) was recorded in Jelenia Gora on October 30, and the lowest minimum temperature (–4.2°) in Kozienice on October 21.	
Cold wave	2022-10-20	2022-10-21	2 days	Cały kraj	Unusual	Arctic air, previously located over northern Greenland, flowed into Poland. Because of this, on October 20, the temperature dropped to –5°C in Łódź, Toruń and Piła, and on October 21, the lowest temperature of –7°C at ground level was recorded at the station in Kozienice. The coldest weather was in the Orawsko-Nowatorska basin. The temperature dropped to –8.5°C, and at the ground to –11.9°C.	
Cold wave	2022-11-18	2022-11-19	2 days	Entire country	Unusual	Cooling associated with the advection of arctic air. The highest frost (–12°C) at ground level was recorded at the meteorological station in Poznań and Słubice, and outside the lowlands (–14.6°C) on Śnieżka.	
Heavy snowfall, severe frost, blizzards and blowing snow, freezing rainfall	2022-12-09	2022-12-17	8 days	Entire country	Unusual	The onset of winter due to the Brygid low, moving from southern Europe towards Poland and Ukraine. The snowfall increased with each passing day; the snow cover in the Tatra Mountains was up to 15 cm per day, and in Beskid Śląski and Beskid Żywiecki, up to 30 cm per day. The night of December 13/14 was the coldest. The greatest frost occurred in southeastern Poland. At the Poronin station in Małopolska voivodeship, the temperature dropped to –21°C. Frosty in the sudeckie basins: up to –18.4°C (Jakuszyce) and –17.1°C (Jelenia Góra). Zamość was the coldest synoptic station, with a temperature of –18.6°C. At ground level, air temperature drops were even greater, up to –24°C (Lublin region). Strong wind gusts, in the Tatras up to 120 km/h and in the Sudetes up to 55 km/h, causing blizzards and blowing snow. Freezing rainfall in the south and southeast of the country.	Icing and glaze causing major traffic difficulties on roads and tracks. Heavy snow cover causing broken branches and small building components. Freezing precipitation - roads, tracks and pavements very slippery, icing of overhead lines and trees. Blizzards and blowing snows - snowdrifts, traffic difficulties, roads covered with snow, poor visibility, closed airports. Severe frost causing freezing of the water surface and blockages on rivers and reservoirs.
Heat wave	2022-12-29	2022-12-31	3 days	Entire country	Unusual	Because of cyclones over Scandinavia and a high in southern Europe, warm air flowed to Poland. The highest air temperature value (18.1°C) was recorded on December 31 in Słubice. On that day, the highest December temperature occurred at almost all stations in Poland. The exceptions were Kasprowy Wierch, where the highest value was recorded on 21 December (6.9°C), and Śnieżka, where the warmest value was on 20 December (5.3°C).	

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