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Temporal and spatial variability of air temperature and precipitation at the Polish coastal zone of the southern Baltic Sea

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Abstract The study concerns the analysis of temporal and spatial variability of thermal and precipitation conditions at the Polish Baltic coastal zone in the second half of the twentieth century and the first decade of the twenty–first century. The paper also presents its annual and daily extreme values of air temperature and precipitation. The study area includes the Polish coast of the Baltic Sea at which long–term measurements and observations of weather conditions have been performed within the national meteorological services at seven Baltic coastal stations. Their daily data of air temperature and precipitation taken from the measuring period of 1966–2009 were used in the study. For each meteorological station was set thresholds of annual average air temperature and annual total precipitation. Temporal variability of air temperature was determined by the thermal classification made by Lorenc (1998). Temporal variability of precipitation was determined by the precipitation classification made by Kaczorowska (1998).

Keywords *• Thermal conditions • Precipitation conditions • Extreme weather events • Polish Baltic Sea shore*

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INTRODUCTION

The specific recognition of climatic and weather conditions has a major importance in determining the functioning of a particular sea coastal zone. The temporal and spatial variability of thermal and precipitation conditions affects the functioning of the Baltic coast natural environment. The intensity of precipitation determines the dynamics of seashore geomorphological changes, which are the results of water erosion processes and mass movements. The annual course of temperature determines the duration of the growing season and the development of vegetation at the coastal area.

Air temperature and precipitation changes have been studied in Baltic Region. Kriaučiūnienė *et al.* (2012) reported variability of temperature and precipitation in Lithuania, Latvia and Estonia in the last century. Jaagus (1998) analysed climatic fluctuations and trends in Estonia in the 20th century. In Latvia Avotniece *et al.* (2010), Lizuma (2000) reported air temperature trends and frequency of extreme climate events. Bukantis and Rimkus (2005) analysed warming of winters and the contrasts between seasons in the last decade of 20th century in Lithuania. Impact of climate change on the functioning of the Baltic Sea region presented Dankers and Hiederer (2008), Dreier *et al.* (2013), Heino *et al.* (1999), Klein Tank and Konnen (2003), Plag and Tsimplis (1999).

The main objective of the study refers to the determination of thermal and precipitation characteristics in the Polish Baltic coastal zone. There are reliable and homogeneous measurement series of weather conditions available for the period of 1966–2009. They were conducted at coastal meteorological stations in Gdynia, Hel, Leba, Ustka, Kolobrzeg, Dziwnow and Swinoujscie. These meteorological stations covering the entire Polish coastal zone of the Baltic Sea belong to the national observation and measuring network supervised by the Institute of Meteorology and Water Management.

The set threshold values were used to construct the thermal–precipitation classification for particular years of the studied long–term period. The existing climatological publications at the Polish maritime zone consisted primarily of studies and research papers on individual weather elements for some selected coastal meteorological stations (Bielec–Bakowska, Lupikasza 2009; Filipiak 2007; Mietus 1996; Stach 2007; Swiatek 2011; Tylkowski 2012).

STUDY AREA

The Polish seacoast is about 500 km long and consists of major basic types – dune, barrier beaches and cliffs (Pruszak 2004). Dunes and sandy beaches occupy most of the coast, over 400 km. Cliffs comprise almost 100 km. Coast barriers between the lakes and sea is well developed in the central and eastern part of seashore. The Hel Peninsula in the eastern part of coast is extensively eroded and flooding during severe storm surges. In the western part of Polish Baltic coast, there are two islands: Wolin and Uznam. Poland's coastline has two major gulfs – the Pomeranian Gulf and Gdansk Gulf, and two large lagoons connected to the sea by narrow straits: the Szczecin Lagoon and Vistula Lagoon (Pruszak 2004). According to the universal decimal classification of the International Documentation Federation, the study area belongs to the Central Lowlands province and the Southern Baltic Coastland subprovince (Kondracki 2000). Three macro–regions: Szczecin Coastland, Koszalin Coastland and Gdansk Coastland were singled out at the Southern Baltic Coastland within the Polish Baltic coast (Fig. 1).

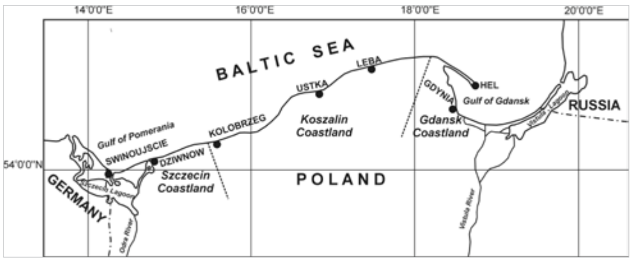

Fig. 1 The study area – location of the meteorological stations at the Polish coastal zone of the Baltic Sea. Compiled by J. Tylkowski, 2013.

The characteristics of air temperature and precipitation dynamics were obtained for particular macro–regions on the grounds of data collected from the following meteorological stations: Gdynia and Hel (Gdansk Coastland), Leba, Ustka and Kolobrzeg (Koszalin Coastland), Dziwnow and Swinoujscie (Szczecin Coastland). The thermo–precipitation characteristics of the climate presented in the study only refer to low dune shore (below 8 m above sea level) where the meteorological stations covered in the study are located. Unfortunately, no long–term meteorological measurements were conducted at the sea zone of the cliff coast.

The following form the uniqueness of the below–presented study:

- presenting a regional comparison of thermal–precipitation climatic characteristics of the Polish coastal zone of the Baltic Sea,
- setting its threshold values of air temperature and precipitation.

MATERIAL AND METHODS

All the daily average, maximal and minimal values of air temperature and total daily precipitation collected in the period of 1966–2009 were the data source used to formulate the thermal–precipitation characteristics of the Polish Baltic coastal zone. The long–term and homogeneous series of measurements used in the study ensure comparability and reliability of the resulted trends.

The widely used thermal and precipitation classification were applied to quantify the climatic characteristics of particular years (Kaczorowska 1962, Lorenc 1998). The thermal classification was developed for average annual values of air temperature (Lorenc 1998). In the thermal classification was compared the average temperature of each year in relation to the climate norm. The climate norm was the average annual air temperature in the 1966–2009 periods. The thermal class accounted the value of the norm climate, for which has been added to or deducted appropriate standard deviation value (σ) (Table 1). All the thermal standards (thresholds) were calculated for data obtained from the analysed period of 1966–2009. The classification criterion in the form of standard deviation applied by Lorenc at the thermal evaluation significantly facilitates understanding and interpretation of the obtained results and marginalizes any extreme cases (Czernecki, Mietus 2011) which largely reflect minor thermal climatic contrasts of the Baltic coast. The precipitation classification was formed on the grounds of annual total precipitation according to the methodology developed by Kaczorowska (1962). This

Table 1 Thermal conditions classification. Compiled by J. Tylkowski, 2013 (after Lorenc 1998).

Year's thermal class	Class limits
Extremely warm	$T>T_{norm.}+2,5\sigma$
Anomalously warm	$T_{norm.}+2,0\sigma<T\leq T_{norm.}+2,5\sigma$
Very warm	$T_{norm.}+1,5\sigma<T\leq T_{norm.}+2,0\sigma$
Warm	$T_{norm.}+1,0\sigma<T\leq T_{norm.}+1,5\sigma$
Slightly warm	$T_{norm.}+0,5\sigma<T\leq T_{norm.}+1,0\sigma$
Normal	$T_{norm.}-0,5\sigma\leq T\leq T_{norm.}+0,5\sigma$
Slightly cold	$T_{norm.}-1,0\sigma\leq T<T_{norm.}-0,5\sigma$
Cold	$T_{norm.}-1,5\sigma\leq T<T_{norm.}-1,0\sigma$
Very cold	$T_{norm.}-2,0\sigma\leq T<T_{norm.}-1,5\sigma$
Anomalously cold	$T_{norm.}-2,5\sigma\leq T<T_{norm.}-2,0\sigma$
Extremely cold	$T<T_{norm.}-2,5\sigma$

classification is based on the calculation of the percentage of precipitation in a particular year compared to the standard threshold values in the multi–year period of 1966–2009 (Table 2).

The results of the thermal and precipitation classification of the Polish coastal zone at the Baltic Coast are presented in the form of thermal and precipitation charts of individual meteorological stations. They form the basis for determining the temporal and spatial changes in climatic conditions on an annual basis. Moreover, the quantitative comparisons of extreme annual and daily values of air temperatures and total precipitation were made for the macro–regions of the coastal zone of the Baltic Sea.

Table 2 Precipitation conditions classification. Compiled by J. Tylkowski, 2013 (after Kaczorowska 1962).

Year's precipitation class	Class delimitation criteria
Extremely wet	P > 150% $P_{norm.}$
Very wet	P = 126% – 150% $P_{norm.}$
Wet	P =111% – 125% $P_{norm.}$
Normal	P = 90% – 110% $P_{norm.}$
Dry	P = 75% – 89% $P_{norm.}$
Very dry	P = 50% – 74% $P_{norm.}$
Extremely dry	P < 50% $P_{norm.}$

RESULTS

The thermal–precipitation classification applied in the study required to determine average annual thresholds of air temperature and annual total precipitation. The threshold values were set for all the analysed meteorological stations in reference to the multi–year of 1966–2009 (Table 3).

Thermal–precipitation classification of the Gdansk Coastland

Gdynia meteorological station

In Gdynia average annual air temperature values showed that normal thermal conditions (according to Lorenc thermal classification) occurred during seventeen out of 44 years, which accounted for 39% of the studied period. There were thirteen colder–than–standard years, including four slightly cold ones and five cold ones. The following three years were very cold: 1980, 1985 and 1996. Then, 1987 was classified as abnormally cold. There were fourteen warmer–than–standard years, including six slightly warm ones and five warm ones. The warmest were 1989, 1990 and 2007 years, which were classified as very warm ones. There were no extremely cold as well as anomalously and extremely warm years recorded in Gdynia. The precipitation evaluation showed that its standard precipitation conditions occurred in 24 cases, which accounted for 55% of the studied period. There were eleven wetter–than–standard years, including nine wet ones and two very wet ones (1970 and 2007). Then, there were nine cases of drier–than–standard years among which there were seven dry ones and two very dry ones (1979 and 1982). There were no extremely dry and extremely wet years in Gdynia (Fig. 2).

Hel meteorological station

The evaluation of Hel annual air temperature values showed that standard thermal conditions occurred in nineteen cases. There were twelve colder–than–standard years, including nine slightly cold ones and nine cold ones. The following three years were very cold: 1969, 1980 and 1996. The 1987 year was the

Table 3 Threshold average annual values of air temperature [°C] and annual total precipitation [mm] for 1966–2009 period. Compiled by J. Tylkowski, 2013.

Meteorological station	Gdynia	Hel	Łeba	Ustka	Kołobrzeg	Dziwnów	Świnoujście
Thermal class	Threshold values of annual air temperature T [°C]						
Extremely warm	T>10.6	>10.2	>9.9	>10.3	>10.4	>10.6	>10.6
Anomalously warm	10.2<T≤10.6	9.8<T≤10.2	9.5<T≤9.9	9.9<T≤10.3	10.0<T≤10.4	10.2<T≤10.6	10.2<T≤10.6
Very warm	9.7<T≤10.2	9.4<T≤9.8	9.1<T≤9.5	9.5<T≤9.9	9.6<T≤10.0	9.8<T≤10.2	9.8<T≤10.2
Warm	9.3<T≤9.7	9.0<T≤9.4	8.7<T≤9.1	9.0<T≤9.5	9.2<T≤9.6	9.4<T≤9.8	9.4<T≤9.8
Slightly warm	8.9<T≤9.3	8.6<T≤9.0	8.3<T≤8.7	8.6<T≤9.0	8.7<T≤9.2	9.0<T≤9.4	9.0<T≤9.4
Normal	8.1≤T≤8.9	7.8≤T≤8.6	7.5≤T≤8.3	7.8≤T≤8.6	7.9≤T≤8.7	8.2≤T≤9.0	8.2≤T≤9.0
Slightly cold	7.7≤T<8.1	7.4≤T<7.8	7.1≤T<7.5	7.3≤T<7.8	7.5≤T<7.9	7.7≤T<8.2	7.8≤T<8.2
Cold	7.2≤T<7.7	7.0≤T<7.4	6.7≤T<7.1	6.9≤T<7.3	7.1≤T<7.5	7.3≤T<7.7	7.4≤T<7.8
Very cold	6.8≤T<7.2	6.6≤T<7.0	6.2≤T<6.7	6.5≤T<6.9	6.7≤T<7.1	6.9≤T<7.3	6.9≤T<7.4
Anomalously cold	6.4≤T<6.8	6.2≤T<6.6	5.8≤T<6.2	6.0≤T<6.5	6.3≤T<6.7	6.5≤T<6.9	6.5≤T<6.9
Extremely cold	T<6.4	T<6.2	T<5.8	T<6.0	T<6.3	T<6.5	T<6.5
Precipitation class	Threshold values of annual total precipitation P [mm]						
Extremely wet	P>792.2	P>876.8	P>980.3	P>1048.0	P>974.1	P>863.6	P>803.6
Very wet	660.2<P≤792.2	730.7<P≤876.8	816.9<P≤980.3	873.4<P≤1048	811.7<P≤974.1	719.7<P≤863.6	669.7<P≤803.6
Wet	581.0<P≤660.2	643.0<P≤730.7	718.9<P≤816.9	768.6<P≤873.4	714.3<P≤811.7	633.3<P≤719.7	589.3<P≤669.7
Normal	475.3<P≤581.0	526.1<P≤643.0	588.2<P≤718.9	628.8<P≤768.6	584.5<P≤714.3	518.2<P≤633.3	482.2<P≤589.3
Dry	396.1<P≤475.3	438.4<P≤526.1	490.2<P≤588.2	524.0<P≤628.8	487.0<P≤584.5	431.8<P≤518.2	401.8<P≤482.2
Very dry	264.1≤P≤396.1	292.3≤P≤438.4	326.8≤P≤490.2	349.4≤P≤524.0	324.7≤P≤487.0	287.9≤P≤431.8	267.9≤P≤401.8
Extremely dry	P<264.1	P<292.3	P<326.8	P<349.4	P<324.7	P<287.9	P<267.9

coldest that was classified as abnormally cold. Then, there were thirteen warmer–than–standard years, including five slightly warm ones and five warm ones. The following years were very warm: 1989, 1990 and 2007. There were no anomalously and extremely cold as well as anomalously and extremely warm years in Hel. The analysis of Hel annual amounts of precipitation showed that its standard precipitation conditions occurred in twenty cases, which accounted for 45% of the studied period. There were twelve wetter–than–standard years (27% of the studied period), including eight wet ones and four very wet ones (1970, 1980, 1981 and 1999). Then, there were twelve drier–than–standard years, among which nine dry ones and three very dry ones (1969, 1975, and 1982) were noted. There were no extremely dry and extremely wet years recorded in Hel (Fig. 3).

At the Gdansk Coastland, the average annual air temperatures in the period of 1966–2009 were as follows: 8.2°C in Hel and 8.5°C in Gdynia. The highest average annual air temperature occurred in 1990 and amounted to 10.0°C in Gdynia and 9.6°C in Hel. However, the lowest average annual air temperature occurred in 1987 and reached the level of 6.4°C in Hel and 6.7°C in Gdynia. Gdynia located at the Gdansk Bay is characterized by higher thermal contrasts than Hel that is closer to the open sea area. Larger thermal extremes occur in Gdynia than in Hel. In Gdynia, the absolute minimum air temperature –18.7°C was observed on 2 February 1970 and the absolute maximum 35.0°C occurred on 21 July 1998. In Hel, the extreme daily air temperature amounted –18.2°C on 20 January 1987 and 33.7°C on 29 July 1994.

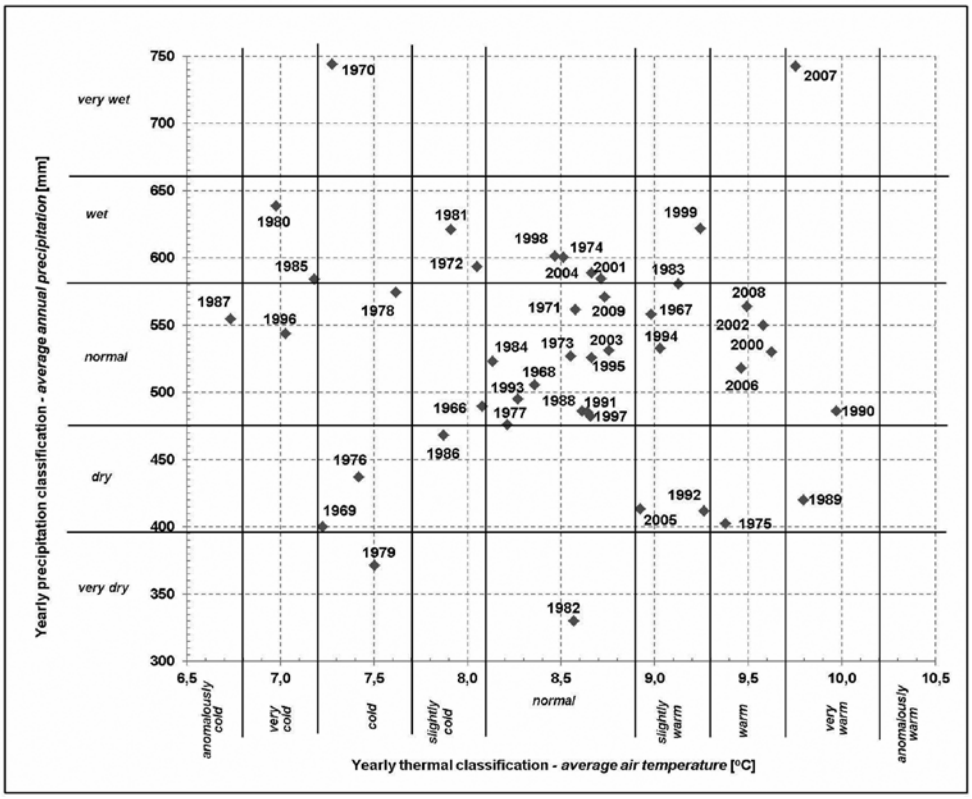

Fig. 2 Annual thermal–precipitation classification in Gdynia (1966–2009). Compiled by J. Tylkowski, 2013.

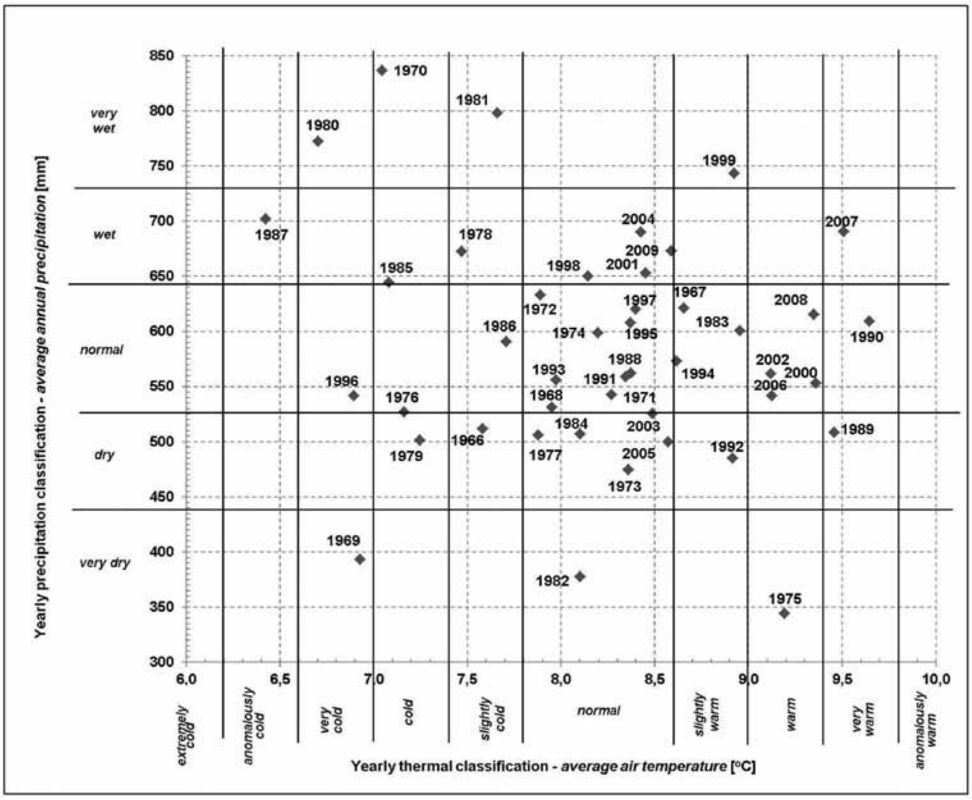

Fig. 3 Annual thermal–precipitation classification in Hel (1966–2009). Compiled by J. Tylkowski, 2013.

At the Gdansk Coastland, there is more precipitation in Hel (584.6 mm) than in Gdynia (528.1 mm). In Gdynia, the minimum annual total precipitation 330.3 mm was recorded in 1982 and the maximum one 744.3 mm in 1970. Then, in Hel, the extreme annual total precipitation amounted to 344.8 mm in 1975 and 836.8 mm in 1970. Within one year, there are 178 days with precipitation on average in Hel and there are nine days less in Gdynia. In addition, the annual precipitation in Hel are characterized by more irregularity than the one in Gdynia which is reflected in a slightly higher index of precipitation irregularity (k = Pmax/Pmin) amounting to 2.4. For Gdynia, the index of precipitation irregularity is less by 0.1. The precipitation at the Gdansk Coastland is characterized by a relatively low yield, which is reflected in low values of its absolute maximal daily amounts of precipitation (76 mm) which was recorded in Gdynia and Hel on 10 July 1980.

Thermal–precipitation classification of the Koszalin Coastland

Leba meteorological station

The classification of average annual air temperature values showed that it experienced standard thermal conditions for 39% of the studied period. There were thirteen colder–than–standard years, including four slightly cold ones, two cold ones and seven very cold ones. The coldest years were as follows: 1969, 1970, 1976, 1980, 1985, 1987 and 1996. Then, there were fourteen warmer–than–standard years, including three slightly warm ones and three warm ones. The very cold years were as follows: 1989, 1990, 2000 and 2007. There were no anomalously and extremely cold as well as anomalously and extremely warm years recorded in Leba. The analysis of its annual amounts of precipitation showed that it experienced standard precipitation conditions in sixteen years (36% of the studied period). There were wetter–than–standard twelve years (27%), including eight wet ones, three very wet ones (1967, 1981 and 2004) and one extremely wet ones (1970). Then, its drier–than–standard years occurred in sixteen cases among which there were seven dry ones and four very dry ones (1975, 1979, 1982 and 2005). There were no extremely dry years recorded in Leba (Fig. 4).

Ustka meteorological station

The analysis of its average annual air temperature values showed that it experienced standard thermal conditions in nineteen out of 44 years (43%). There were twelve colder–than–standard years, including four slightly cold ones and three cold ones. The following years were very cold: 1969, 1970, 1980, 1987 and 1996. In turn, 1987 was anomalously cold. Then, there were thirteen warmer–than–standard years, including six slightly warm ones and four warm ones. The following three years were very warm: 1990, 2000 and 2007. There were no extremely cold as well as anomalously and extremely warm years recorded in Ustka. The classification of its annual amounts of precipitation showed that it experienced standard precipitation conditions in 23 cases (52% of the studied period). There were nine years wetter than standard (20%), including five wet ones (1967, 1973, 1977, 1983 and 1990) and four very wet ones (1970, 1974, 1981 and 1998). Then, there were drier–than–standard years in twelve cases among which nine dry ones (1969, 1966, 1976, 1989, 1996, 2000, 2005, 2006 and 2008) and three very dry ones (1975, 1982 and 2003).

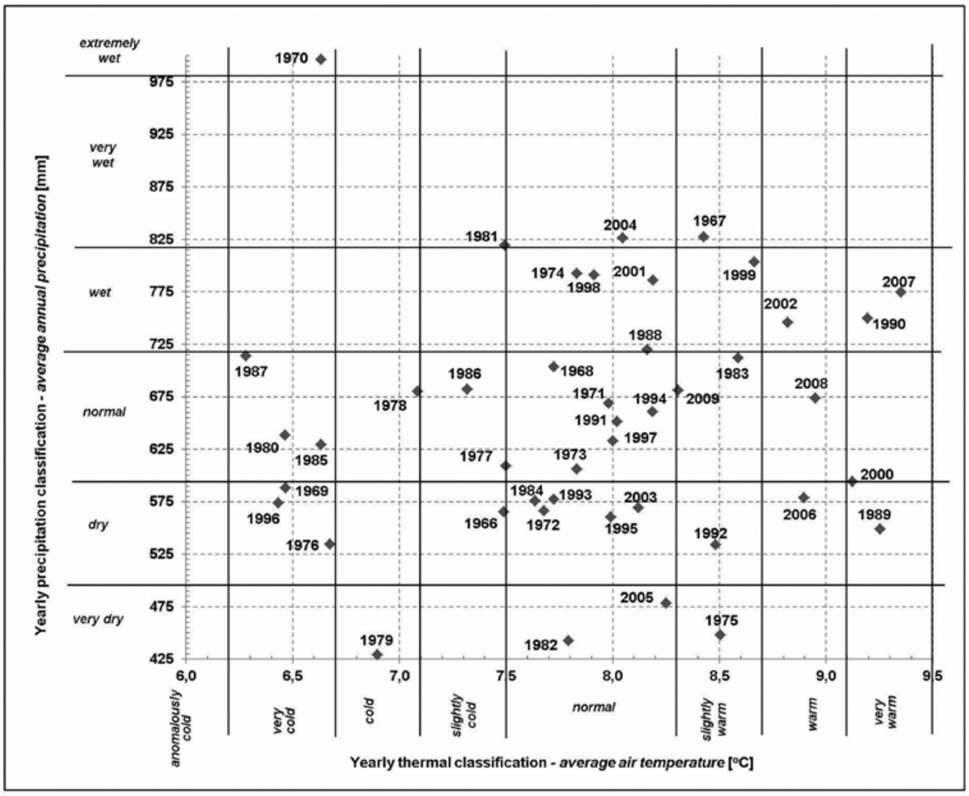

Fig. 4 Annual thermal–precipitation classification in Leba (1966–2009). Compiled by J. Tylkowski, 2013.

There were no extremely wet and extremely dry years reported in Ustka (Fig. 5).

Kolobrzeg meteorological station

The thermal classification showed that it experienced standard thermal conditions in seventeen out of 44 years (43%). There were twelve colder–than–standard years, including four slightly cold ones and three cold ones. The following years were very cold: 1970, 1980 and 1987. In turn, it experienced anomalously cool thermal conditions between 1969 and 1996. Then, there were thirteen warmer–than–standard years, including five slightly warm ones and four warm ones. The following three years were very warm: 1989, 1990 and 2007. There were no extremely cold as well as anomalously and extremely warm years recorded in Kolobrzeg. The assessment of its annual amounts of precipitation showed that it experienced standard precipitation conditions in 23 years (52% of the studied period). There were nine wetter–than–standard years (20%), including five wet ones (1967, 1970, 1978, 1980 and 2001) and four very wet ones (1981, 1998, 2002 and 2007). Then, it experienced drier–than–standard years in twelve cases among which there were eleven dry ones (1969, 1971, 1972, 1976, 1982, 1989, 1994, 1997, 2000, 2003 and 2006) and only one very dry ones in 1975. There were no extremely wet and extremely dry years reported in Kolobrzeg (Fig. 6).

At the Koszalin Coastland, the highest average annual air temperature occurs within its western part, in Kolobrzeg 8.3° and the lowest in the eastern part, in Leba 7.9°C. Within the central part of the region,

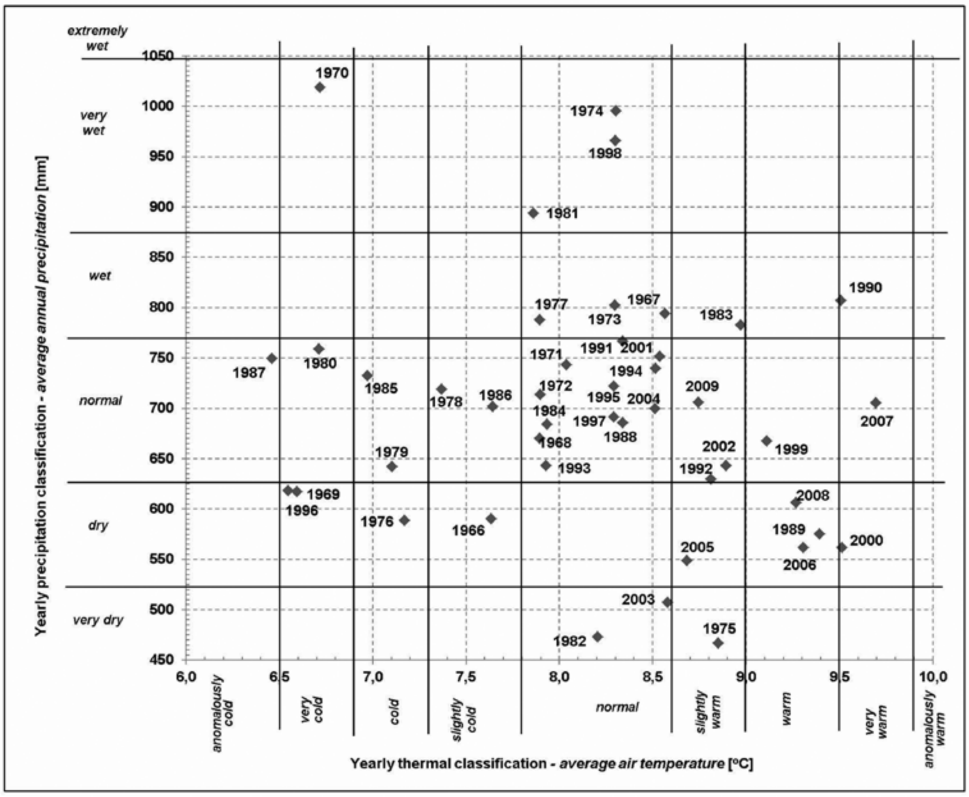

Fig. 5 Annual thermal–precipitation classification in Ustka (1966–2009). Compiled by J. Tylkowski, 2013.

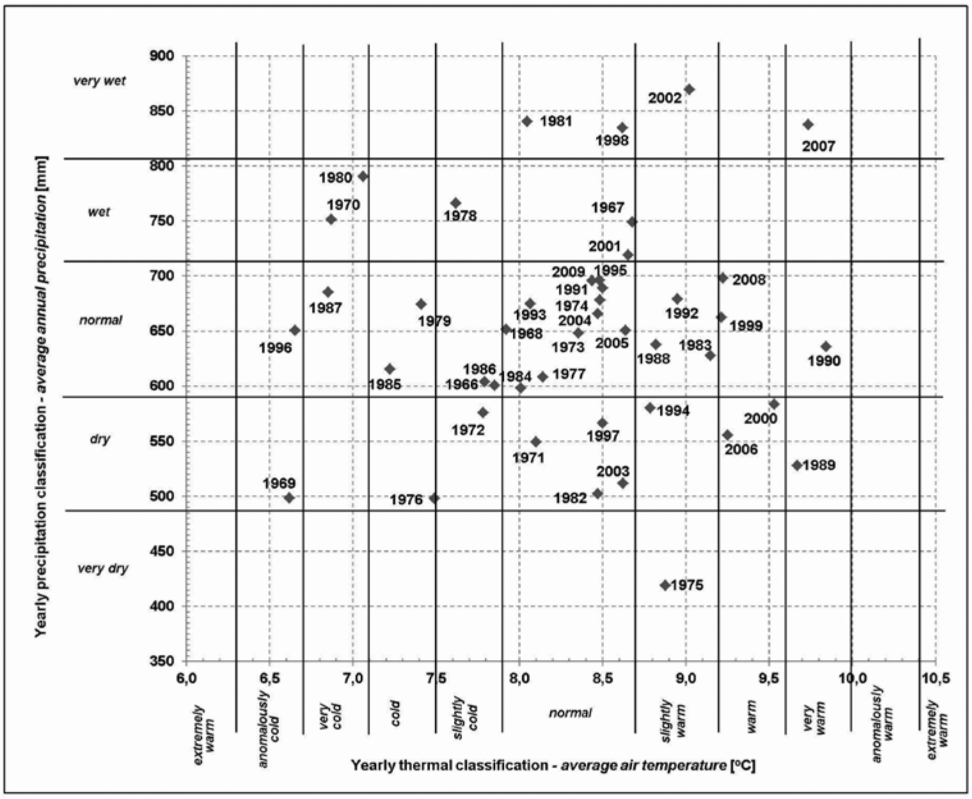

Fig. 6 Annual thermal–precipitation classification in Kolobrzeg (1966–2009). Compiled by J. Tylkowski, 2013.

its average annual air temperature amounts to 8.2°C in Ustka. At the Koszalin Coastland the absolutely highest average annual air temperature 9.8°C was recorded in 1990 in Kolobrzeg. In Leba and Ustka, the highest average annual temperature occurred in 2007 and was equal to 9.4°C and 9.7°C, respectively. The extremely low value of average annual air temperature was recorded in Kolobrzeg in 1969 (6.6°C), in Ustka in 1996 (6.5°C) and in Leba in 1987 (6.5°C). The thermal contrasts are the largest in Leba, which is reflected in the absolute amplitude of air temperature at the level of 60.4°C. In Leba, the absolute daily thermal maximum at 37.2°C occurred on 10 August 1992 and the absolute daily air temperature minimum at –23.3°C was recorded on 6 January 2003. In the central part of the Coastland, in Ustka, the extremely lowest air temperature at –20.7°C was observed on 11 January 1987 and the absolutely highest value at 37.8°C was recorded on 10 August 1992. Then, the absolute air amplitude is the lowest in Kolobrzeg – it is equal to 58.2°C. In Kolobrzeg, the absolutely minimum air temperature at –20.2°C was measured on 11 January 1987 and the extremely maximum air temperature at 38.0°C occurred on 10 August 1992.

At the Koszalin Coastland, the highest precipitation occurs in its central part, in Ustka, where its average annual amount of precipitation is equal to 698.7 mm. In Ustka the minimum of precipitation 467.0 mm was recorded in 1975 and the maximum 1019.1 mm in 1970. The precipitation in the western and eastern parts of Koszalin Coastland is about 50 mm less than in Ustka, in Kolobrzeg 649.4 mm and in Leba 653.5 mm. In Leba, the minimum amount of precipitation 429.6 mm was recorded in 1975 and the maximum 996.5 mm in 1979. In Leba, the annual index of precipitation irregularity is the highest in the region and equal to 2.3. Then, in Kolobrzeg, the index of precipitation irregularity is the lowest and equal to 2.1. It is a quotient of the maximum annual amount of precipitation (869.9 mm) recorded in 2002 to the minimum value (419.5 mm) measured in 1975. At the Koszalin Coastland on average there are 181 days with precipitation within a year. The absolutely highest daily precipitation yield increases towards the east and amounts to 85.2 mm in Kolobrzeg (9 July 1996), 94.2 mm in Ustka and 141.0 mm in Leba (24 July 1988).

Thermal–precipitation classification of the Szczecin Coastland

Dziwnow meteorological station

The thermal classification showed that it experienced standard thermal conditions in sixteen out of 44 years (36%). There were thirteen colder–than–standard years (30%), including three cold ones (1978–1980) and five very cold ones (1969, 1970, 1985, 1987 and 1996). Then, there were fifteen warmer–than–standard years (34% of the studied period), including four warm ones (1999, 2002, 2006 and 2008) and four very warm ones (1989, 1990, 2000 and 2007). There were no anomalously and extremely cold as well as anomalously and extremely warm years recorded in Dziwnow. The annual assessment of precipitation showed that it experienced standard precipitation conditions for twenty years (45% of the studied period). The following years were very wet: 1981, 1995, 1998 and 2007. On the other hand, the decade of the 70s was a very dry period when four very dry years (1971, 1973, 1975 and 1976) were recorded. There were no extremely wet and extremely dry years reported in Dziwnow (Fig. 7).

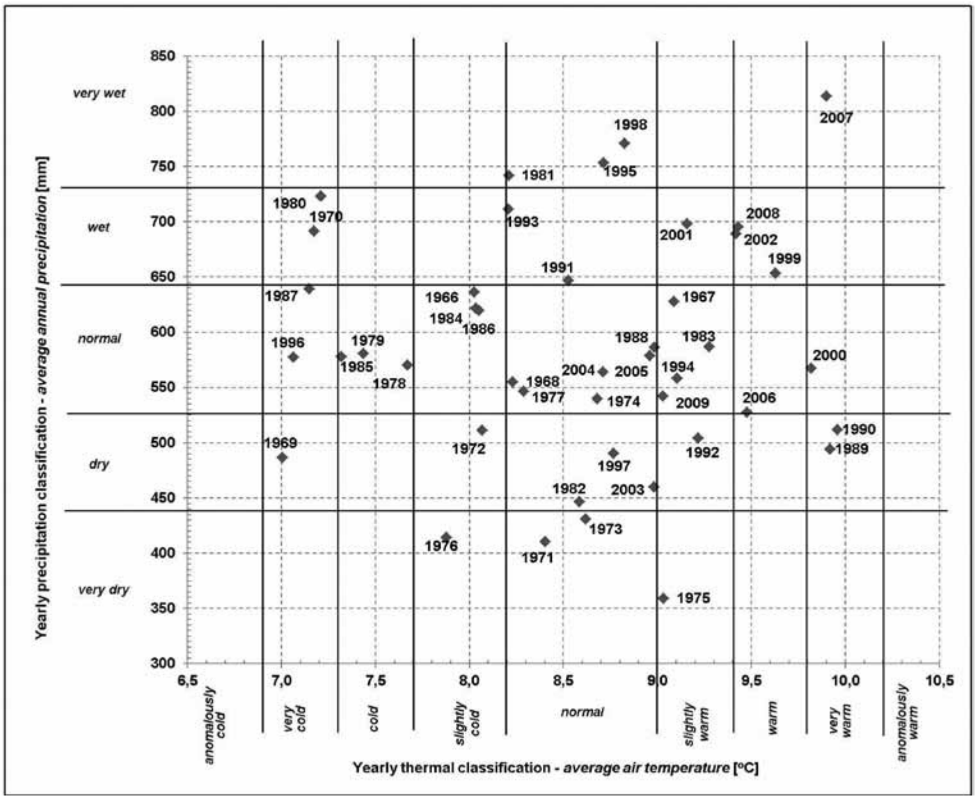

Fig. 7 Annual thermal–precipitation classification in Dziwnow (1966–2009). Compiled by J. Tylkowski, 2013.

Swinoujscie meteorological station

The evaluation of its annual air temperature values showed that it experienced standard thermal conditions in eighteen out of 44 years (41%). There were twelve colder–than–standard years (27%) including five slightly cold ones (1972, 1976, 1978, and 1984) and one cold ones (1979). The following years were very cold: 1969, 1970, 1980, 1985 and 1987. 1996 was anomalously cold with its average annual air temperature at 6.9°C. Then, there were fourteen warmer–than–standard years, including seven slightly warm ones (1967, 1975, 1983, 1994, 2002, 2005 and 2006) and four warm ones (1992, 1999, 2000 and 2008). 1989, 1990 and especially 2007 were very warm years with their average annual air temperature at 9.9°C. There were no extremely cold as well as anomalously and extremely warm years recorded in Swinoujscie. The analysis of its annual precipitation showed that it experienced standard precipitation conditions for 22 years constituting half of the studied year. There were eleven wetter–than–standard years, including nine wet ones (1968, 1980, 1981, 1987, 1995, 1998, 2000, 2007 and 2008) and two very wet ones (1967 1970). Then, there were drier–than–standard years, including seven dry ones (1973, 1978, 1991, 1992, 1997, 2003 and 2006) and for very dry ones (971, 1975, 1982 and 1989). There were no extremely wet and extremely dry years reported in Swinoujscie (Fig. 8).

At the Szczecin Coastland in Dziwnow and Swinoujscie, average annual air temperature for the period of 1966–2009 was at the level of 8.6°C. The highest average annual air temperature at 10.0°C was recorded in Dziwnow in 1990. In Swinoujscie 2007 was the warmest year when its average temperature reached the level of 9.9°C. Then, the lowest average annual air temperature occurred in Swinoujscie in 1987 (6.9°C) and in Dziwnow in 1969 (7.0°C). In Dziwnow, the absolute minimum air temperature at the level of –20.1°C was observed on 23 January 2006 and the absolute maximum amounting to 37.4°C was measured on 10 August 1992. In Swinoujscie, its extreme values of daily air temperature is very close to the extremes in Dziwnow and are equal to –20.4°C on 10 January 1985 and 37.4°C on 1 August 1994.

At the Szczecin Coastland, there is a significantly higher average annual precipitation in Dziwnow (584.7 mm) than in Swinoujscie (535.7 mm). In Dziwnow the minimum of precipitation 359.6 mm was recorded in 1989 and the maximum 813.9 mm in 2007. Then, in Swinoujscie, the extremely low annual amount of precipitation was equal to 370.6 mm in 1975 and the extremely high 724.8 mm in 1970. Its annual index of precipitation irregularity is significantly higher in Dziwnow (2.3) than in the western part of the coastland where it reaches 2.0 for Swinoujscie. In Dziwnow, its precipitation occurs in 173 days a year on average, three days more than in Swinoujscie. In the eastern part of the region the maximum daily precipitation are characterized by its higher yield. The absolute extreme at 66.4 mm occurred in Dziwnow on 16 July 1995. In Swinoujscie, its maximum daily amount of precipitation was measured on 29 August 1969 and amounted to 58.7 mm.

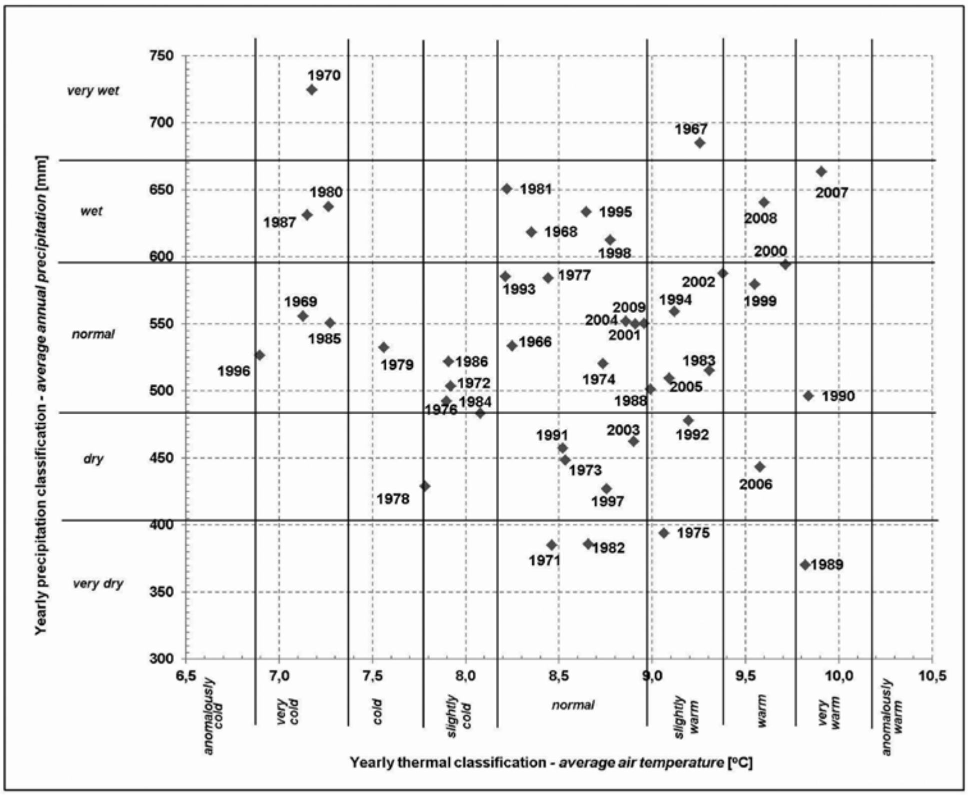

Fig. 8 Annual thermal–precipitation classification in Swinoujscie (1966–2009). Compiled by J. Tylkowski, 2013.

DISCUSSION

The thermal analysis of the Polish coastal zone of the Baltic Sea made for the period of 1966–2009 showed an increasing trend of its average annual air temperature with a linear correlation of 0.51 for all coast (Fig. 9). This trend of temperature increase is similar to the results of studies, which have been converted in publications IPCC (2007). The standard deviation of its average annual air temperature within the studied period for all the analysed stations was equal to 0.8°C. The statistically significant coefficient of linear trend for the entire coast was equal to 0.3°C/10 years. The presented increasing trend of air temperature is similar to the results presented in other publications, for example in Ustka for the period of 1951–2005, the coefficient of linear trend was equal to 0.26°C/10 years (Michalska 2011). The highest increase of air temperature with its value of 0.32°C/10 years concerns the region of the Szczecin Coastland, which is located in the western part of the Polish Baltic coast. Then, the slightest increase of its average annual air temperature (0.28°C/10 years) was recorded in the eastern part of the Polish part of the Baltic coast, at the Gdansk Coastland.

The characteristics of the annual amount of precipitation of the Polish coastal zone of the Baltic Sea did not show any statistically significant trend of increase or decrease in precipitation in the period of 1966–2009 (Fig. 10). The central part of the Polish coast of the Baltic Sea dramatically distinguishes itself in terms of its spatial variability. Within the Koszalin Coastland, its average annual amount of precipitation is equal to 667.2 mm and it is higher by around 20% than at the Gdansk Coastland (556.3 mm) and the Szczecin Coastland (560.2 mm). The standard deviation of its annual amount of precipitation ranged from 84 mm in Swinoujscie and Gdynia up to 120 mm in Ustka.

The annual thermal and precipitation classification that was conducted for the macro–regions of the southern coast of the Baltic Sea showed their extensive time–space diversity. The regional classification of thermal and precipitation conditions was made through

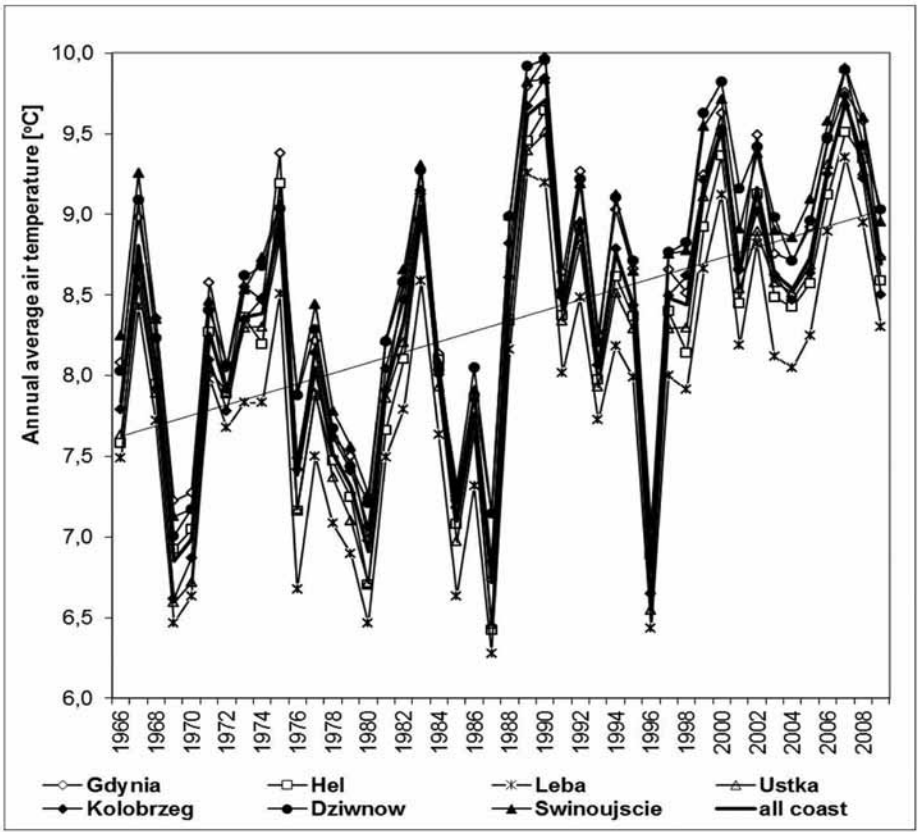

Fig. 9 Average annual air temperature on Polish Baltic coast in 1966–2009 period. Compiled by Tylkowski 2013.

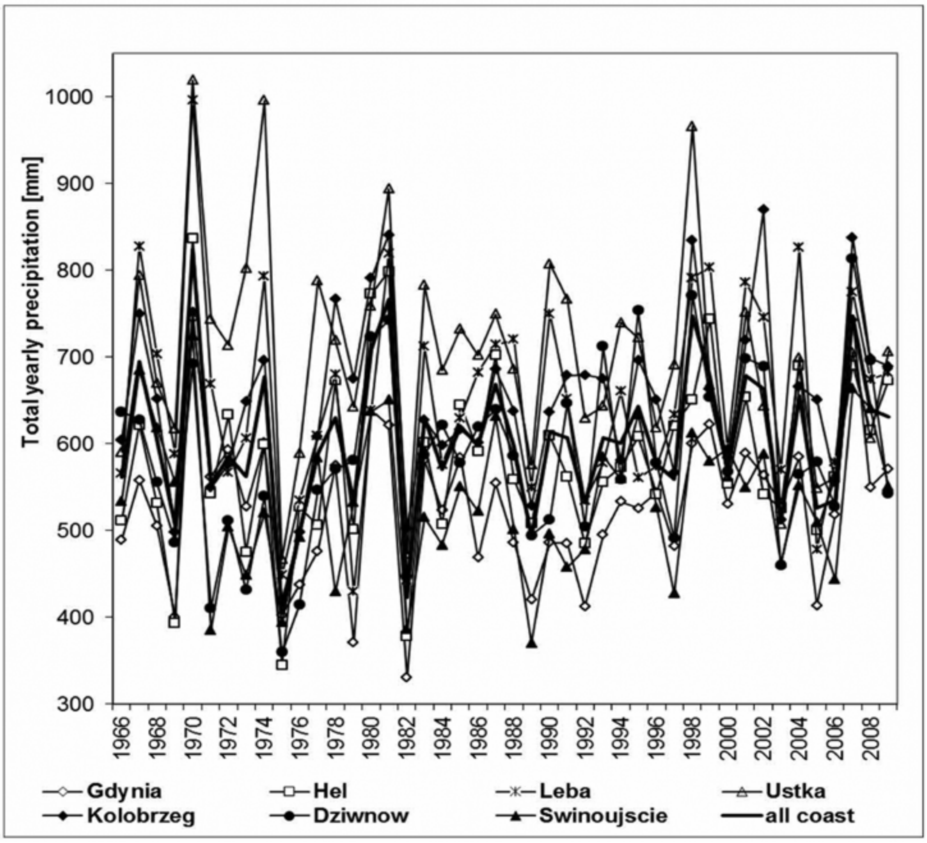

Fig. 10 Total annual precipitation on Polish Baltic coast in 1966–2009 period. Compiled by J. Tylkowski, 2013.

averaging the annual thermal and precipitation classes for all the stations occurring at the given macro–region: Gdansk, Koszalin or Szczecin Coastlands. In thermal terms for the entire Southern Coastland of the Baltic Sea, it is possible to very clearly distinguish one colder period, which lasted, from 1966 to 1988. A very large (45%) share of colder–than–standard years was recorded within the period of time. The decade of the 70s turned out to be the coldest period when only 1975 were warmer than the standard and there were up to four colder–than–standard years within the pentad of 1976–1980. From 1989 up to 2009, a strong warming can be observed (only 1996 were colder than the standard). A particularly warm period occurred in the first decade of the twenty–first century within which there were no cooler years at all. The analysis of time series of the thermal conditions of the Baltic coast showed relatively higher similarities of the share of thermally standard years at the Szczecin Coastland and Koszalin Coastland (39%) than at the Gdansk Coastland (43%). A climatic characteristic of the Polish Baltic coast refers to a reduction of the share of warmer–than–standard years towards the west – the Gdansk Coastland 30% and the Szczecin Coastland 25%. However, at the central part of the Polish Coast (the Koszalin Coastland) there is a lower share of colder–than–standard years (25%) compared to the other macro–regions (30%). Furthermore, at the Koszalin Coastland there was no – unlike at the Gdansk Coastland and the Szczecin Coastland – anomalously cold years (Table 4).

Precipitation in the coastal zone of the Southern Baltic Sea is characterized by its very high variability in time and space. There were both wet and dry years within all the decades of the studied period. The 2008 year was a special year with a high spatial variability of precipitation (it was a dry year for the Koszalin Coastland, a standard year for the Gdansk Coastland and a wet year for the Szczecin Coastland). No clear variance among the regions was recorded in terms of the variability of their share of standard precipitation years. Most standard precipitation years occurred at the Szczecin Coastland (50%) and least – at the Koszalin Coastland (45%). The macro–region of the Koszalin Coastland distinguishes itself in terms of its relatively high frequency of wet years and its relatively low share of dry years. There were up to three very wet years and only five very dry ones at the region. A different situation was observed in the other macro–regions. At the Gdansk Coastland, only one year was very wet and nine years were very dry. Then, the Szczecin Coastland was characterized by the largest number of very dry years (up to eleven). However, there was not any very wet year at the region. The highest extreme daily precipitation at the Polish coast of the Baltic Sea occurs at the Koszalin Coastland (especially in Leba where they amount up to 150 mm). However, the lowest extreme daily precipitation occurs at the Szczecin Coastland and they amount to less than 70 mm.

Table 4 Thermal and precipitation classification of the Gdansk, Koszalin and Szczecin Coastlands (1966–2009). Compiled by J. Tylkowski, 2013.

Year	Gdansk Coastland		Koszalin Coastland		Szczecin Coastland	
	Thermal classification	Precipitation classification	Thermal classification	Precipitation classification	Thermal classification	Precipitation classification
1966	7	V	7	V	7	IV
1967	5	IV	6	III	5	III
1968	6	IV	6	IV	6	IV
1969	9	VI	9	V	9	V
1970	8	II	9	II	9	III
1971	6	IV	6	IV	6	VI
1972	7	IV	7	V	7	V
1973	6	V	6	IV	6	VI
1974	6	IV	6	III	6	IV
1975	4	VI	5	VI	5	VI
1976	8	V	8	V	7	V
1977	6	V	6	IV	6	IV
1978	8	IV	7	IV	8	V
1979	8	VI	8	V	8	IV
1980	9	III	9	IV	9	III
1981	7	III	6	II	6	III
1982	6	VI	6	VI	6	VI
1983	5	IV	5	IV	5	IV
1984	6	V	6	IV	7	IV
1985	9	III	8	IV	9	IV
1986	7	V	7	IV	7	IV
1987	10	IV	9	IV	9	IV
1988	6	IV	6	IV	6	IV
1989	3	V	3	V	3	VI
1990	3	IV	3	III	3	V
1991	6	IV	6	IV	6	IV
1992	5	V	5	IV	5	V
1993	6	IV	6	IV	6	IV
1994	5	IV	6	IV	5	IV
1995	6	IV	6	IV	6	III
1996	9	IV	9	V	10	IV
1997	6	IV	6	IV	6	V
1998	6	III	6	II	6	III
1999	5	III	4	IV	4	IV
2000	4	IV	3	V	4	IV
2001	6	III	6	III	6	IV
2002	4	IV	5	III	5	IV
2003	6	V	6	V	6	V
2004	6	III	6	III	6	IV
2005	6	V	5	V	6	IV
2006	4	IV	4	V	5	V
2007	3	III	3	III	3	III
2008	4	IV	4	V	4	III
2009	6	IV	5	IV	6	IV

Thermal classification: 1 – extremely warm, 2 – anomalously warm, 3 – very warm, 4 –warm, 5 – slightly warm, 6 – normal, 7 –slightly cold, 8 – cold, 9 – very cold, 10 – anomalously cold, 11 – extremely cold
Precipitation classification: I – extremely wet, II –very wet, III – wet, IV –normal, V – dry, VI –very dry, VII – extremely dry

Depicted results of air temperature and precipitation variability on the Polish Baltic coastal zone are similar to the results of the European climate research: Domonkos *et al.* (2003), Kurbis *et al.* (2009), Moberg, Jones (2005). Climate research in Polish Baltic Coastlands has confirmed European rules the annual average temperature increase in the second half of the 20th century. On the Polish coast as well as in Central Europe there was no statistically significant trend of increase or decrease of annual total precipitation.

CONCLUSIONS

A characteristic feature of the Polish coastal zone of the Southern Baltic Sea refers to a lack of years with their extreme thermal and precipitation properties that is related to, among others, the presence of maritime temperate climate at the studied area. The significant impact of the Baltic Sea onto the coastal climate can be attested by low (as for Polish conditions) extremes of weather elements, for example absolute minimal air temperatures do not exceed –25°C and maximal daily amounts of precipitation do not exceed 150 mm. The highest growth rate of air temperature recorded in the western part of the Polish Baltic Coast, in Szczecin Coastland. In addition, the lowest rate of air temperature change was observed in eastern part, in Gdansk Coastland. Temporal variability of precipitation showed no significant differences between the studied regions.

The study results constitute the basis for determining trends within Polish climatic conditions of the coastal zone of the Southern Baltic Sea. The conducted annual thermal and precipitation classification makes the grounds for determining actuall and future trends of climatic changes at the Polish coastal zone of the Baltic Sea.

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