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# CLIMATE OF POLAND 2021

The 6th Report of the Intergovernmental Panel on Climate Change Working Group I (IPCC WGI) published in 2021 confirms that the Earth's climate has been changing at a pace never seen before since the mid-19th century and that the progressive warming endangers 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 future of the Earth. The Intergovernmental Panel on Climate Change Working Group II (IPCC WGII), in a report published at the beginning of March this year, states that the impact of progressive warming threatens agricultural production, both in terms of quantity and quality, water resources, human safety and health, and infrastructure security. All this is due to the progressive intensification of extreme phenomena – both meteorological and climatic - and, consequently, hydrological ones.

The reports of both IPCC working groups and the WMO Atlas on the mortality and economic losses caused by extreme weather, climate, and water conditions between 1970 and 2019 published in September 2021, confirm the thesis that the observed climate change leads to the exhaustion of civilization resources.

Therefore, multidirectional measures are required, including the necessary, systematic monitoring of the climate system, undertaking activities to slow down or even eliminate the causes of contemporary climate change, forecasting the future evolution of the climate system and developing 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 climatic variables. We inform society and public admin-istration about the climate system condition and the threats resulting from climate variabil-ity 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 2021". It is the second report, after last year's one concerning 2020, which is 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.

Prof. Mirosław Miętus
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Director of the Research and Development Center
Permanent Representative of Poland with World Meteorological Organization (WMO)

The presentation was prepared on the basis of the POLISH CLIMATE MONITORING BULLETIN developed by the team consisting of: Prof. ZBIGNIEW USTRNUL, AGNIESZKA WYPYCH, Ph.D., MICHAŁ MAROSZ, Ph.D., DAWID BIERNACIK, DANUTA CZEKIERDA, ANNA CHODUBSKA, KAMILA WASIELEWSKA, KLAUDIA KUSEK, DIANA KOPACZKA.

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 (Halina Lorenc, 2010), Poznań (Leszek Kolendowicz et al., 2019), Gdańsk (Mirosław Miętus, 1996) and Wrocław (Krystyna and Tadeusz Bryś, 2010) extended by Janusz Filipiak.

IMGW-PIB own study 2021.

Design: Michał Seredin (IMGW-PIB).



The animation of climate change in Poland is also available on the IMGW-PIB YouTube channel (https://www.youtube.com/c/IMGWMETEO).

# CLIMATE OF POLAND IN 2021

The area average air temperature in 2021 in Poland reached 8.7°C and was equal to the average annual long-term temperature value for the climatological normal period 1991-2020. The year 2021 should be classified as a thermally normal if you consider the average temperature for Poland.

The warmest regions of Poland were the Coast and the Southern-Baltic Coastlands belt, where an area average air temperature amounted to 9.0°C and was higher than the standard normal for that area by only 0.1°C. The coldest region was the Sudetes, where the average annual air temperature was 7.9°C and was lower than the standard normal by 0.2°C.

Let's look at the lake districts and lowlands, considering also 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 1.2°C and in the lowlands it was 1.1°C. After taking these differences into account, it can be concluded that the warmest region of Poland in 2021 was the western part of the lowlands belt, with an average annual air temperature of 9.4°C.

Last year, June and July, and all autumn months, were particularly warm. Conversely, the coldest month was February, characterized by an average air temperature of 1.5°C below normal.

The highest temperature (36.1°C) was recorded on 20 June in Słubice. In turn, the lowest temperature at 2 m above ground (–26.4°C) was recorded on 18 January in Suwałki. The lowest air temperature at the ground, i.e., at 5 cm height, was recorded on 18 January at the Białystok station ; its value was –32.9°C.

The summer of 2021, i.e., the period from June to August, was the fourth 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 2021. Since 1951, the total annual temperature increase has been estimated at 2.0°C. The value of the trend coefficient differs in the individual climatic regions of the country. The strongest temperature increase occurs in the lake districts, where it exceeds 2.1°C, the weakest in the Sudety Mountains, reaching almost 1.8°C.

The analysis of the historical series shows that since 1851 the air temperature in selected large Polish cities has increased from 1.4°C to 2.3°C. It should be emphasized that the rate of temperature increase in large urban agglomerations has increased significantly over the last 40 years.

The area-averaged precipitation total in 2021 in Poland was 627.4 mm, which was almost 103% of the so called normal value determined on the basis of 30 years measurements (1991-2020). According to Kaczorowska's pluvial conditions classification, the past year should be classified as normal.

In 2021, precipitation was characterized by a strong spatial variability. The area average annual precipitation total ranged from over 450 mm to nearly 1050 mm. The highest annual precipitation total was recorded in the Tatra Mountains. Compared to the long-term normal (1991-2020), the precipitation in 2021 ranged between 80 and 130% of the climatological normal.

In the warm season of the year, numerous cases of violent and extremely heavy rainfalls causing local floods and flooding occurred. Such phenomena struck several agglomerations and resulted in urban flash floods. Szczecin and Słubice (June 30: 96.3 mm and 71.3 mm, respectively) and Poznań (June 22: 79.4 mm) were particularly affected by heavy rainfalls. The highest daily precipitation total of 104.4 mm, occurred on August 23 at Śnieżka.

In the central part of the Coast and Pomerania, there was a rainfall deficit of up to 20% of the long-term normal, while in Eastern Poland, annual rainfall was higher by 10 to 30% compared to the 1991-2020 normal.

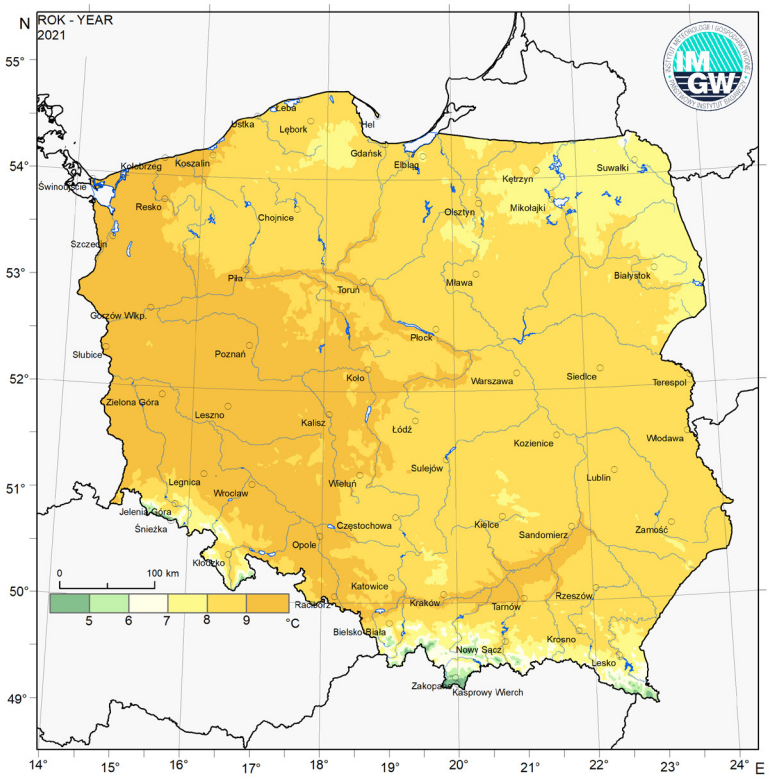
In the entire western and central part of eastern Poland, in 2021, evapotranspiration outweighed precipitation. The moisture loss in the mentioned area reached 220 mm, i.e. about 1/3 of the precipitation totals.

The annual value of sunshine duration ranged from just over 1458 hours in Śnieżka and 1564 hours in Mława to 2127 hours in Łeba.

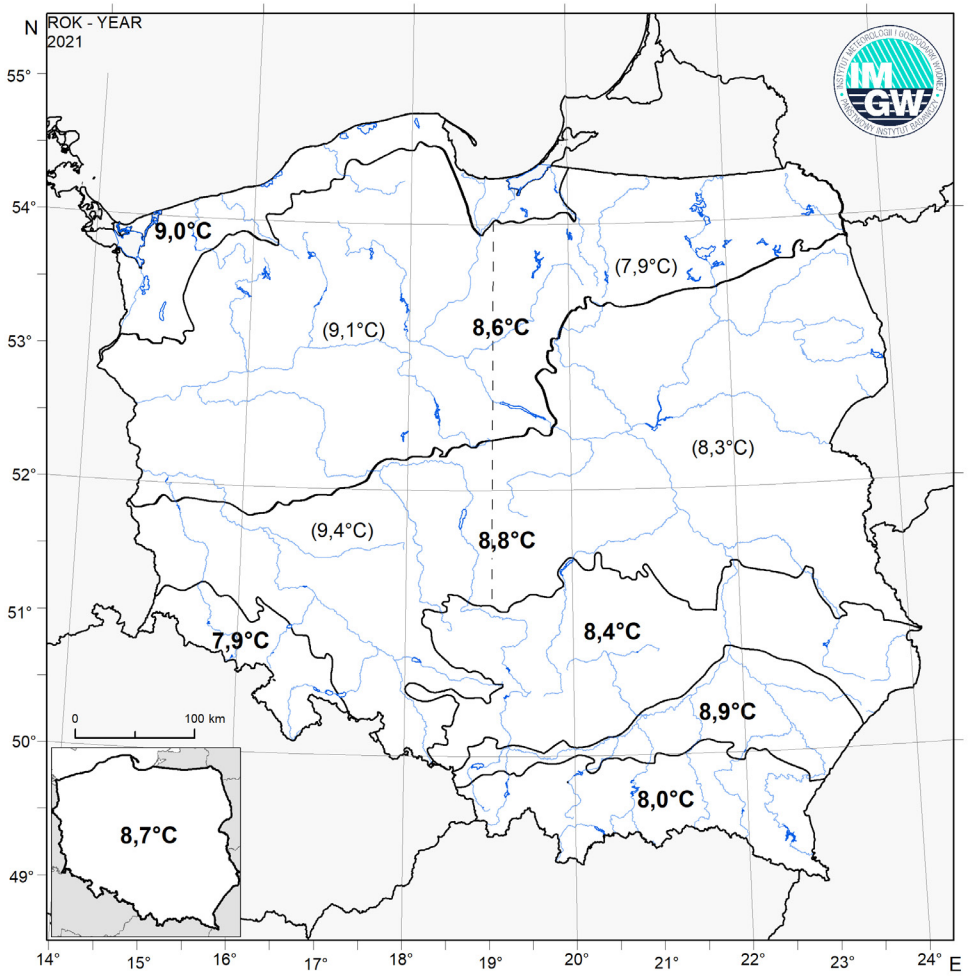
## SPIS TREŚCI

# AIR TEMPERATURE

The spatial variability of air temperature in 2021 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 region of the country in 2021 was almost the entire western part of Poland and the Vistula valley in its upper reaches to Sandomierz. Whereas, the coldest was, except for the higher parts of the Sudetes and the Carpathians, 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 coldest areas on an annual basis is practically an exact reflection of the temperature variability in the long-term period 1991-2020.




Spatial variability of the average air temperature anomaly against the so-called climatological standard normal, i.e. the average value for the period 1991-2020, shows that the values of anomalies were between –0.5°C and 0.5°C.

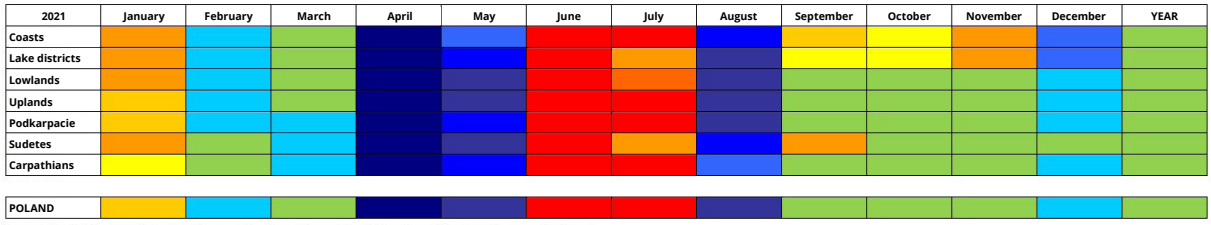



The area average air temperature is an indicator that allows the synthetic description of the thermal conditions in a given area. Moreover, it allows a comparison between regions and provides references to values determining temperature on a regional or global scale. For this purpose, uniform temperature values are calculated for the basic physio-geographical units of Poland. They 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 were divided into western and eastern parts along the 19°E meridian. Such a division allows showing possible differences related to the thermal regionalization of Poland. The warmest regions of Poland were the Coast belt and the Southern-Baltic Coastlands belt, where the area average temperature was 9.0°C. This value was higher than the normal for this region by only 0.1°C. The coldest region was the Sudetes, where the average annual temperature was 7.9°C and was 0.2°C lower than the standard normal. 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 1.2°C, and in the lowlands, it was 1.1°C. After taking these differences into account, it can be concluded that the warmest region of Poland in 2021 was the western part of the lowland belt, with an average annual air temperature of 9.4°C

# AIR TEMPERATURE
## Thermal conditions classification

| | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Z | W | L | J | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2021 | –1,0 | **–1,6** | 3,2 | 6,0 | 12,0 | 19,3 | **20,9** | 17,0 | 14,0 | 9,4 | 5,2 | –0,6 | –0,2 | 7,1 | 19,1 | 9,5 | 8,7 |
| Delta | 0,1 | –1,5 | 0,1 | –2,6 | –1,4 | 2,5 | 2,1 | –1,5 | 0,2 | 0,6 | 1,1 | –0,8 | 0,1 | –1,3 | 1,0 | 0,7 | –0,1 |

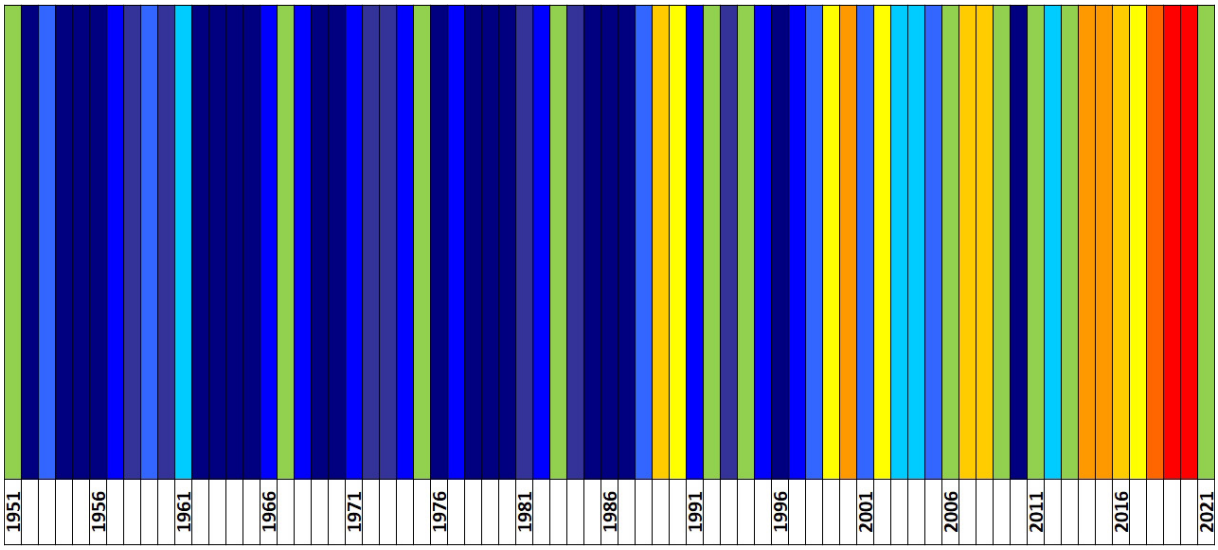
The air temperature is characterized by inter-annual variability. The warmest month in 2021 was July. The average temperature this month reached 20.9°C. It was 2.1°C higher than the average long-term temperature for this month. In turn, the coldest month was February. The average monthly temperature reached 1.6°C and was 1.5°C lower than the climatological standard normal. The first two months of summer, June and July, were particularly warm when the average monthly temperatures were over 2.0°C higher than the climatological standard normal. Spring was the period characterized by the strongest deviations from the normal. The temperature this season was as much as 1.3°C lower than the climatological standard normal. April was particularly anomalous when the temperature was 2.6°C lower. It was another cold May in Poland. In 2020 this month was colder.




| 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 | | |

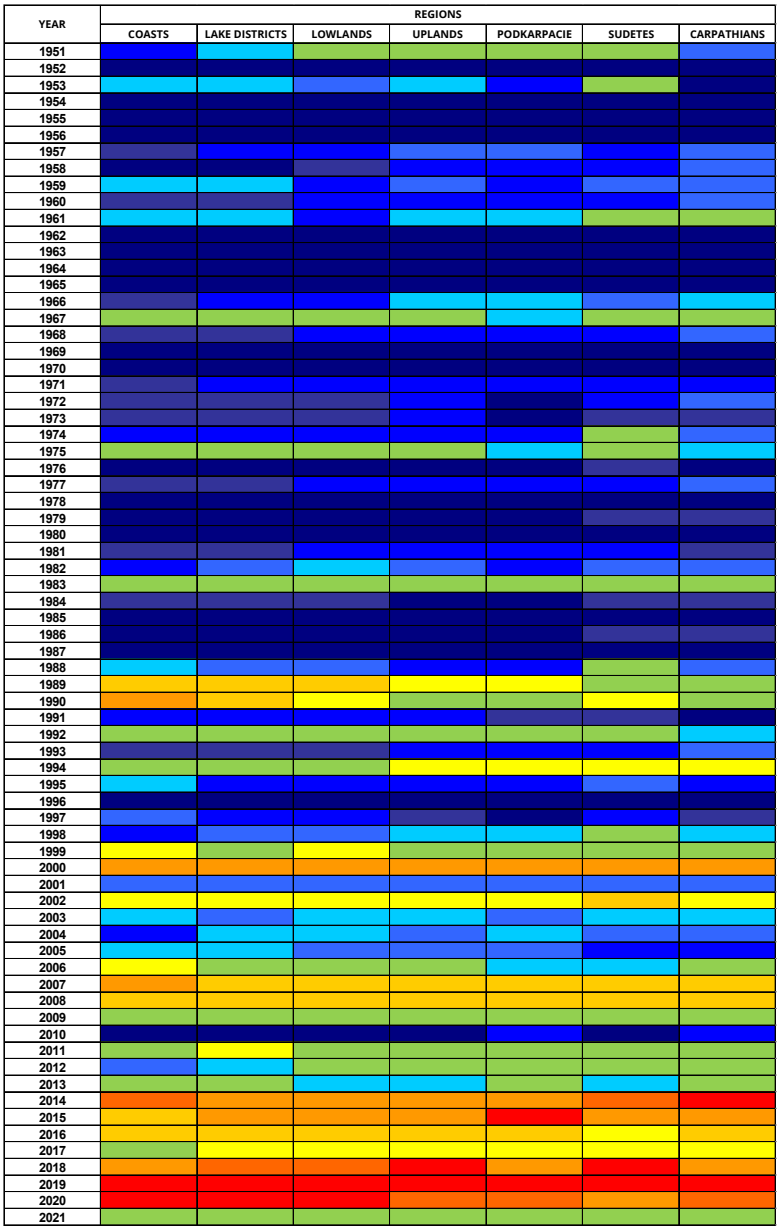
Descriptive classifications are often used to determine to what extent the thermal conditions of the month, the climatic season, or the year differed from typical conditions. One such qualification is based on an empirical cumulative distribution function of average air temperature values for each month, 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 descriptive names, as shown above.

On the basis of this classification, thermal conditions in almost all climatic regions were classified as: extremely warm in June, anomalously and extremely warm in July, very warm or warm in January, extremely cold in April, very cold or anomalously cold in August. In other months, thermal conditions in most regions were classified as thermally normal.




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 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 known as normal or warmer. The last decade has seen conditions ranging from very warm to extremely warm. The warm period is marked by the years 1996 and 2010. The year 1996 was extremely cold with an average temperature of 6.6°C, and the year 2010 was very cold, with an average temperature of 7.5°C. In 1996, it was determined by very cold winter months, both from January to February and in December. In the case of 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 have been years when thermal conditions variability in the regions was significant (e.g., 1951, 1966, and 1997). The warming process is clearly visible. As you move along the timeline, the cool colours are replaced by warm colours. This colour change reflects the global warming process in all regions.



# AIR TEMPERATURE
## Thermal conditions variability, 1951-2021

| Decade | Average air temperature (°C) | | Normal period |
|---|---|---|---|
| 1951-1960 | 7,25 | | |
| 1961-1970 | 7,08 | | |
| 1971-1980 | 7,25 | 7,19 | 1951-1980 |
| 1981-1990 | 7,61 | 7,31 | 1961-1990 |
| 1991-2000 | 7,91 | 7,59 | 1971-2000 |
| 2001-2010 | 8,22 | 7,91 | 1981-2010 |
| 2011-2020 | **9,33** | **8,73** | 1991-2020 |
| **2012-2021** | **9,31** | **8,76** | **1992-2021** |

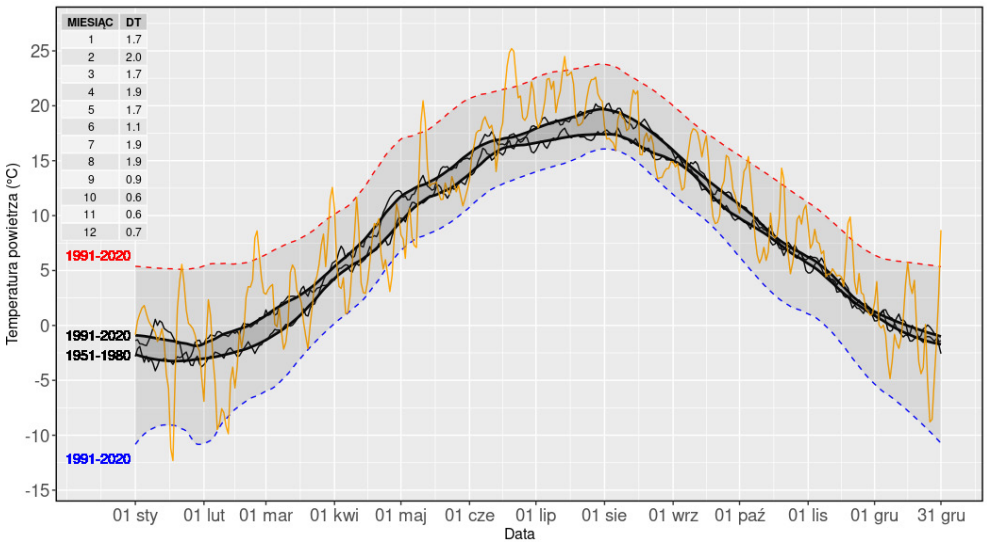
Average air temperature values in the individual decades of the period 1951-2020 are between 7.1°C (more precisely 7.08°C in the decade 1961-1970) and 9.3°C (more precisely 9.33°C in the last decade 2011-2020 ). The table showing those values illustrates the progressive increase of air temperature from 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 7.2°C in the period 1951-1980 up to 8.7°C for the last 30-year period, i.e., 1991-2020. It represents an increase of 1.5°C in terms of 30-year normals. Note that for the 30-year period 1992-2021, atypical in the climatological description, the average long-term air temperature value in Poland is 8.76°C. It has been the warmest 30-year period since 1951!

| YEAR | Air temperature (°C) | | | | |
|---|---|---|---|---|---|
| | Winter | Spring | Summer | Autumn | YEAR |
| 2000 | 0,5 | 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** |

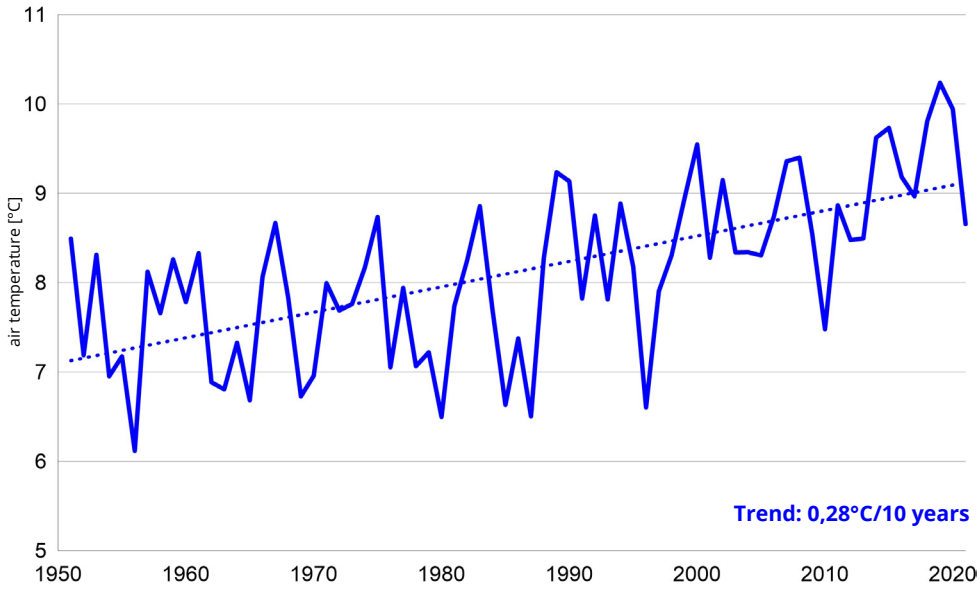
As mentioned before, the last 21 years have been the warmest period since the mid-20th century. During this period, the warmest winter was in the season December 2019 - February 2020 (season temperature 3.1°C), the warmest spring (March-May) occurred in 2007 (10.0°C), the warmest summer (June-August) in 2019 (19.9°C), and the warmest autumn (September-November) in 2006 (11.0°C). With regard to the year, the warmest one was recorded in 2019 (10.2°C).

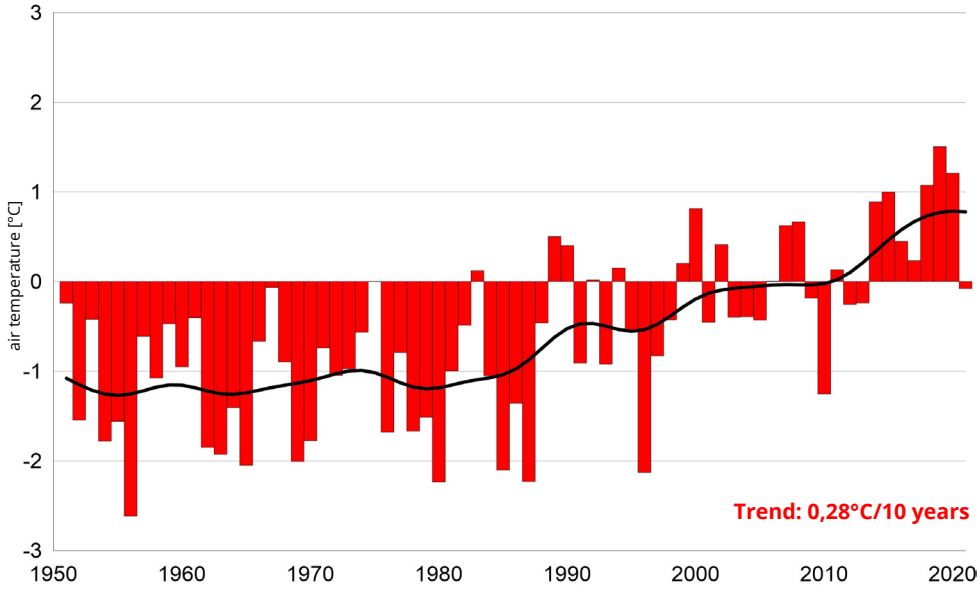
| YEAR | Air temperature (°C) | | |
|---|---|---|---|
| | YEAR | Anomaly relative to 1981-2010 | Anomaly relative to 1991-2020 |
| 2019 | 10,2 | 1,9 | 1,5 |
| 2020 | 9,9 | 1,6 | 1,2 |
| 2018 | 9,8 | 1,5 | 1,1 |
| 2015 | 9,7 | 1,4 | 1,0 |
| 2014 | 9,6 | 1,3 | 0,9 |
| 2008 | 9,4 | 1,1 | 0,7 |
| 2007 | 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 21 years, only in 2010, the annual average air temperature was below the long-term average for the period 1981-2010. The anomaly reached –0.8°C and was a of the 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 average temperature was below the normal, precisely 8. This is because the last 30-year period, 1991-2020, was the warmest since the middle of the 20th century.

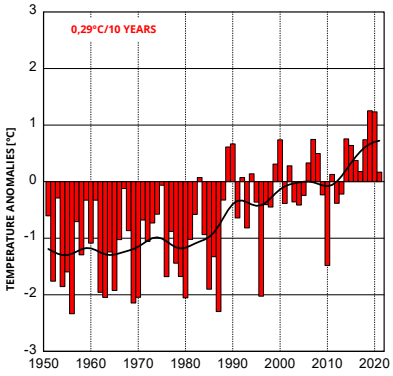



In 2021, the mean daily air temperature values (area average for Poland) were usually between 5% and 95% quantiles' values of average temperature (determined for measurements in the years 1991-2020). The episodes of heat waves, i.e., those in which the mean daily air temperature exceeded its 95% quantile value , were more frequent and much longer-lasting in the past year than the episodes of cold waves (mean daily air temperature below its 5% quantile value). To illustrate the scale of climate warming, the discussed diurnal variation is presented against the variability of long-term mean daily temperature values for the years 1951-1980 and 1991-2020. A constant difference between the mean daily values in the long-term period of 1991-2020 and 1951-1980 is clearly visible. This difference for each day is positive. Characteristically, these differences are stronger in January-August (between 1.1°C and 2.0°C) and weaker in September-December (between 0.6°C and 0.9°C).

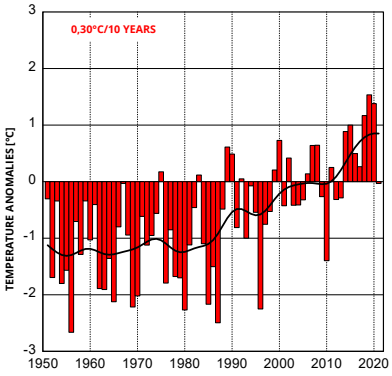


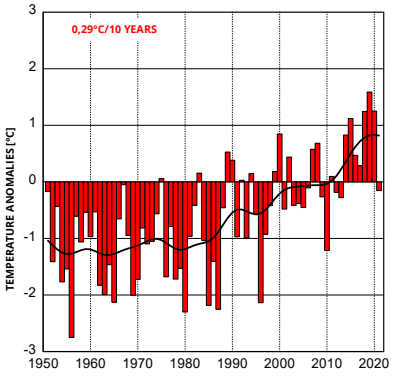

The increase of the average annual temperature during the period 1951-2020 is characterized by a positive, statistically significant (at level of 1 – α = 0.95) trend of 0.29°C/10 years. It corresponds to an increase of temperature in the given period from 1951 up to 2.0°C. To illustrate the variability of temperatures, series are often presented in the form of 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 (deviations) from the normal 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 fluctuations.



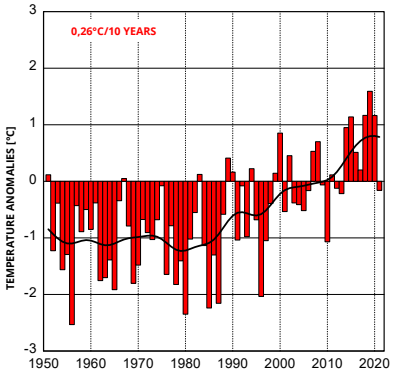

**REGION 1 – COASTS**



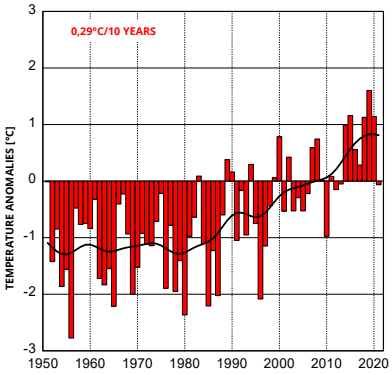

**REGION 2 – LAKE DISTRICTS**



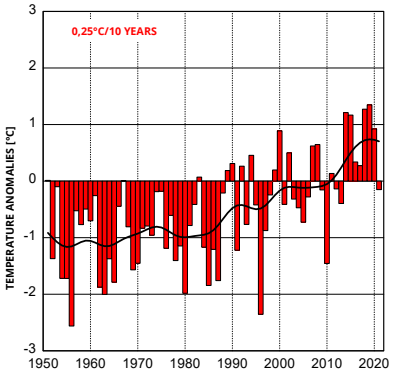

**REGION 3 – LOWLANDS**



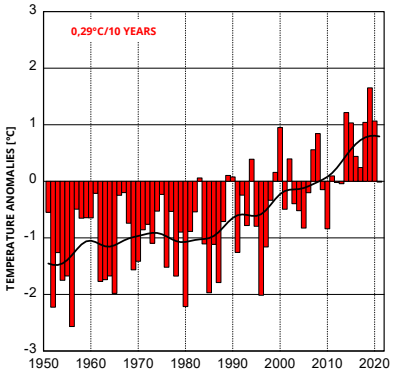

**REGION 4 – UPLANDS**




**REGION 5 – PODKARPACIE**




**REGION 6 – SUDETES**

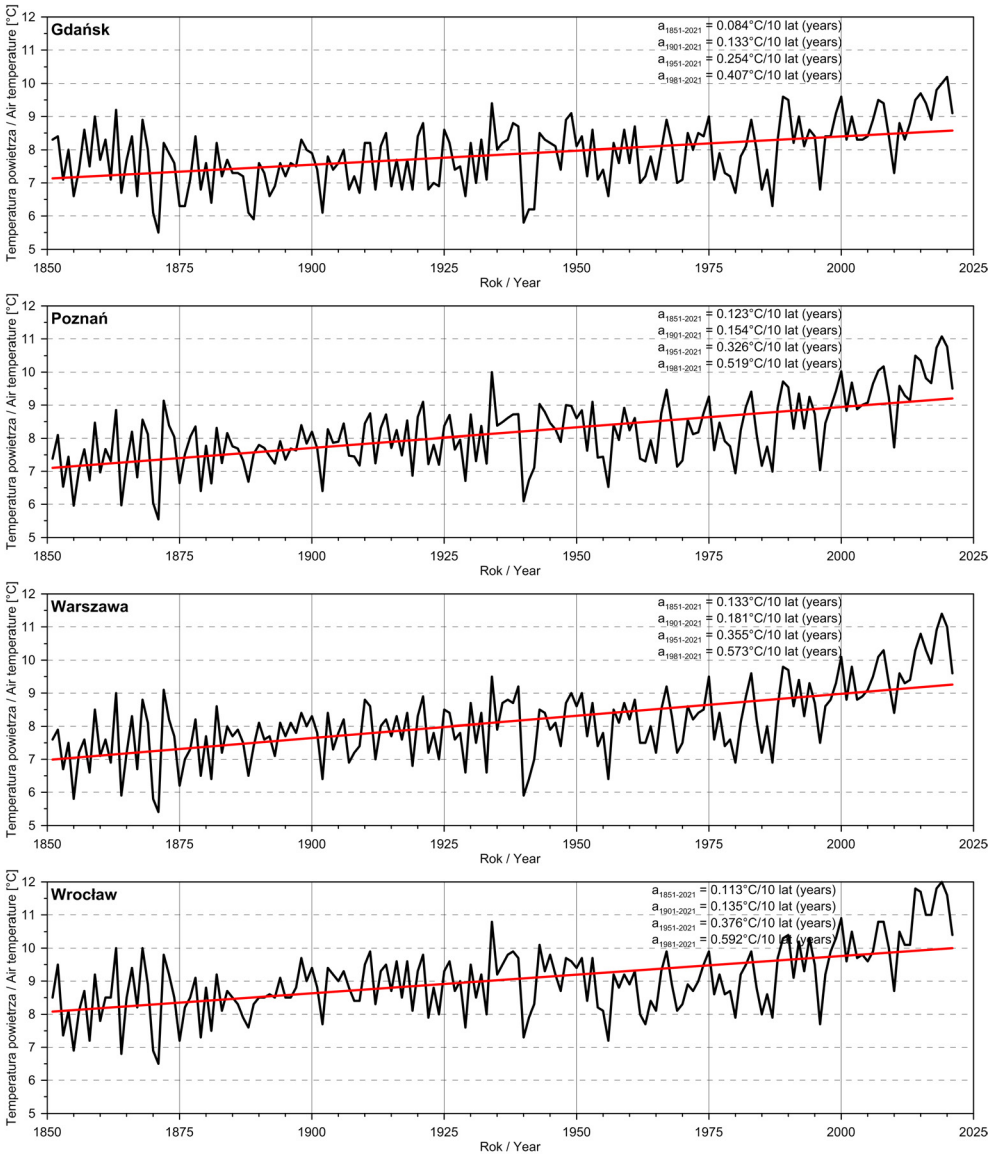



**REGION 7 – CARPATHIANS**

The series of deviations show the temperature variability in particular physio-geographical regions in the period 1951-2020. 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, where it exceeds 2.1°C, the weakest is in the Sudetes, reaching nearly 1.8°C since 1951.

# AIR TEMPERATURE

## Thermal conditions variability, 1851-2021

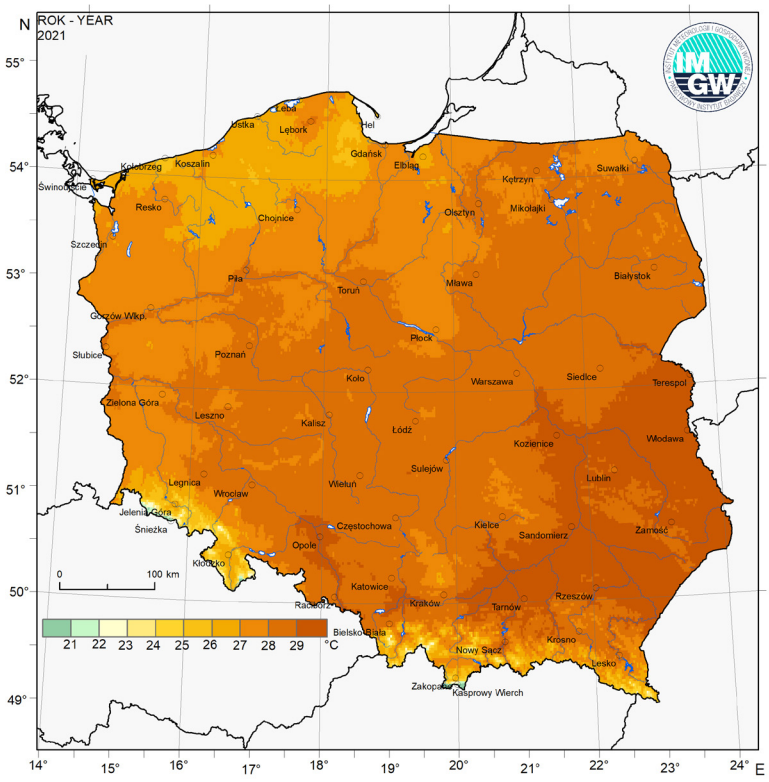


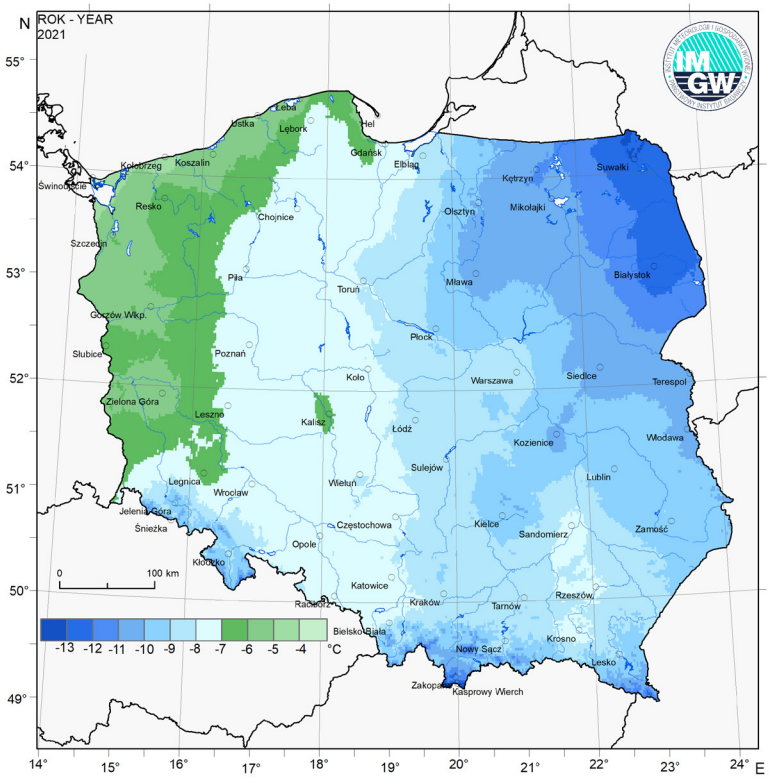

Regular instrumental temperature measurements began in Poland in the 18th century, including Warsaw (in 1779), Wrocław (in 1791), and Kraków (in 1792). However, at the earliest, they commenced in Gdańsk in 1739. In the first half of the 19th century, regular meteorological measurements were launched in other Polish cities. Intergovernmental Panel on Climate Change (IPCC) has been systematically publishing temperature variability analyses for the global and regional series since 1851. For this reason, we present the temperature variability in Gdańsk, Poznań, Warsaw, and Wrocław in the period 1851-2020. Each series documents an increase in air temperature, although the pace of change varies. The weakest temperature rise, reaching 1.4°C, occurs in Gdańsk, and the strongest, reaching 2.3°C, in Warsaw. Presented series clearly illustrate that the rate of warming is steadily increasing. Trend coefficients calculated for the period 1901-2020 are higher than those for 1851-2020, and these calculated for the period from 1951 – even higher. The values of the trend coefficients increased sharply in the period after 1980.

# 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 the south-east (the warmest areas) to north-west Poland (the coldest ones). The influence of the southern Baltic's cold water masses, responsible for the „flattening" of the highest temperature values, is clearly visible in late spring and summer. 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 part 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 in the western part of the country.

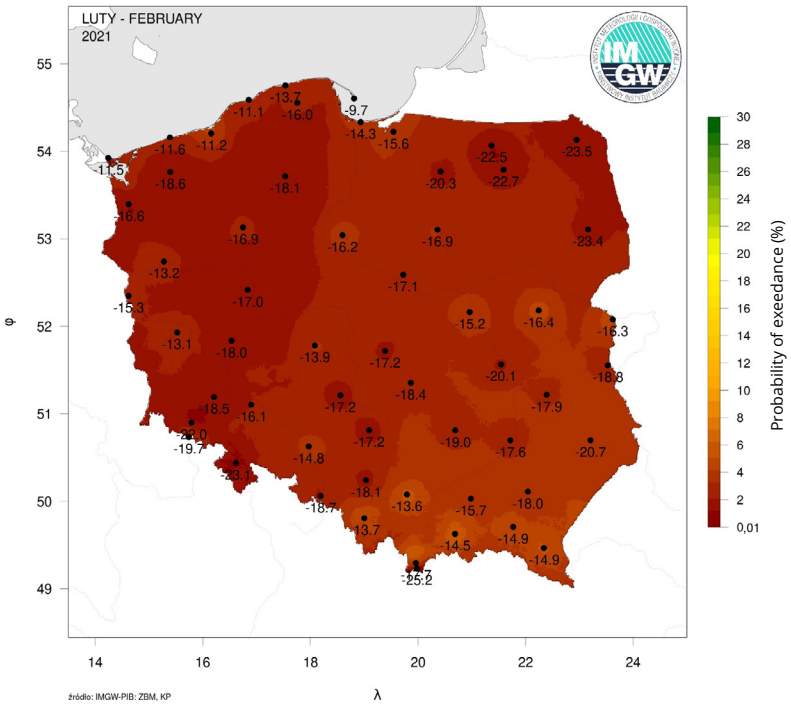


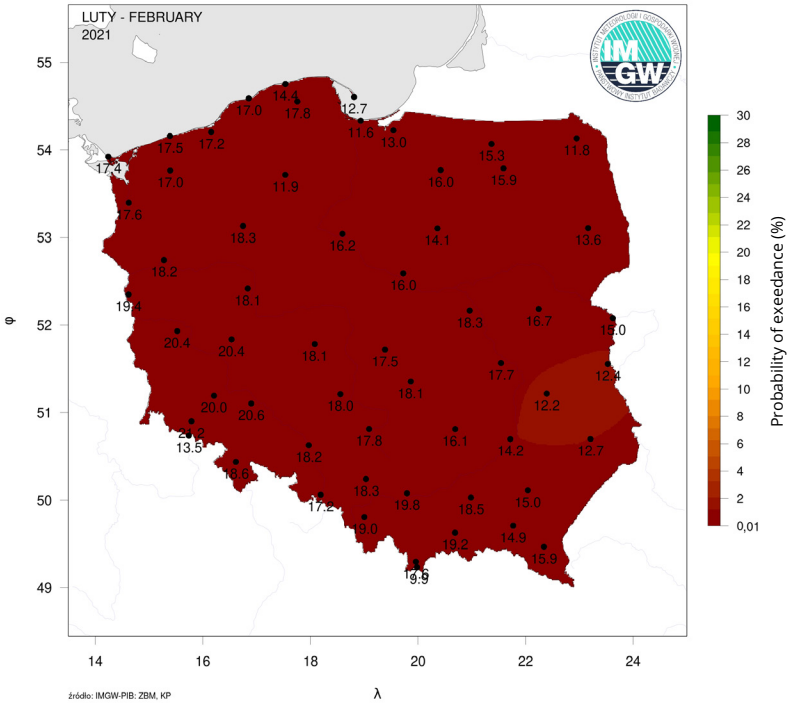



# AIR TEMPERATURE

## Extreme temperature in February – thermal hazards risk

Last February was the coldest month of the year, with an average air temperature of –1.6°C and an anomaly to the normal of –1.5°C. At the same time, there was a substantial temperature variability in that month with an amplitude exceeding 43°C (Jelenia Góra). At the other stations, the amplitudes of temperature changes were lower but often between 35-38°C. Such strong temperature variability cause numerous hazards - both for the natural environment, infrastructure, especially roads, municipal and energy infrastructure, agriculture, as well as for human health and life. The maximum temperature values recorded in February at the majority of stations in Poland corresponded to values of the probability of exceeding 5% or less. At the same time, in the case of absolute minimums of air temperature at most stations, the probabilities of occurrence of values lower than those recorded were 2% or less.

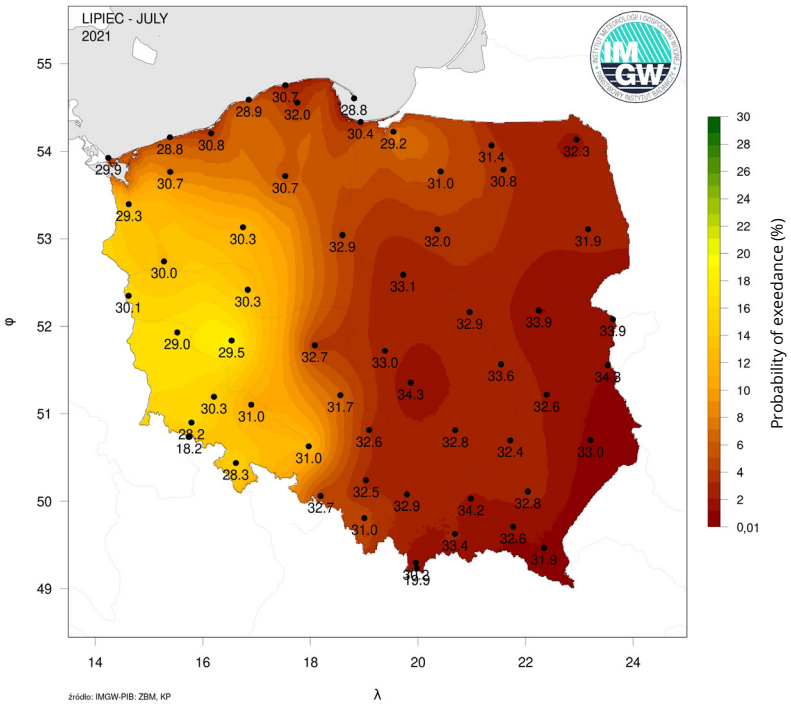


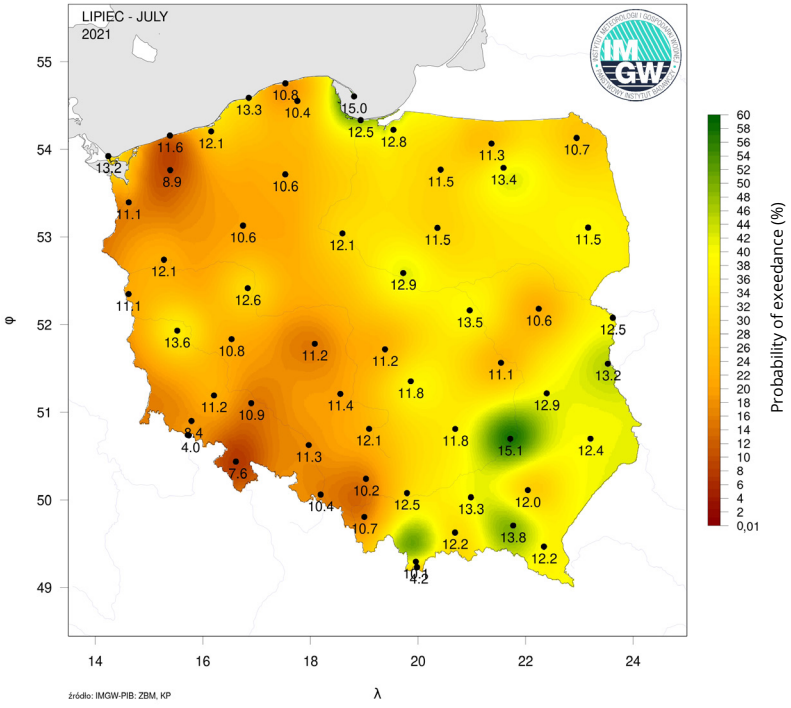



# AIR TEMPERATURE

## Extreme temperature in July – thermal hazards risk

In turn, July last year was the warmest month, with an average air temperature of 20.9°C and an anomaly compared to the normal of 2.1°C. At the same time, there was a substantial temperature variability in that month with amplitudes of up to 22,5°C (Sandomierz). At the other stations, the amplitudes of recorded temperatures were lower, but in some places they were close to the indicated. Similarly as in winter, also in summer, strong temperature variabilty cause numerous hazards to the environment, human health, agriculture, the availability of surface water resources, infrastructure, etc. The maximum temperature values recorded in July at the majority of stations located in the eastern part of the country corresponded to values which the probability of exceeding is within the range of 2-8%. At the same time, in the case of absolute minima of air temperature at most stations in eastern Poland, the probabilities of occurrence of values lower than those recorded were from 40% to 60%. It means that the nights in July were thermally close to normal.

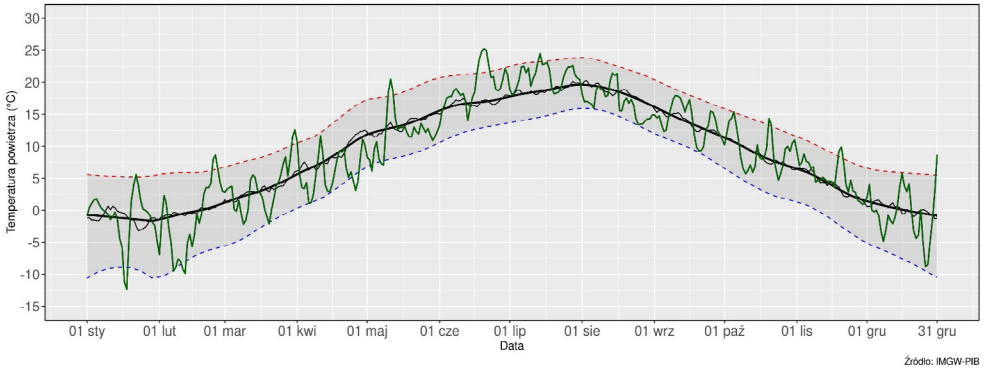


# AIR TEMPERATURE
## Interannual variability

DAILY VARIABILITY OF THE AREA AVERAGE TEMPERATURE

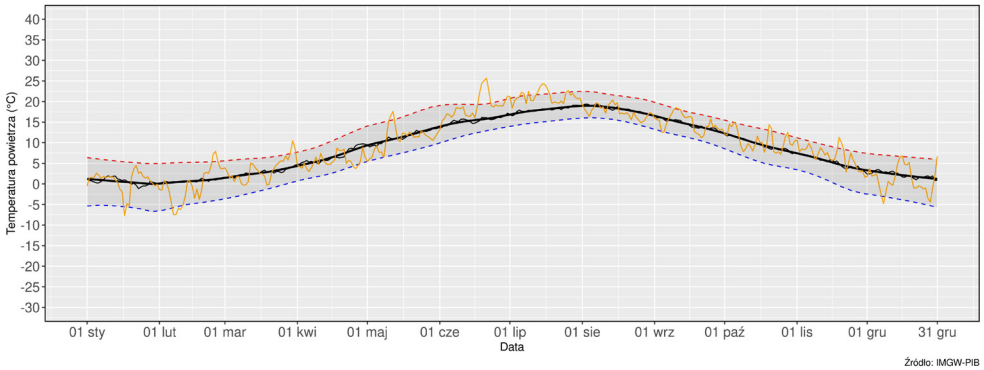
**Variability of the daily mean air temperature (TSRD) in Poland in 2021**
with reference to long-term characteristics 1991-2010; daily mean air temperature in 2021 (green line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression




Źródło: IMGW-PIB

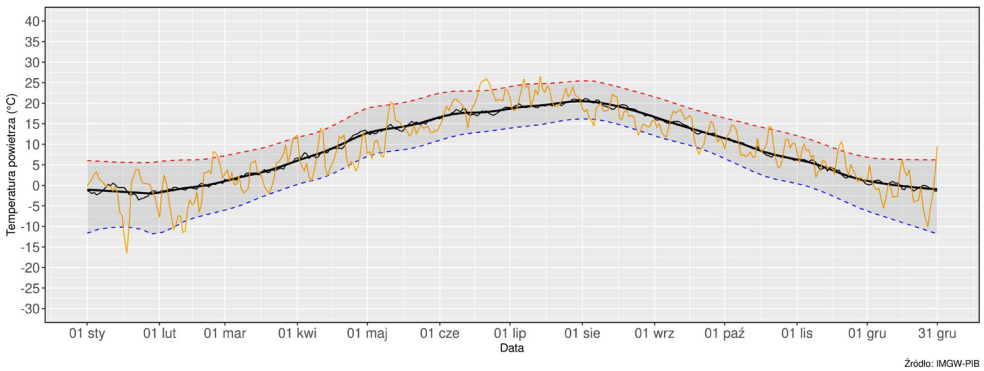
In 2021, the daily mean air temperature values (area average for Poland) were usually between the 5% and 95% quantiles values of the mean temperature (determined on the basis of measurements in the years 1991-2020). Heat waves episodes, i.e., those in which the daily mean air temperature exceeded the 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).

**HEL – variability of the daily mean air temperature (TSRD) in 2021**
with reference to long-term characteristics 1991-2010; daily mean air temperature in 2021 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression



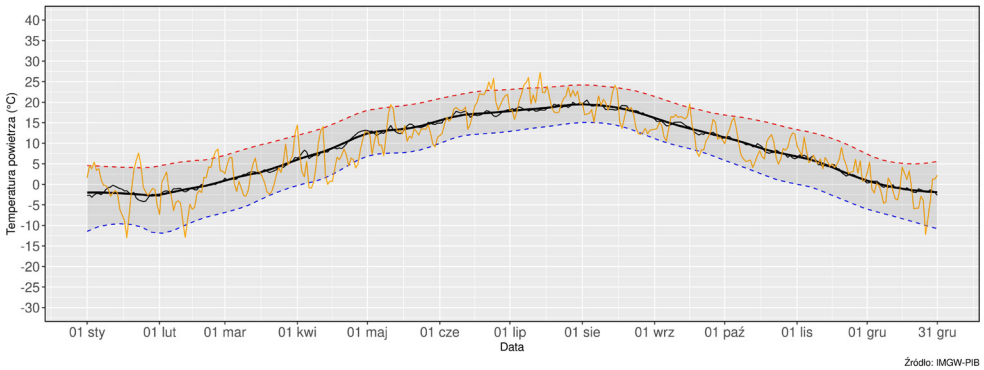

Źródło: IMGW-PIB

**WARSAW-OKĘCIE – variability of the daily mean air temperature (TSRD) in 2021**
with reference to long-term characteristics 1991-2010; daily mean air temperature in 2021 (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 2021**
with reference to long-term characteristics 1991-2010; daily mean air temperature in 2021 (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 mid-January and the first decade of February are clearly visible at all stations, as are the warm episodes in July and August.

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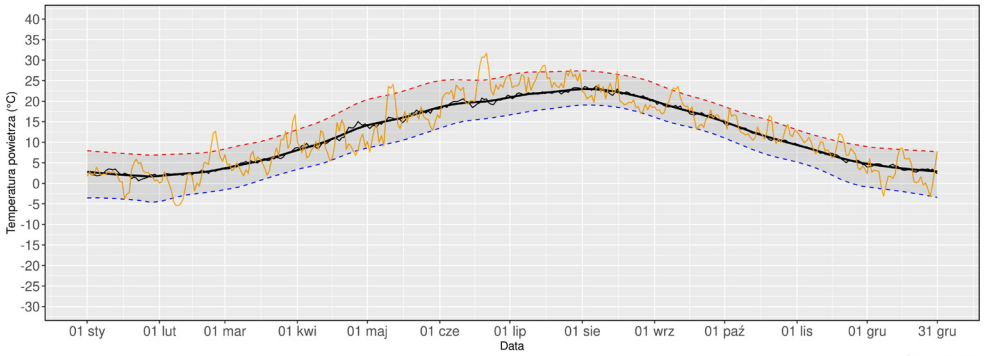
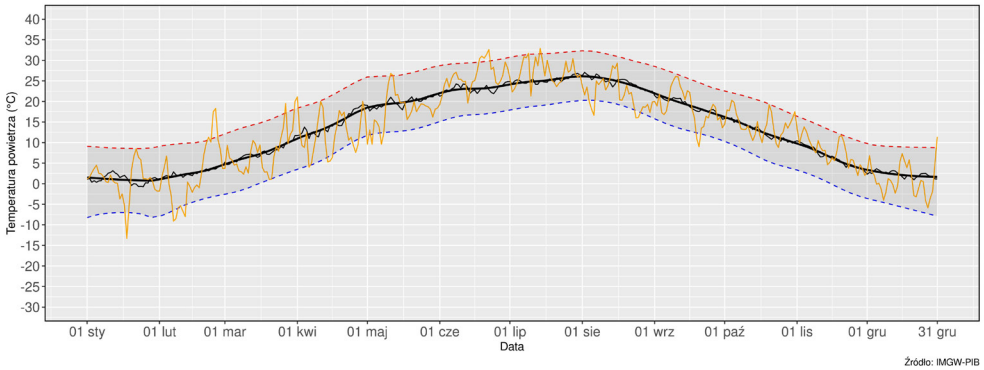
## ANNUAL VARIABILITY OF MAXIMUM DAILY TEMPERATURE

**HEL – variability of the maximum daily air temperature (TMAX) in 2021**
with reference to long-term characteristics 1991-2010; maximum daily air temperature in 2021 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) - smoothed with locally weighted polynomial regression



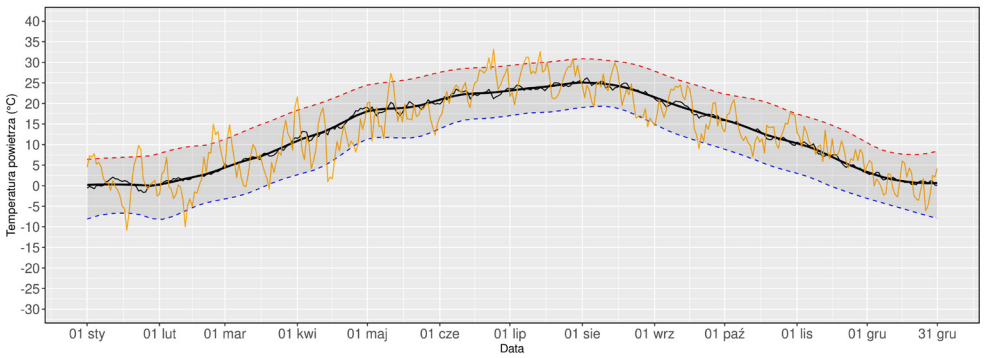

Źródło: IMGW-PIB

**WARSAW-OKĘCIE – variability of the maximum daily air temperature (TMAX) in 2021**
with reference to long-term characteristics 1991-2010; maximum daily air temperature in 2021 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) - smoothed with locally weighted polynomial regression




Źródło: IMGW-PIB

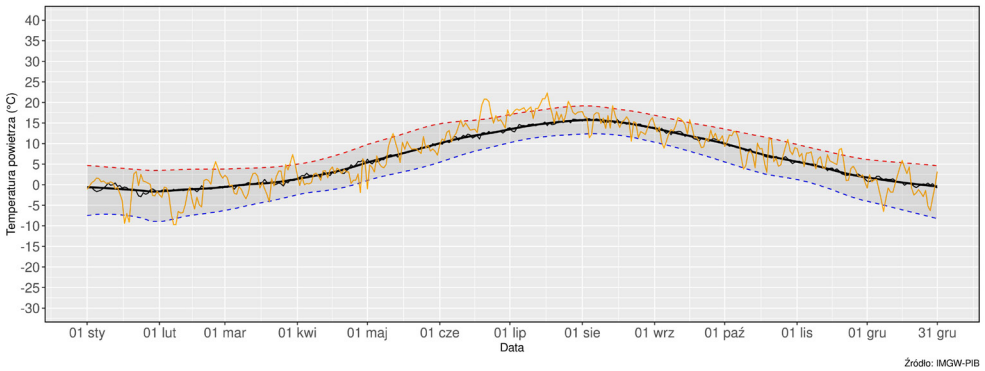
**KROSNO – variability of the maximum daily air temperature (TMAX) in 2021**
with reference to long-term characteristics 1991-2010; maximum daily air temperature in 2021 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) - smoothed with locally weighted polynomial regression




Źródło: IMGW-PIB

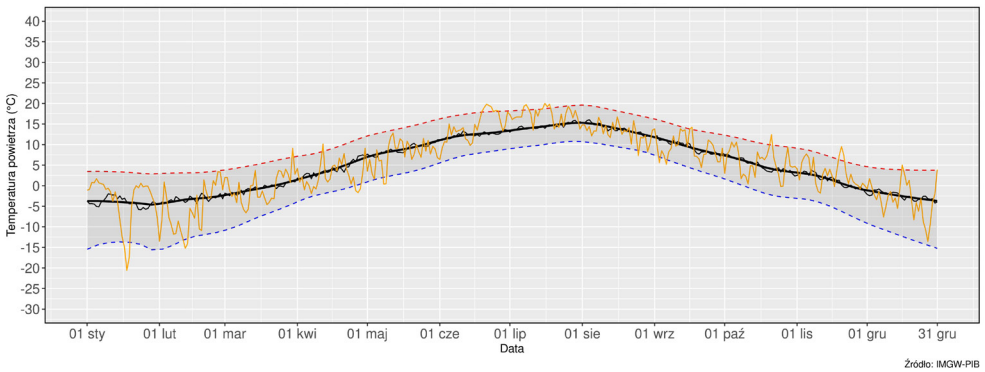
The interannual variability of the maximum daily temperature is reflected in the variability of daily mean temperature. It is worth noting that the cold episodes occurring in January and February were so strong that they were also confirmed by the variability of the maximum temperature at stations located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

**HEL – variability of the minimum daily air temperature (TMIN) in 2021**
with reference to the long-term characteristics 1991-2010; minimum daily air temperature in 2021 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression



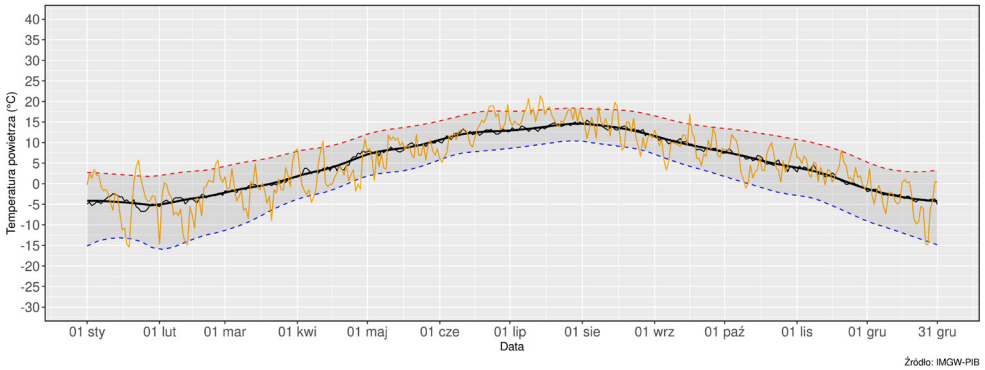

Źródło: IMGW-PIB

**WARSAW-OKĘCIE – variability of the minimum daily air temperature (TMIN) in 2021**
with reference to long-term characteristics 1991-2010; minimum daily air temperature in 2020 (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 2021**
with reference to long-term characteristics 1991-2010; minimum daily air temperature in 2021 (orange line),
long-term average (black line), quantiles: 95% (red line) and 5% (blue line) – smoothed with locally weighted polynomial regression

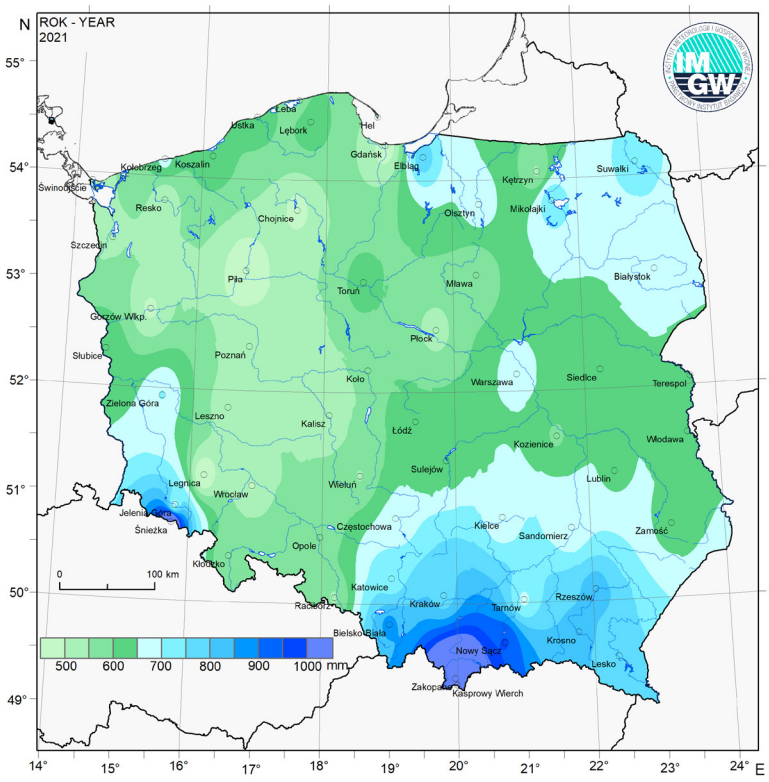


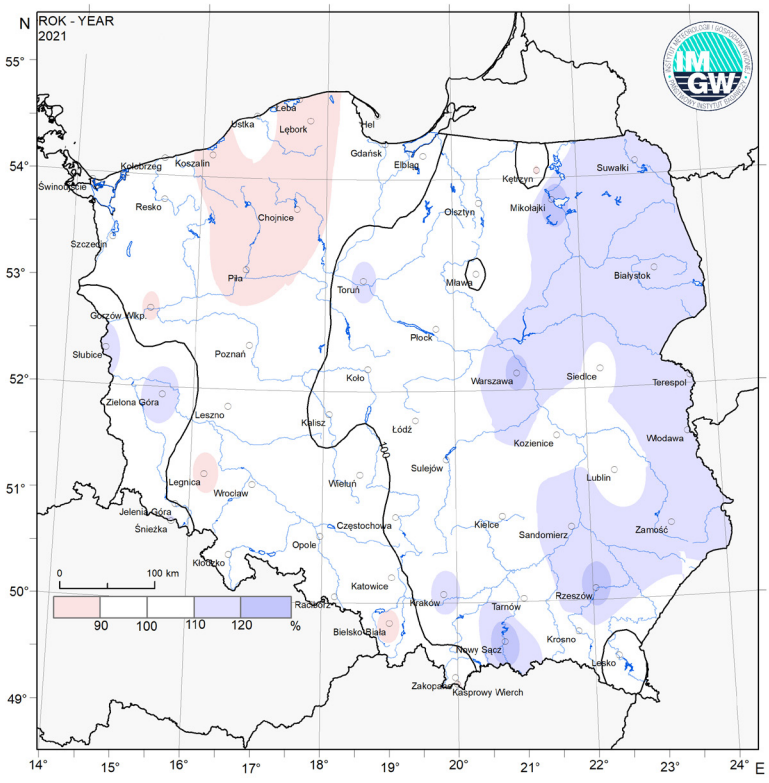

Źródło: IMGW-PIB

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

# PRECIPITATION

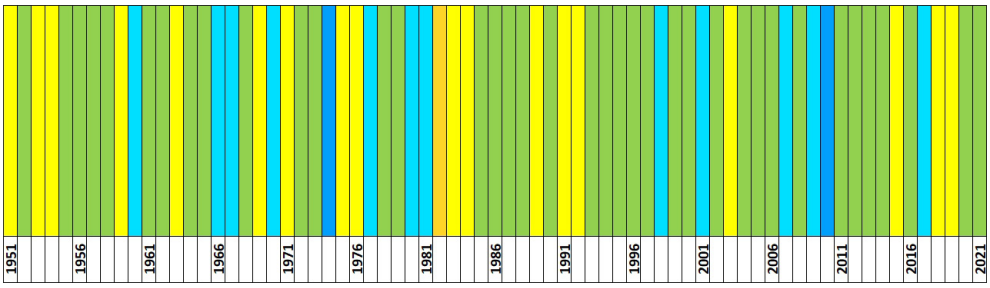
In 2021, the area-averaged annual total precipitation in Poland was 627.4 mm, nearly 103% of the normal determined on the basis of measurements from 1991 to 2020. According to the rank classification of the area average of total precipitation, covering the period since 1951, last year is in the 25th position. 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 in1982 (with only 422.6 mm, 69% of the normal). Precipitation totals in 2021 ranged from slightly over 450 mm to nearly 1050 mm, and the highest was recorded in the Tatra Mountains. In 2021, precipitation was between 80 and 190% of the long-term normal (1991-2020).



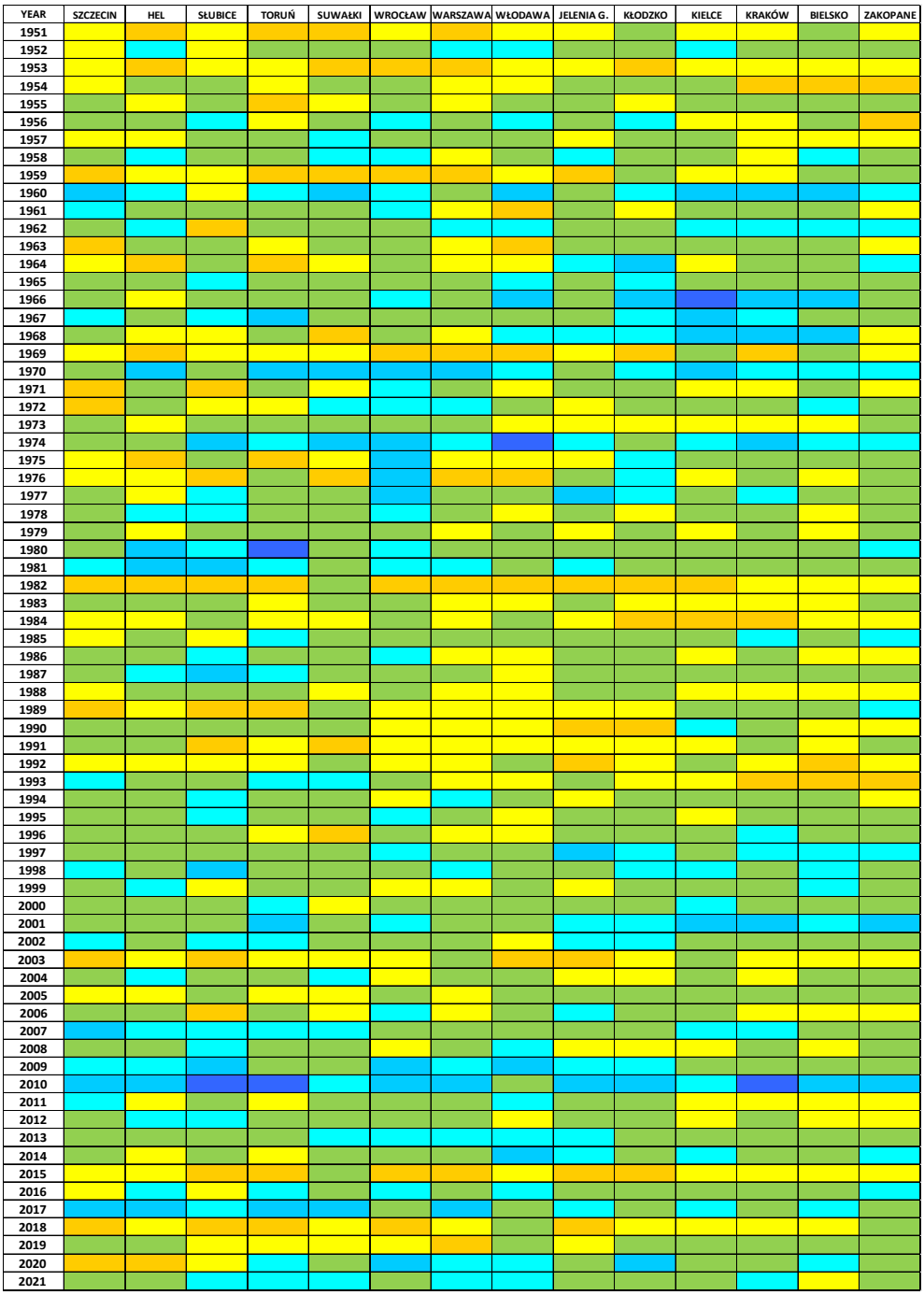



# PRECIPITATION
## Pluvial conditions classification

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 normal one.




| 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 |

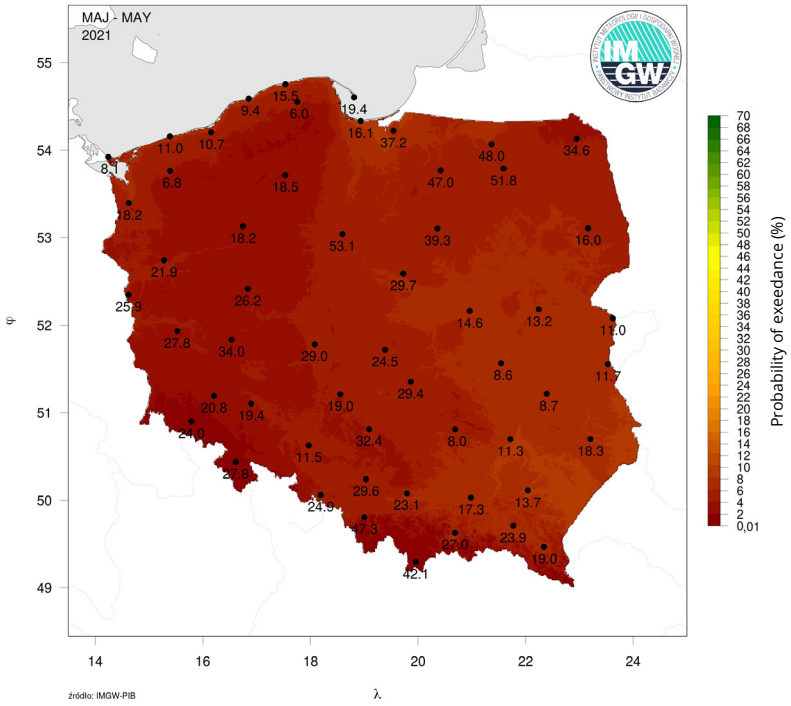


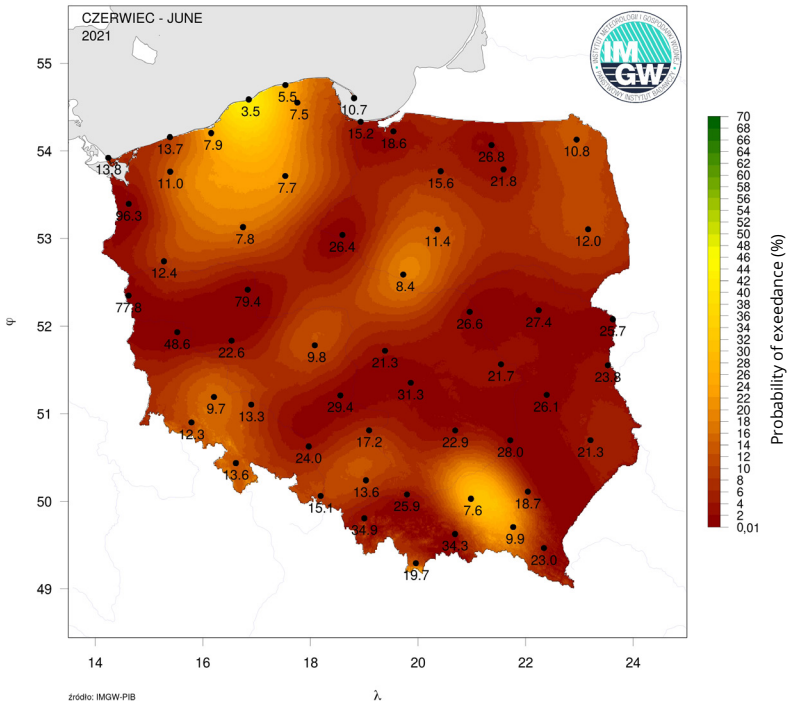

Presentation of the amount of precipitation in a given year as a percentage with reference to the amount of rainfall in the normal period permits the introduction of a classification that allows a descriptive presentation of the pluvial conditions prevailing at a given station or area of interest. Contrary 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 2021. At the same time, we can see that 2021 was another period in which many stations recorded below normal precipitation.

# PRECIPITATION

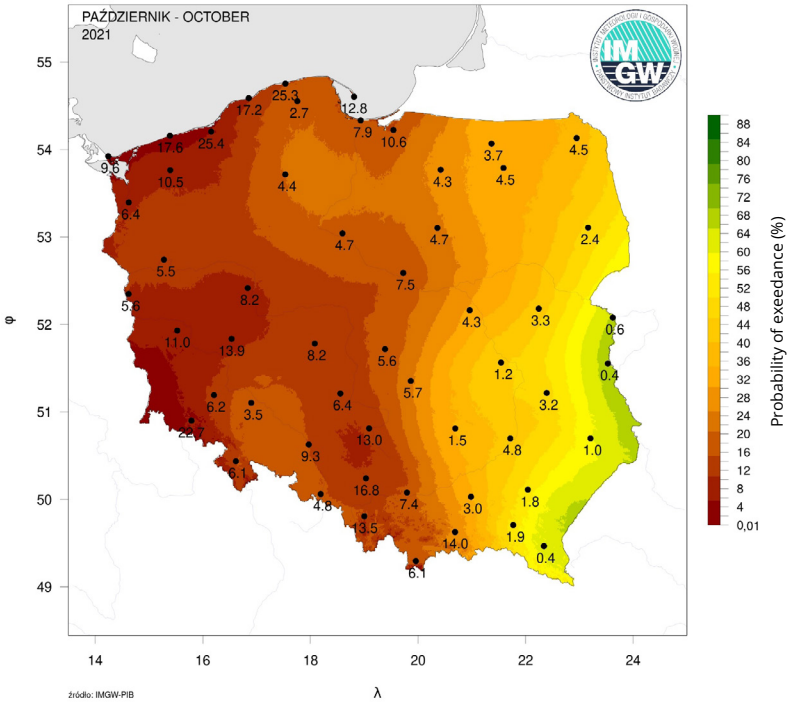
## Probabilities of exceedance of the maximum daily precipitation totals in May and June 2021

The presented maps of exceedance probability of maximum daily precipitation in May and June 2021 show both the diversity of pluvial conditions in these two months, and illustrate the occurrence of high precipitation in several large cities in Poland, which resulted in the so-called urban flash floods.



In October, pluvial conditions changed significantly when moving from west to east. While in the western part of the country there was precipitation with maximum daily totals, the probability of exceeding was 5% or less, in the eastern part of Poland, the maximum daily precipitation totals were low, and the probability of exceeding was 70%, calculated using data from 1991-2020.

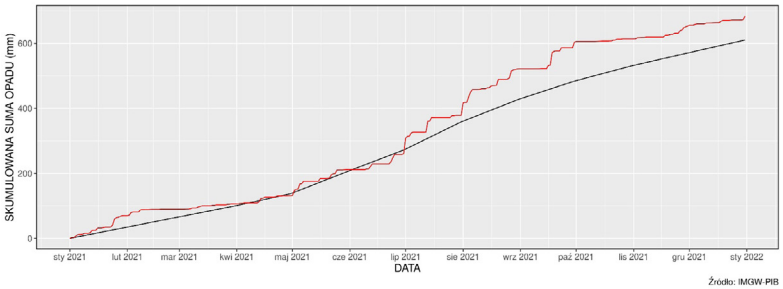


# PRECIPITATION

## Cumulative precipitation totals and cumulative number of days with precipitation

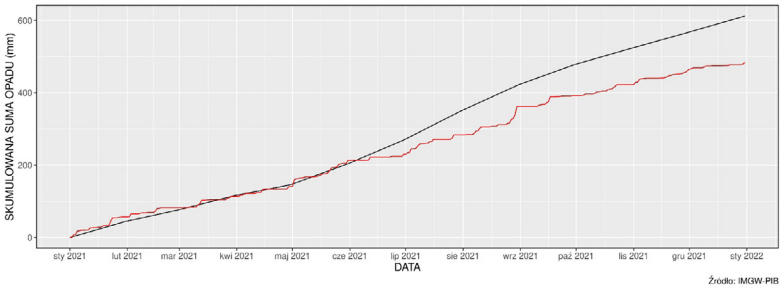
The graphs of cumulative precipitation totals in 2021 at selected stations enable us to visualize how the precipitation totals evolved over time during the past year with reference to the long-term normal. The periods of excess rainfall and their deficit compared to the normal are clearly visible. It is simple to identify non-precipitation periods and efficient precipitation events with large totals. The presented material also illustrates a strong variability of precipitation at individual stations with reference to the normals characterizing precipitation at a given station.

Cumulative daily precipitation totals in 2021 – red line
with reference to cumulative long-term normals 1991-2020 – black line, Białystok



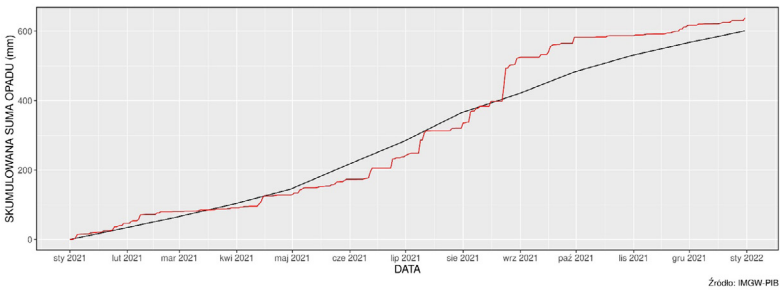

Źródło: IMGW-PIB

Cumulative daily precipitation totals in 2021 – red line
with reference to cumulative long-term normals 1991-2020 – black line, Chojnice



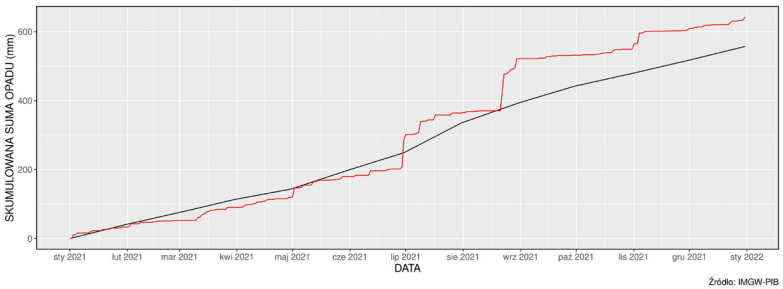

Źródło: IMGW-PIB

Cumulative daily precipitation totals in 2021 – red line
with reference to cumulative long-term normals 1991-2020 – black line, Lublin-Radawiec




Źródło: IMGW-PIB

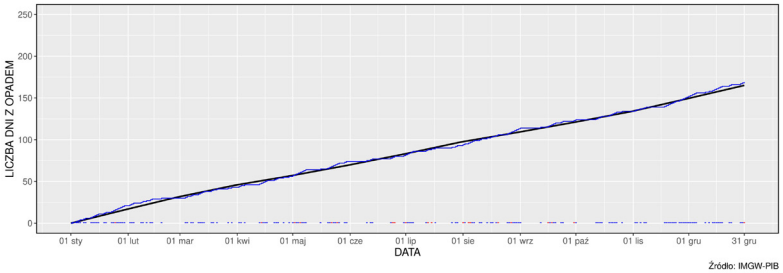
Cumulative daily precipitation totals in 2021 – red line
with reference to cumulative long-term normals 1991-2020 – black line, Słubice




Źródło: IMGW-PIB

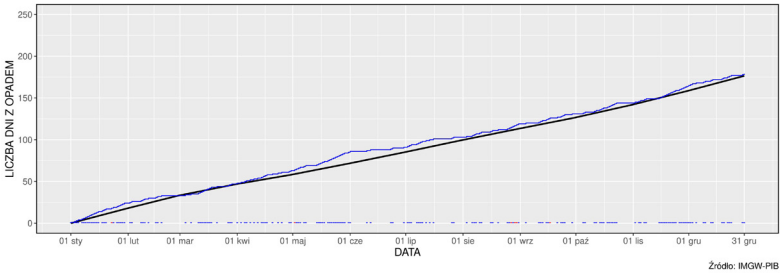
The interpretation of the cumulative precipitation total with reference to the normal informs us how often precipitation occurred in 2021 and whether there were more or less days with rainfall. If the annual precipitation was much higher than the normal and the number of days with rainfall was within 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 2021 – 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, Białystok



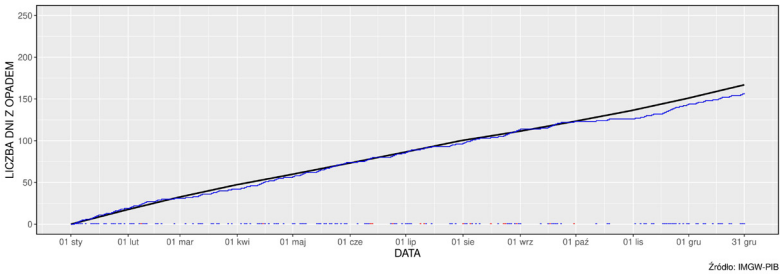

Źródło: IMGW-PIB

Cumulative number of days with precipitation (daily precipitation total > = 0.1 mm) in 2021 – 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, Chojnice



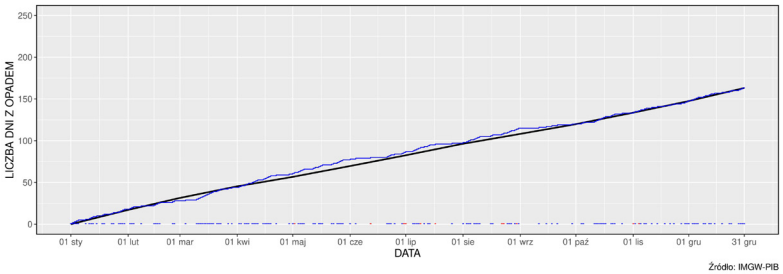

Źródło: IMGW-PIB

Cumulative number of days with precipitation (daily precipitation total > = 0.1 mm) in 2021 – 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, Lublin – Radawiec




Źródło: IMGW-PIB

Cumulative number of days with precipitation (daily precipitation total > = 0.1 mm) in 2021 – 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, Słubice




Źródło: IMGW-PIB

# PRECIPITATION
## Thunderstorms at selected stations*

| 2021 | June | | | July | | | August | | | YEAR |
|---|---|---|---|---|---|---|---|---|---|---|
| **Station** | **Thunder-storm** | **Distant thunder-storm** | **Total** | **Thunder-storm** | **Distant thunder-storm** | **Total** | **Thunder-storm** | **Distant thunder-storm** | **Total** | **Total** |
| BIAŁYSTOK | 4 | 12 | 16 | 4 | 18 | 22 | 3 | 7 | 10 | 61 |
| ELBLĄG-MILEJEWO | 4 | 8 | 12 | 10 | 26 | 36 | 8 | 6 | 14 | 78 |
| HEL | 1 | 6 | 7 | 3 | 11 | 14 | 1 | 5 | 6 | 40 |
| KALISZ | 3 | 9 | 12 | 7 | 19 | 26 | 1 | 10 | 11 | 53 |
| KASPROWY WIERCH | 3 | 17 | 20 | 6 | 27 | 33 | 2 | 8 | 10 | 76 |
| KOŁOBRZEG-DŹWIRZYNO | 3 | 9 | 12 | 9 | 12 | 21 | 3 | 4 | 7 | 55 |
| KOSZALIN | 1 | 3 | 4 | 8 | 10 | 18 | 3 | 6 | 9 | 48 |
| KOZIENICE | 10 | 19 | 29 | 18 | 24 | 42 | 5 | 11 | 16 | 99 |
| KRAKÓW-BALICE | 14 | 17 | 31 | 28 | 33 | 61 | 9 | 9 | 18 | 124 |
| KROSNO | 10 | 15 | 25 | 17 | 57 | 74 | 7 | 24 | 31 | 161 |
| ŁEBA | 1 | 6 | 7 | 3 | 10 | 13 | 4 | 10 | 14 | 58 |
| ŁÓDŹ-LUBLINEK | 8 | 12 | 20 | 15 | 23 | 38 | 5 | 10 | 15 | 77 |
| MŁAWA | 4 | 7 | 11 | 28 | 43 | 71 | 2 | 9 | 11 | 108 |
| OPOLE | 3 | 9 | 12 | 6 | 17 | 23 | 0 | 4 | 4 | 42 |
| POZNAŃ-ŁAWICA | 1 | 2 | 3 | 4 | 0 | 4 | 5 | 3 | 8 | 26 |
| RZESZÓW-JASIONKA | 3 | 23 | 26 | 4 | 26 | 30 | 4 | 17 | 21 | 84 |
| SIEDLCE | 3 | 16 | 19 | 6 | 25 | 31 | 3 | 11 | 14 | 77 |
| SZCZECIN | 2 | 1 | 3 | 2 | 1 | 3 | 2 | 1 | 3 | 21 |
| ŚNIEŻKA | 0 | 5 | 5 | 3 | 16 | 19 | 5 | 3 | 8 | 40 |
| TORUŃ | 2 | 4 | 6 | 4 | 13 | 17 | 2 | 5 | 7 | 35 |
| WARSZAWA-OKĘCIE | 10 | 11 | 21 | 22 | 14 | 36 | 6 | 3 | 9 | 81 |
| WŁODAWA | 5 | 20 | 25 | 4 | 23 | 27 | 6 | 17 | 23 | 82 |
| WROCŁAW-STRACHOWICE | 9 | 8 | 17 | 13 | 13 | 26 | 5 | 5 | 10 | 60 |
| ZAKOPANE | 6 | 26 | 32 | 8 | 41 | 49 | 1 | 11 | 12 | 111 |
| ZIELONA GÓRA | 8 | 9 | 17 | 2 | 21 | 23 | 5 | 12 | 17 | 76 |
| **Total observed In the country** | **195** | **528** | **723** | **391** | **980** | **1371** | **154** | **386** | **540** | **3239** |

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

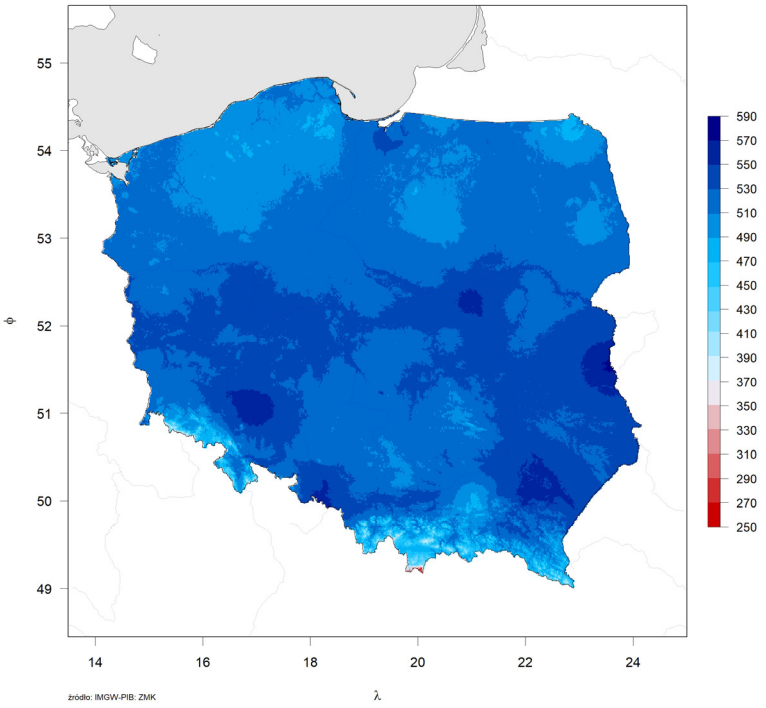
Thunderstorms are a dangerous phenomenon. The thunderstorm season in Poland culminates in the summer, from June to August. In July 2021, more than 1300 thunderstorms were observed in Poland. Most in Krosno (74), Mława (71) and in Kraków-Balice (61). In total, over 3200 thunderstorms were recorded in the country last year. Most in Krosno (161), Kraków-Balice (124) and Zakopane (111). In turn, the least number of stormes were recorded in Szczecin (21) and Poznań (26).

# CLIMATIC WATER BALANCE
## Warm half-year

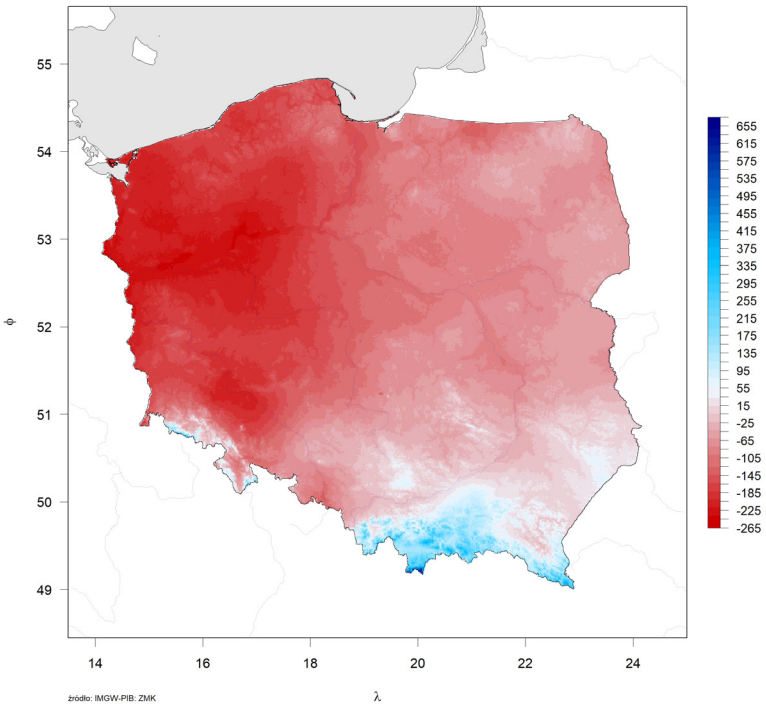
The climatic water balance (CWB) is the difference between the precipitation, i.e. precipitation total, and evapotranspitation, which can be determined based on measurements or using empirical formulas. Positive CWB value means that there was more precipitation than evaporation during the analysed period.
In the case of 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 important sector of the economy as agriculture, is of great significance.
The evaporation values are high. They range between 350 mm to 590 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 CWB values were generally present in the higher parts of the Sudetes and the Carpathians Mountains, and Podkarpacie. In the remaining area of Poland, the KWB in May-October 2021 was negative.
The loss of moisture in western Poland, reaching nearly 260 mm in the warm season, is of particular concern.

**Total Evapotranspiration – May – October 2021**



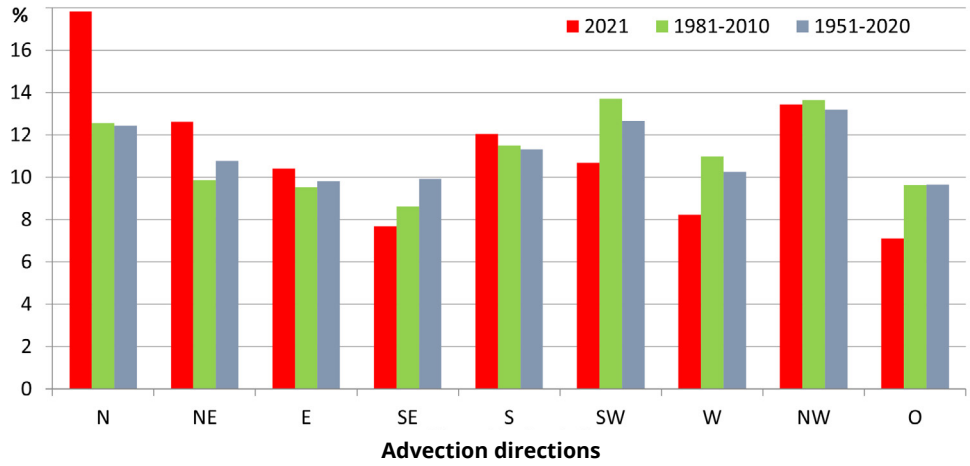

**Total Climatic Water Balance – May – October 2021**



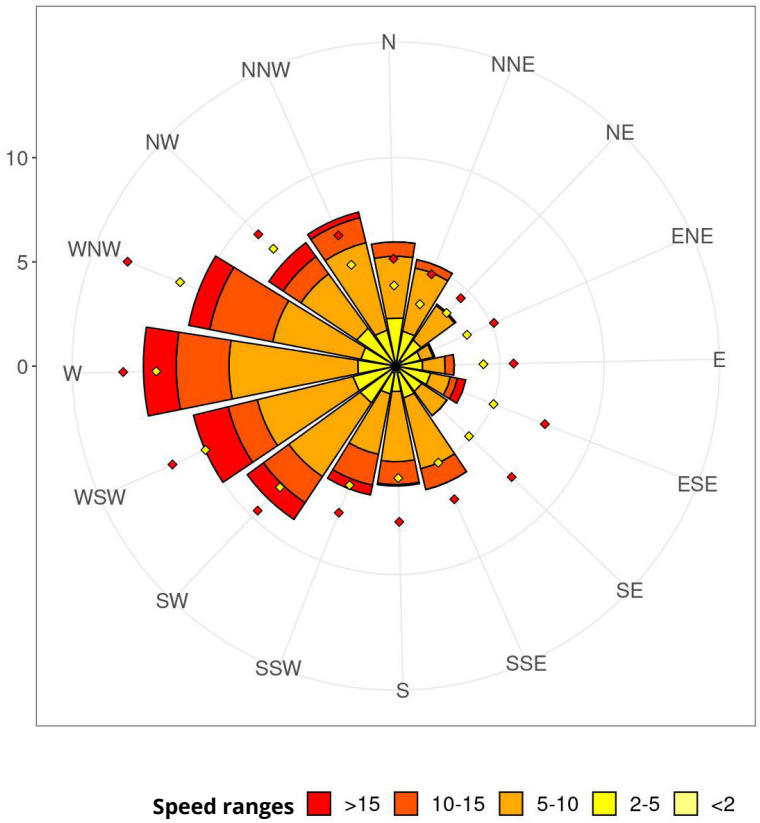
# ATMOSPHERIC CIRCULATION
## Indices and surface wind

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

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 anti-cyclonic). In a given season of the year, these parameters determine the thermal and humidity characteristics of air masses flowing over the studied area.



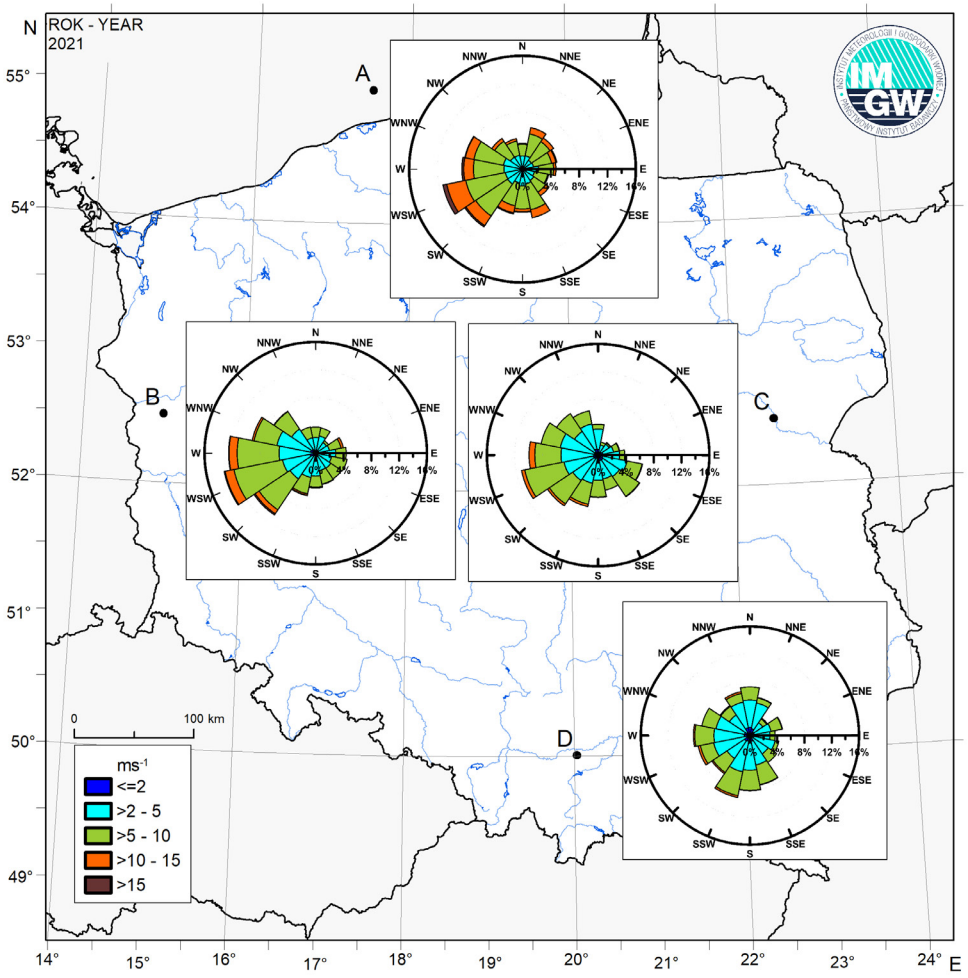

The circulation index's calendar indicates that in 2021 the air masses flowing from the north (from NW to NE, nearly 46%) and then from the west (from SW to NW, almost 33%) were prevailing in 2021. Compared to the normal period, the frequency of the flow of air masses from the north was higher by nearly 8%, and from the west, it was almost 5% lower than in the long-term period 1991-2020. The frequency of occurrence of air masses flowing from the south, from SE to SW, was in 2021 lower by more than 6% compared to the long-term period.



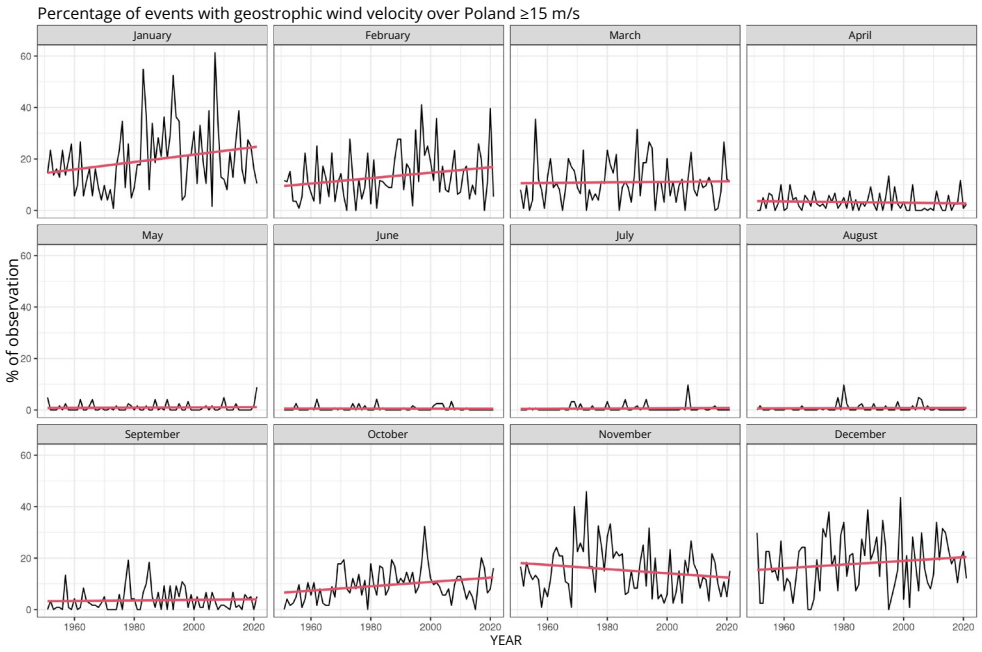

| Characteristic | V (m/s) | u (m/s) | v (m/s) |
|---|---|---|---|
| **Mean (1991-2020)** | **8.2** | **2.7** | **0.5** |
| **Mean** | **7.9** | **3.0** | **0.2** |
| Minimum | 0.4 | –17.5 | –15.6 |
| Quantile $Q_{10}$ | 3.3 | –3.5 | –6.6 |
| Quantile $Q_{50}$ | 7.1 | 2.4 | 0.2 |
| Quantile $Q_{90}$ | 13.9 | 11.0 | 7.2 |
| Maximum | 24.7 | 22.6 | 18.8 |
| **Mean direction (1991-2020)** | **259** | | |
| **Mean direction** | **266** | | |
| **Coefficient of constancy η** | **0.38** | | |
| **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.

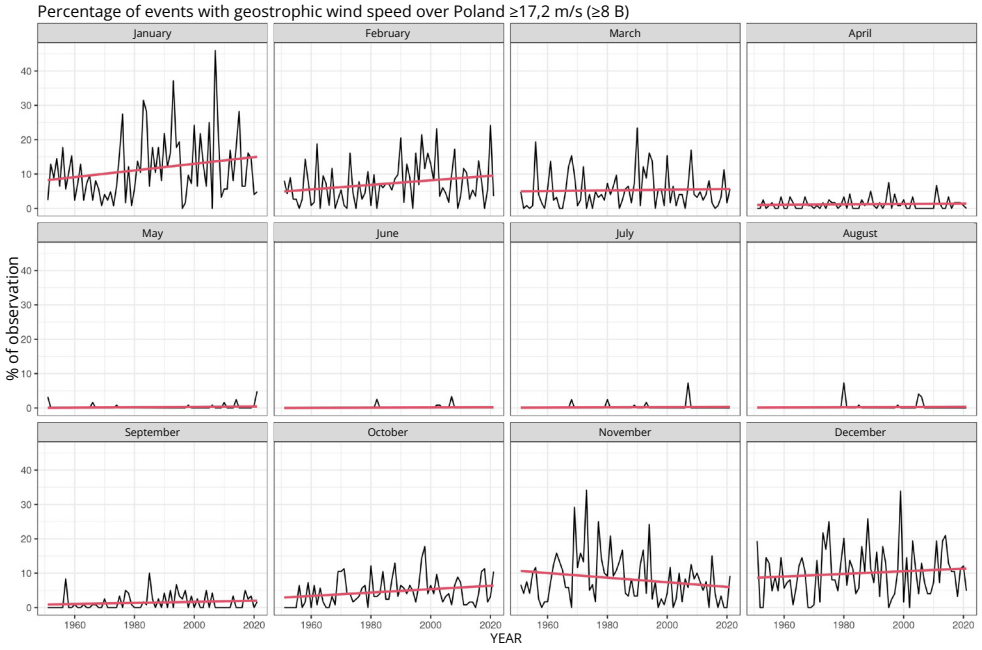
The average annual wind vector in 2021 was similar to the vector characteristic for the long-term period 1991-2020, which shows a moderate advection of air masses from the west. It is also reflected in the wind rose, showing the dominance of advection from the SW to NW sectors.




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




The increase in danger associated with strong wind has been observed for many years. This danger is particularly frequent in the period from October to March. 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. The threshold of 15 $ms^{-1}$ is a critical value, the exceedance of which is the basis for issuing a 1st level warning.

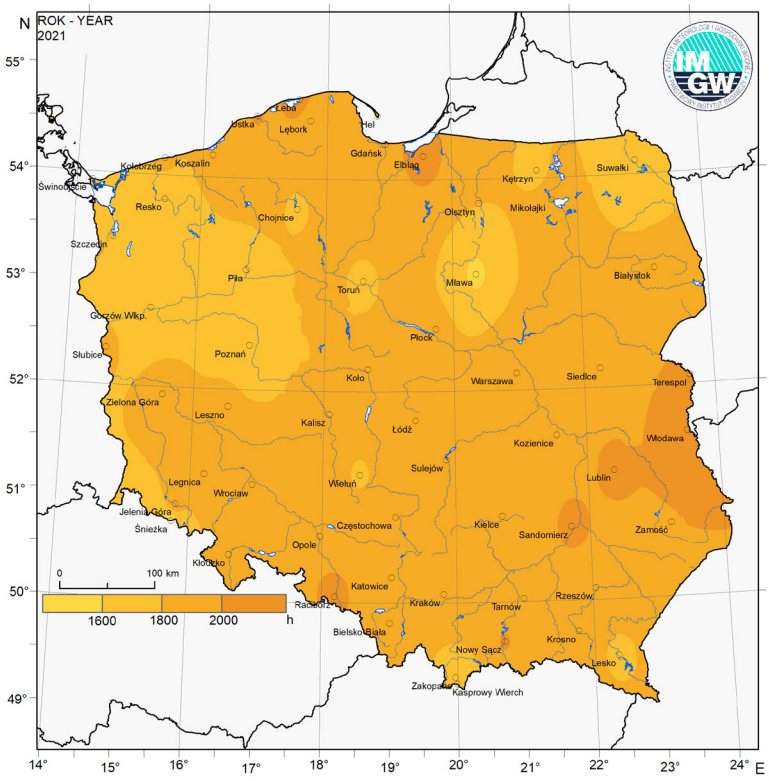


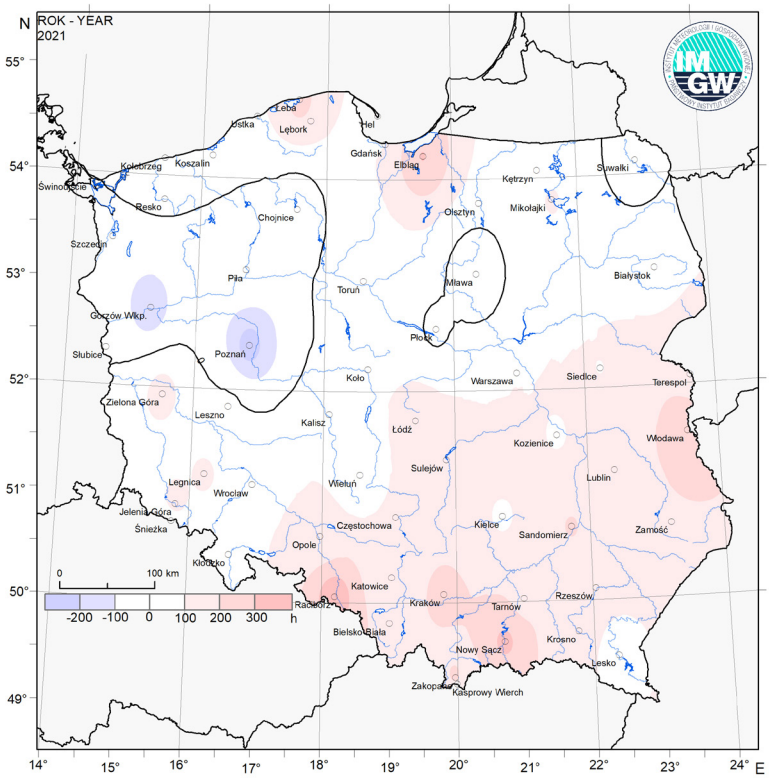

A wind speed of at least 17.2 $ms^{-1}$ is called a strong gale – It is the wind force threshold for 8 on the Beaufort scale. At sea, the waves reach a height of around 5 m, tree branches can be broken on land, and motor vehicles may have difficulties keeping the track. As the speed increases, the destructive force of the wind increases, and the damage becomes more severe and extensive. There is also a systematic increase in the frequency of wind events above 17.2 $ms^{-1}$. Since the mid-twentieth century, the frequency of such winds has increased by 3.5% in October, more than 3% in December, 7% in January, and 4.7% in February.

# 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 effective sunshine duration to the maximum possible, determined by the length of the day (i.e., from sunrise to sunset) was between 35% and 47% in 2021.

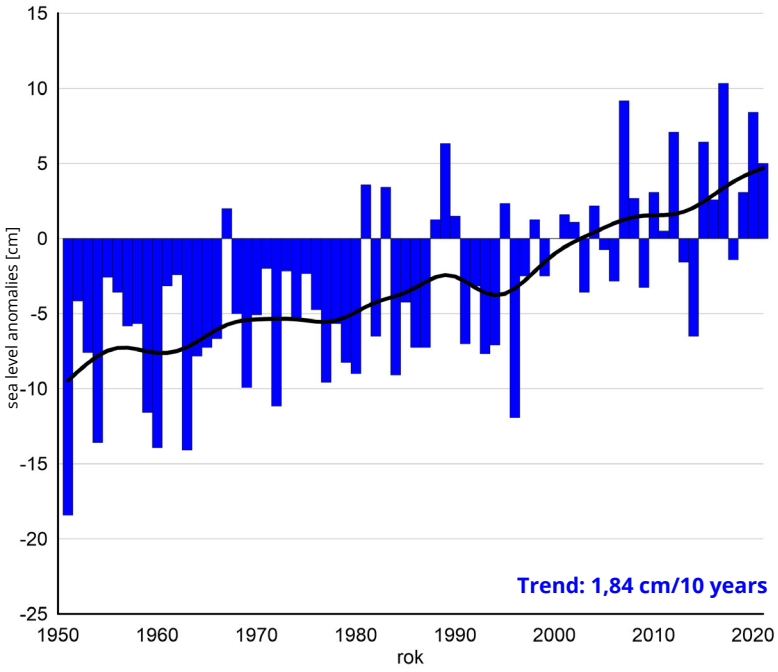
The annual total of sunshine duration in Poland was between 1,500 and 2,300 hours and was higher than the climatological normal from 100 up to 400 hours in the south-eastern part of the country. The sun shone shorter than the long-term normal in the western part of Pomerania and the north-western and central part of Wielkopolska. The sun shone the longest in Łeba, for 2,127 hours. The lowest number of hours with the sun was recorded in 2021 on Śnieżka (1,458 hours) and in Mława (1,564 hours).



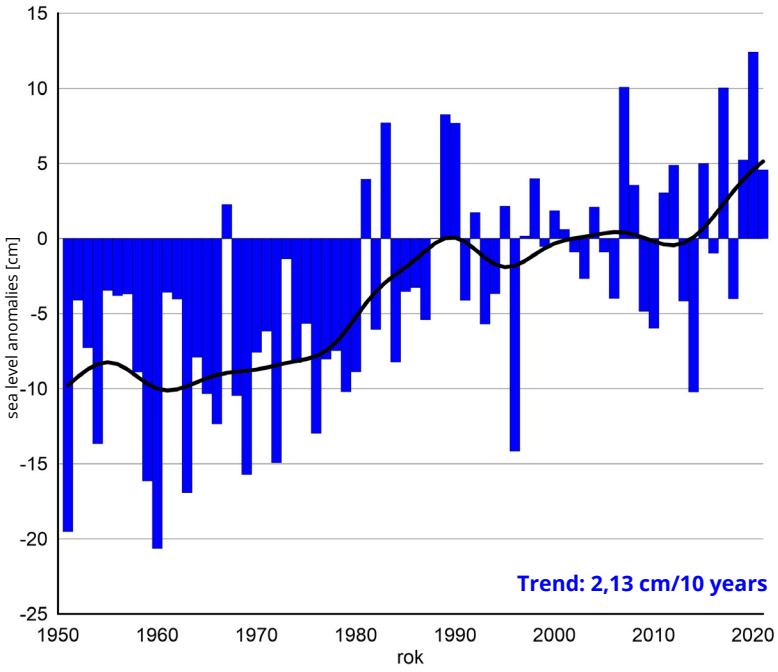



# SEA LEVEL

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 domination 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 (mean sea level increase by nearly 13,1 cm in Świnoujście and by about 15,1 cm in Władysławowo). This variation is a consequence of the dominance mentioned above of the western zonal circulation, which maintains a constant inclination of the Baltic mirror, increasing from west to east.



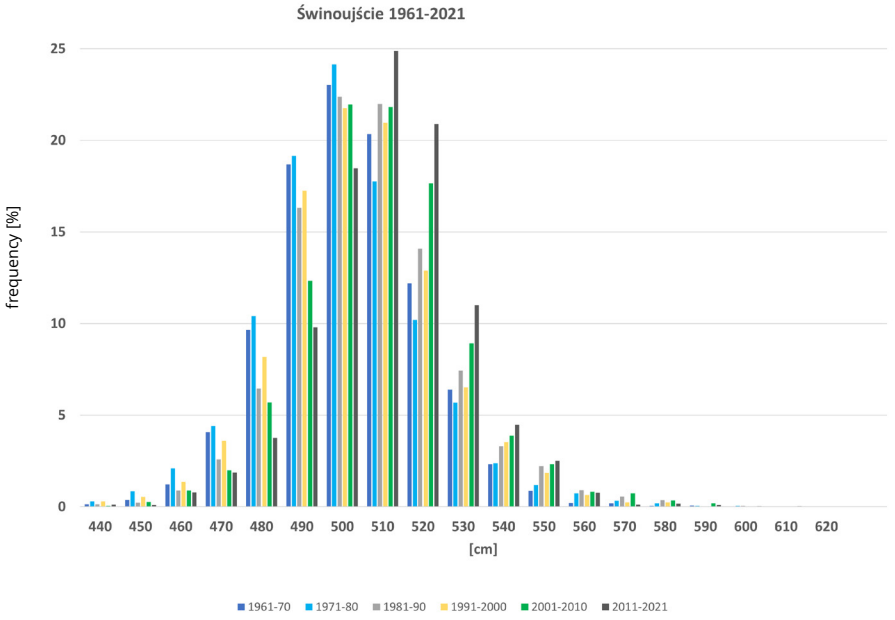

In 2021, the maximum recorded daily mean level on the water gauge in Świnoujście was 553 cm, while the lowest was 465 cm. In the past year, no daily mean levels above the warning level of 560 cm or below the SNW (416 cm) were observed. The most frequent mean daily sea levels were in the range 501 and 510 cm (32.3%) and 511-520 cm (18.9%). In turn, in Władysławowo, the recorded maximum sea level was 577 cm, and the minimum sea level was 463 cm. Most often, sea levels on the water gauge in Władysławowo were in the range of 501-510 cm (28.68%) and 511-520 cm (21.97%). There were three cases of exceedance of the alarm state. There was no case below SNW.

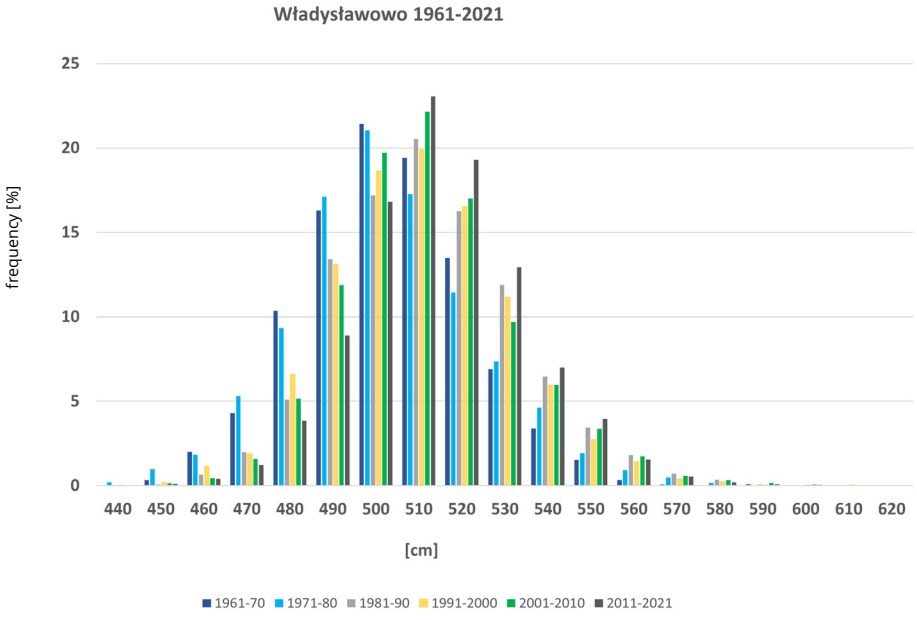



The change in the frequency of sea levels from a low range of values, below the so-called medium level, visibly stands-out from decade to decade. In the western and eastern parts of the coast, we can observe a decrease in the number of low levels, especially in Świnoujście. At the same time, we can observe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

| Świnoujście | 1961-1970 | 1971-1980 | 1981-1990 | 1991-2000 | 2001-2010 | 2011-2021 |
|---|---|---|---|---|---|---|
| below SNW [%] | 0.000 | 0.028 | 0.000 | 0.027 | 0.000 | 0.080 |
| above the alarm level [%] | 0.137 | 0.110 | 0.084 | 0.055 | 0.220 | 0.224 |

| Władysławowo | 1961-1970 | 1971-1980 | 1981-1990 | 1991-2000 | 2001-2010 | 2011-2021 |
|---|---|---|---|---|---|---|
| below SNW [%] | 0.082 | 0.547 | 0.027 | 0.109 | 0.055 | 0.082 |
| above the alarm level [%] | 0.110 | 0.164 | 0.465 | 0.328 | 0.549 | 0.373 |



# EXTREMES

| VARIABLE | | VARIABLE | DATA | STATION |
|---|---|---|---|---|
| **Temperature*** (T°C) | max | **36.1** | 20.06.2021 | Słubice |
| | min | **–26.4** | 18.01.2021 | Suwałki |
| | min 5 cm** | **–32.9** | 18.01.2021 | Białystok |
| **Precipitation** (RR mm) | Σ max 24 h | **104.4** | 23.08.2021 | Śnieżka |
| | Σ max | **1,531.9** | | Kasprowy Wierch |
| | Σ min | **442.1** | | Legnica |
| **Sunshine duration** (U h) | Σ max 24 h | **16.9** | 29.06.2021 | Kalisz |
| | Σ max | **2,127.0** | | Łeba |
| | Σ min | **1,458.0** | | Śnieżka |

*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 2021

| Observed extreme weather or climate event | Physical characteristics of event | | | | | | Interferences occurring |
|---|---|---|---|---|---|---|---|
| | Event Start | Event End | Duration | Location/Area | Rarity | Description of event | |
| Snowstorms | 2021–01–13 | 2021–01–13 | several dozen minutes | Western part of the country | Unusual | Snowstorms caused by a low over the Baltic Sea and an accompanying cold front; the PERUN system recorded atmospheric lightning in the western part of the country. | |
| Cold wave | 2021–01–10 | 2021–01–19 | 10 days | Almost the entire country, especially the north-eastern, eastern, central and southern parts of the country | Unusual | As a result of the influence of an extended high and the flow of frosty continental air, frosty days with Tmax and Tmin below 0°C occurred for several consecutive days. | |
| Heavy snowfall | 2021–01–25 | 2021–01–25 | 1 day | Podkarpacie | Unusual | Heavy snowfall caused by a low center with an occlusion front over the south-eastern part of the country; the increase in snow cover in 1 day was over 20 cm in some places, e.g. meteorological station Puławy Dolne – 25 cm, Jasło – 30 cm. | Transport problems, damage to power lines, broken branches and trees. |
| Heavy snowfall | 2021–02-07 | 2021–02-07 | 1 day | Southern part of the country | Unusual | Heavy snowfall occurring below the parallel line passing through Zielona Góra – Łódź, caused by the movement of the warm atmospheric front. | Transport problems, damage to power lines, broken branches and trees. |
| Dust from the Sahara desert | 2021–02-07 | 2021–02-07 | 1 day | Southern part of the country | Unusual | The dust zone from the Sahara desert reached the southern part of the country, where there was snowfall with Saharan dust particles falling as a result of the warm atmospheric front. | |
| Freezing rain | 2021–02-07 | 2021–02-08 | 2 days | Southern part of the country (Małopolskie, Podkarpackie and partly Świętokrzyskie voivodeships) | Unusual | Heavy precipitation of freezing rain and wet snow on the cooled surface, associated with the warm atmospheric front, caused the occurrence of glaze in a large area. | Transport problems, damage to power lines, broken branches and trees. |
| Blizzards/Snowstorms | 2021–02-07 | 2021–02-08 | 2 days | Southern part of the country (Małopolskie, Podkarpackie, Lubelskie and partly Świętokrzyskie voivodeships) | Unusual | Heavy snowfall combined with strong wind gusts exceeding 20 m/s caused blizzards and snowstorms. | Transport problems, difficult road conditions. |
| Cold wave | 2021-02-05 | 2021-02-16 | 11 days | Almost entire country, especially the north-eastern, eastern, central and southern parts of the country | Unusual | As a result of the influence of an extensive high and frosty continental air flow, for several consecutive days at many measuring stations, frosty days occurred with Tmax and Tmin below 0°C. At many synoptic stations, Tmin dropped below –20°C (e.g. Białystok, Suwałki, Mława, Olsztyn). | |
| Heat wave/Thaw | 2021-02-21 | 2021-02-26 | 6 days | Western and southern part of the country to Małopolska | Unusual | The influence of the high-pressure wedge extending from the Mediterranean Sea resulted in the advection of warm air from the south over the country. At many measuring stations located in the western and southern part of the country, Tmax exceeded 17°C, and locally also 20°C (e.g. synoptic station Zielona Góra – 20.4°C, Wrocław Starachowice – 20.6 C, Jelenia Góra – 21,2°C). | |
| Cold wave | 2021-02-22 | 2021-02-22 | 1 day | The Tatra Mountains and the Sudetes Mountains | Unprecedented | Record high air temperatures were recorded at the high mountain meteorological observatories due to the thermal inversion. At the Kasprowy Wierch synoptic station, the Tmax was 9.9°C and was higher by 2.1°C than the previous record for February in 1989. At the Śnieżka synoptic station, Tmax was 13.5°C and was higher by 3.4°C for February from the beginning of the measurements. | |
| Drought | 2021-03-01 | 2021-03-31 | 31 days | Entire country | Unusual | At many synoptic stations, the monthly precipitation total was below the long-term average, and the month was classified as dry and locally also very dry (e.g. synoptic station Sandomierz – 6.8 mm). | |
| Heat wave | 2021-03-31 | 2021-03-31 | 1 day | Almost entire country, especially southern part of the country | Unusual | As a result of the advection of warm air from the south at many measuring stations Tmax ≥ 20°C. The highest air temperature of the month was recorded at the Otmuchów measuring station at 24.3°C. | |
| Cold wave | 2021-04-01 | 2021-04-30 | 30 days | Entire country | Unprecedented | Extremely cold April all over the country. The average monthly air temperature in the country was 6.0°C (the coldest April in the 21st century). | |
| Snowfall | 2021-04-13 | 2021-04-14 | 2 days | Southern part of the country | Unusual | In the southern part of the country, wet snowfall occurred in the foothills and mountain areas (at many stations, the snow cover increased from 5 to 20 cm, in the mountains up to 40 cm). | Transport problems. |
| Rain | 2021-04-13 | 2021-04-17 | 5 days | Southern and south-eastern part of the country | Unusual | Due to the influence of the Black Sea low with the atmospheric fronts system over the southern and south-eastern part of the country, precipitation of a spreading nature occurred (e.g. Rzeszów synoptic station - the precipitation total in the third decade of the month was the third-highest since 1952; Nowy Sącz synoptic station – 24.3 mm daily precipitation total). | |

| Observed extreme weather or climate event | Physical characteristics of event | | | | | | Interferences occurring |
|---|---|---|---|---|---|---|---|
| | Event Start | Event End | Duration | Location/Area | Rarity | Description of event | |
| Rain/Thunderstorm | 2021-05-02 | 2021-05-02 | 1 day | Almost entire country | Unusual | Moving through the country of the moisture-rich low "Daniel" caused heavy rainfall in many regions of Poland; the daily totals locally exceeded 50 mm, e.g. at the Toruń synoptic station, the daily precipitation total was 53.1 mm). In Lower Silesia, there was a 3rd level hydrological warning for the Barycz river basin. | Flooding, damage to roads and buildings. |
| Tornado | 2021-05-02 | 2021-05-02 | 1 day | Tereszpol Zygmunty (50,558858°N; 22,928202°E) | Unprecedented | A tornado was formed as a result of the thunderstorm supercell moving through the municipality of Tereszpol. | Destruction of residential buildings and outbuildings, broken trees, damaged vehicles. |
| Snow | 2021-05-08 | 2021-05-09 | 2 days | Śnieżka | Unprecedented | In May, a record snow cover of 130 cm was recorded on Śnieżka for this month (not recorded in May since World War II). | |
| Cold wave | 2021-05-01 | 2021-05-31 | 31 days | Almost entire country | Unusual | In most parts of the country, May was below the thermal normal, and locally in the west much below the normal, e.g. in Warsaw, the average monthly temperature was 12.9°C and was 1.4°C lower than the long-term average. | |
| Rain | 2021-05-01 | 2021-05-31 | 31 days | Almost entire country | Unusual | In most parts of the country, May was humid and very humid, e.g. at the synoptic station in Toruń the monthly precipitation total was 111.8 mm and constituted 218.3% of the precipitation normal. | |
| Hail | 2021-06-05 | 2021-06-05 | several hours | Małopolskie voivodeship | Unusual | In the south of the Świętokrzyskie voivodeship, a thunderstorm supercell formed, which moved over 100 km through the Małopolska region. The size of the hailstones based on HAILSZ radar product was about 40 mm. | Destroyed crops and orchards. |
| Heat wave | 2021-06-17 | 2021-06-21 | 4 days | Western and central part of the country | Unusual | Due to the advection of hot tropical air mass, at many stations the maximum daily air temperature exceeded 30°C (e.g. at the synoptic station in Słubice, the highest maximum temperature in this period was 35.8°C – 20.06.2021). | |
| Rain | 2021-06-22 | 2021-06-22 | several dozen minutes | Poznań (52°52′N; 16°58′E) | Unprecedented | Because of the cold atmospheric front and its preceding convergence line moving through the country's territory, a thunderstorm cell was formed within which torrential precipitation occurred, causing flash floods (e.g. 60.8 mm of rainfall fell within 1 hour at the synoptic station in Poznań). | Tunnels, roads, streets and cars flooded as well as residential buildings and outbuildings. More than 1500 interventions by the fire brigade. |
| Tornado | 2021-06-24 | 2021-06-24 | several dozen minutes | Koniuszowa (49,656423°N; 20,787117°E) Librantowa (49,666132°N; 20,756902°E) | Unprecedented | A tornado formed under one of the thunderstorm supercells due to the movement of the cold front, where the development of highly developed thunderstorm cells was taking place. | More than 80 fire brigade interventions. Dozens of residential buildings and outbuildings damaged. |
| Rain/Thunderstorms | 2021-06-24 | 2021-06-24 | several hours | Southern and central part of the country | Unprecedented | From the Lublin region, through the center of the country, to Silesia, a mesoscale convective system was moving with heavy rainfall and strong wind gusts (e.g. at the Wronowice measuring station, the daily precipitation was 110.7 mm). | Flooding of residential buildings and outbuildings, farmland; destruction of road infrastructure. |
| Rain/Thunderstorms | 2021-07-01 | 2021-07-01 | several hours | North-eastern part of the country | Unusual | As a result of the movement of an active storm system through the north-eastern part of the country, at many measuring stations the daily precipitation total exceeded 40 mm (e.g. Białystok station – 46 mm, Trzcińsko-Zdrój station – 70 mm, Narewka station – 55 mm). | Flooding of buildings and streets. |
| Rain | 2021-07-02 | 2021-07-02 | several hours | North-eastern part of the country | Unprecedented | Due to the influence of the occlusion front, on which numerous thunderstorm cells developed, heavy rainfall occurred in the north-eastern part of the country, with a daily total exceeding 134 mm at the Zawady measuring station. | |
| Rain/Thunderstorms | 2021-07-08 | 2021-07-08 | 1 day | Western and central part of the country | Unusual | On the convergence line separating hot and very rich in water vapour tropical air from cooler polar maritime air mass extended multicellular thunderstorm structures were formed with strong wind gusts and heavy rainfall. They moved from the west to the east (e.g. Mikołajki measuring station – 71, 3 mm [16.8 mm/10 min]; Oborniki Śląskie measuring station – 73.4 mm [10.2 mm/10 min]). | Flooding of residential buildings and outbuildings, streets and, roads; damage to road infrastructure, broken trees, and roofs. |
| Hail | 2021-07-09 | 2021-07-09 | several dozen minutes | Kraków (19°56′E; 50°04′N) | Unusual | Heavy rainfall (12.8 m/10 min – Cracow Observatory station) and large hail (local hailstones with a diameter of 10 cm) occurred as a result of a thunderstorm supercell formed on the convergence line which moved through Cracow. | Flooding of buildings, flooded roads, and streets; damage to cars and plant crops. |

| Observed extreme weather or climate event | Physical characteristics of event | | | | | | Interferences occurring |
|---|---|---|---|---|---|---|---|
| | Event Start | Event End | Duration | Location/Area | Rarity | Description of event | |
| Rain/Thunderstorms | 2021-07-18 | 2021-07-18 | several hours | Głogoczów (49°54'08''N; 19°50'52''E) | Unusual | As a result of the formation of a stationary thunderstorm cell over the Beskid Makowski and the Wieliczka Foothills, heavy rainfall occurred (e.g. the Radziszów measuring station – the precipitation total for 5 hours was over 50 mm). | Flooding of residential buildings and outbuildings, streets and roads; damage to the road infrastructure |
| Rain/Thunderstorms | 2021-07-18 | 2021-07-18 | several hours | Nowy Sącz (49°37'N; 20°42'E) | Unprecedented | As a result of the formation of a thunderstorm cell over the Sądecka Valley, heavy rainfall occurred (measuring station Nowy Sącz – 16.8 mm/10 min) | Flooding of residential buildings and outbuildings, streets and roads; damage to the road infrastructure. |
| Waterspout | 2021-07-19 | 2021-07-19 | several dozen minutes | Baltic Sea | Unusual | Two waterspouts were observed in the Baltic Sea near Jurata. | |
| Heat wave | 2021-07-01 | 2021-07-31 | 31 days | Entire country | Unusual | July in Poland was classified as extremely warm. The average air temperature reached 20.9°C and was the third highest value since 1951 (the second highest value in the 21st century). | |
| Rain | 2021-08-05 | 2021-08-05 | 1 day | Cracow (19°56′E; 50°04′N) | Unprecedented | As a result of the movement of the low center through southern Poland, precipitation of a spreading nature occurred in this part of the country, during which at many measuring stations the daily precipitation total exceeded 50 mm. The record daily precipitation total of 104.3 mm was recorded at the Cracow Observatory station; it was the highest daily total since the beginning of the measurements, i.e. since 1895. | Flooding of residential buildings and outbuildings, farmlands, roads and streets; damage to road and municipal infrastructure. |
| Rain | 2021-08-30 | 2021-08-31 | 2 days | Most of the country | Unprecedented | As a result of the movement through the country of the low with the occlusion front, heavy rainfall of a spreading nature with locally embedded thunderstorm cells occurred in a considerable area, e.g. at the Szczyrk measuring station, the daily precipitation total was 127.6 mm. In the southern part of the country, there was a 3rd level hydrological warning related to floods and exceeding the alarm levels. | Flooding of residential buildings and outbuildings, farmlands, roads and streets; damage to road and municipal infrastructure. |
| Rain | 2021-08-01 | 2021-08-31 | 31 days | Entire country | Unprecedented | In August, the area-averaged precipitation total amounted to 140.1 mm, which was 212% of the normal for this month, determined by the measurements in the years 1991-2020. According to Kaczorowska's classification, last August should be classified as extremely humid. The highest exceedance of the monthly normal occurred in Sandomierz where 215.1 mm of precipitation dropped, which was 386.2% of the long-term normal 1991-2020. | |
| Strong wind | 2021-09-23 | 2021-09-23 | 1 day | Northern part of the country | Unusual | As a result of the movement of the active low center through the northern part of the country with the atmospheric fronts system, high wind speeds were recorded in the coast belt (e.g. Rozewie measuring station – 101 km/h, Dziwnów measuring station – 100 km/h). | |
| Drought | 2021-10-01 | 2021-10-31 | 31 days | Entire country | Unusual | At many IMGW-PIB measuring stations, the monthly precipitation total did not exceed 5 mm (e.g. synoptic station Włodawa – monthly precipitation 0.4 mm). | |
| Strong wind | 2021-10-21 | 2021-10-21 | 1 day | Most of the country | Unusual | As a result of the shallow secondary low moving through the Baltic Sea, in the western and northern parts of the country, there were strong wind gusts and, in some places thunderstorms (e.g. Rozewie measurement station – 103 km/h, Śnieżka measurement station – 158 km/h). There was a storm in the Baltic Sea with a strength of 10-11 on the Beaufort scale. | Fatalities in Lower Silesia, broken trees, traffic problems, power failures. |
| Cold wave | 2021-12-25 | 2021-12-27 | 3 days | Entire country | Unusual | In most parts of Poland, there were significant drops in air temperature due to the advection of continental air. On 26 December, the negative anomaly of air temperature at some stations reached 14°C below normal (Kłodzko measuring station). | |
| Heat wave | 2021-12-30 | 2021-12-31 | 2 days | Most of the country | Unusual | As a result of the advection of warm air mass from the southwest, in large part of the country, the maximum daily air temperature exceeded 10°C (e.g. Legnica measuring station – 14.6°C – the highest value recorded on 31 December). | |